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Recovery Potential Assessment for 11 Designatable Units of Fraser River Chinook Salmon, *Oncorhynchus tshawytscha*, Part 1: Elements 1 to 11

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Eleven Fraser River Chinook Salmon (FRC) (*Oncorhynchus tshawytscha*) Designatable Units (DU) were assessed as Threatened or Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2018, and are currently under consideration for addition to Schedule 1 of the *Species at Risk Act* (SARA). This first part of the Recovery Potential Assessment (RPA) (Elements 1-11) provides descriptions and status updates for the populations, an overview of biology and habitat requirements, and an assessment of the threats and factors limiting recovery. The major threats impacting DUs were assessed in a workshop with local experts, and were determined to be climate change, natural system modifications, fishing, and pollution. Threats to individual DUs of note include: recent landslides posing serious risks to DUs 8, 9, 10 and 11; competition with hatchery fish for DU2; and particularly high impacts due to natural systems modifications for DUs 9 and 14. All eleven DUs are considered to be at a high-extreme or extreme threat risk, due to the severity and number of threats these DUs are facing. Based on the assessed threats, over the next three generations it is expected that there will be a population level decline of 31-100% for DUs 2, 4, 5, 7, 16 and 17, and a 71% to 100% population level decline for DUs 8, 9, 10, 11, and 14. Alleviating the multiple and complex threats to these DUs will be difficult, especially as many of the threats are exacerbated by climate change. It will be critical to ensure that efforts are appropriately coordinated through effective governance to successfully mitigate the cumulative impacts of these diverse threats. Recovery targets, options for mitigation, forward population projections and allowable harm will be provided in the second half of the RPA (Elements 12-22).

1. INTRODUCTION

Subsequent to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessing an aquatic species as *Threatened, Endangered* or *Extirpated*, Fisheries and Oceans Canada (DFO) undertakes a number of actions required to support implementation of the *Species at Risk Act* (SARA). Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) within a designated timeframe following the COSEWIC assessment. This timing allows for consideration of peer-reviewed scientific analyses into SARA processes including recovery planning.

1.1. SPECIES INFORMATION

Scientific Name – *Oncorhynchus tshawytscha*

Common Names –

English: Chinook Salmon, Spring Salmon, King Salmon (Scott and Crossman 1973)

French: saumon chinook

First Nations: tyee, sac'up, kwexwe, k'utala, keke'su7, po:kw' (Ducommun 2013), ntitiyix, sk'elwis (Vedan 2002[1]), t'kwinnat or quinnat (Scott and Crossman 1973).

The Chinook Salmon is the largest of five semelparous and anadromous Pacific salmon species native to North America, ranging from central California to the Mackenzie River (Northwest Territories, Canada) along the North American coast (Netboy 1958; McPhail and Lindsey 1970; McLeod and O'Neil 1983; Healey 1991). Chinook Salmon represent the most diverse life history patterns of all the semelparous Pacific salmon (Brannon et al. 2004), with considerable variation in size, age at maturation, habitat requirements, and duration of freshwater and saltwater rearing stages. In Canada, Chinook Salmon are an important food source for other fish, mammals, birds, as well as a key target species for recreational and commercial fisheries, and are highly significant to First Nations and Métis in British Columbia (BC) as a cultural symbol and connection to a way of life for subsistence (COSEWIC 2019).

Chinook Salmon populations in southern BC are subdivided into 28 Designatable Units (DUs) by COSEWIC based on geographic distribution, life history variation, and genetic data (COSEWIC 2019). COSEWIC DUs are derived from Wild Salmon Policy (WSP) Conservation Units (CUs) and follow the fundamental approach for maintaining genetic variability at the wildlife species level (COSEWIC 2019); however, in some instances, multiple CUs can make up a DU. For Chinook Salmon in southern BC, 25 of the 28 DUs are exactly the same as the CUs, while 3 of the DUs have different population boundaries. All DUs discussed in this RPA represent a single CU. Detailed descriptions of COSEWIC DUs and WSP CUs for southern BC Chinook Salmon can be found in (COSEWIC 2019) and (Brown et al. 2019) respectively.

For the context of this RPA, all DUs spawn within the Fraser River drainage and will hereby referred to as FRC (Fraser River Chinook). FRC DUs are genetically distinct populations that do not readily interbreed, and spawn within different geographical reaches of the Fraser River

[1] Vedan, A. 2002. Traditional Okanagan Environmental Knowledge and Fisheries Management. Westbank, BC. (Accessed July 22, 2020)

drainage (see COSEWIC 2017 for detailed description of FRC Chinook genetics and geographic distribution). The DUs assessed in this RPA, and their corresponding WSP CUs and fisheries Management Units (MUs), are summarized in Table 1. Short-hand names for FRC DUs are provided in Table 2, which will be used to refer to DUs throughout the document.

Table 1. Fraser River Chinook (FRC) Salmon Designatable Units (DU) and COSEWIC status (2019).

Management Unit (MU)	Conservation Unit (CU)	Designatable Unit (DU)	COSEWIC Status	Reasoning for Status
Spring 5_2	CK-08 FR Canyon-Nahatlatch	DU7 - Middle Fraser River Stream Spring (Nahatlach)	Endangered	This population of spring run Chinook spawning in the Nahatlatch River watershed has declined to very low levels. Declines in freshwater and marine habitat quality, and harvest, are threats facing this population.
	CK-10 MFR Spring	DU9 - Middle Fraser River Stream Spring	Threatened	This spring run of Chinook spawning in multiple middle Fraser River tributaries has declined in abundance. Declines in marine and freshwater habitat quality, and harvest, and pollution from mining activities are threats to this population.
	CK-12 UFR Spring	DU11 - Upper Fraser River Stream Spring	Endangered	This spring run of Chinook spawning in the upper Fraser River watershed has declined in abundance. Declines in marine and freshwater habitat quality, and harvest, are threats facing this population. Anticipated changes to North Pacific weather systems that affect ground water availability, will impact spawning sites and overwinter survival.
	CK-18 NTHOM Spring	DU16 - North Thompson Stream Spring	Endangered	This spring run of Chinook spawning in the North Thompson River has steeply declined in abundance to a low level. Declines in marine and freshwater habitat quality, and harvest, are threats facing this population. Anticipated changes in North Pacific weather systems that affect groundwater availability will impact spawning sites and overwinter survival.
Summer 5_2	CK-05 LFR Upper Pitt	DU4 - Lower Fraser River Stream Summer (Upper Pitt)	Endangered	This summer run of Chinook spawning in the Upper Pitt River in the lower Fraser River watershed has declined, and is now at its lowest recorded abundance. Declines in freshwater and marine habitat quality, and harvest, are continuing threats to this population.
	CK-06 LFR Summer	DU5 - Lower Fraser River Stream Summer	Threatened	This summer run of Chinook spawning in the lower Fraser watershed has declined to low levels. Declines in freshwater and marine habitat quality, and harvest, are threats facing this population.

Management Unit (MU)	Conservation Unit (CU)	Designatable Unit (DU)	COSEWIC Status	Reasoning for Status
	CK-09 MFR Portage	DU8 - Middle Fraser River Stream Fall (Portage)	Endangered	This population of fall run Chinook spawning in the Seton watershed along the middle Fraser River has declined to very low levels, and decline is anticipated to continue. Declines in freshwater and marine habitat quality, and harvest, are threats facing this population.
	CK-11 MFR Summer	DU10 - Middle Fraser River Stream Summer	Threatened	This summer run of Chinook spawning in multiple middle Fraser River tributaries has declined in abundance. Declines in marine and freshwater habitat quality are threats facing this population.
	CK-19 NTHOM Summer	DU17 - North Thompson Stream Summer	Endangered	This summer run of Chinook spawning in the North Thompson River has steeply declined in abundance. Declines in marine and freshwater habitat quality, and harvest, are threats facing this population.
Spring 4_2	CK-16 SThBessette Creek	DU14 - South Thompson Stream Summer (Bessette)	Endangered	This summer run of Chinook spawning in the South Thompson River has steeply declined in abundance to a very low level. Declines in marine and freshwater habitat quality, and harvest, are threats facing this population.
Fall 4_1	CK-03 LFR Fall	DU2 - Lower Fraser River Ocean Fall	Threatened	While the calculation of decline rates is complicated by hatchery releases from 1981 to 2004, this fall run of Chinook spawning in the lower Fraser River has steadily declined in abundance. The abundance data over all available years was thought to best represent natural spawner abundance. Declines in marine and freshwater habitat quality, harvest, and ecosystem modification in the lower Fraser River estuary, are threats facing this population.

Table 2. FRC DU "Short Name" guide. DU "Short Names" are used throughout the document.

DU	CU	MU	DU Full Name	DU Short Name
DU2	CK-03	Fall 4.1	Lower Fraser River Ocean Fall	LFR-Harrison
DU4	CK-05	Spring 5.2	Lower Fraser River Stream Summer (Upper Pitt)	LFR-Upper Pitt
DU5	CK-06	Summer 5.2	Lower Fraser River Stream Summer	LFR-Summer
DU7	CK-08	Spring 5.2	Middle Fraser River Stream Spring (Nahatlach)	MFR-Nahatlach
DU8	CK-09	Summer 5.2	Middle Fraser River Stream Fall (Portage)	MFR-Portage
DU9	CK-10	Spring 5.2	Middle Fraser River Stream Spring	MFR-Spring
DU10	CK-11	Summer 5.2	Middle Fraser River Stream Summer	MFR-Summer
DU11	CK-12	Spring 5.2	Upper Fraser River Stream Spring	UFR-Spring
DU14	CK-16	Spring 4.2	South Thompson Stream Summer (Bessette)	STh-Bessette

DU	CU	MU	DU Full Name	DU Short Name
DU16	CK-18	Spring 5.2	North Thompson Stream Spring	NTh-Spring
DU17	CK-19	Summer 5.2	North Thompson Stream Summer	NTh-Summer

1.2. LISTING AND RECOVERY BACKGROUND

Numerous Chinook Salmon populations from southern British Columbia have experienced repeated years of low spawner abundance over the last three decades, and Fraser River stocks have shown noticeable declines since the early 2000s (Riddell et al. 2013). Observations of smaller size at age, reduced fecundity, and lower proportions of females in spawner surveys has also led to increased uncertainty surrounding the longer term trends in the abundance and productivity of all populations (Brown et al. 2019).

In November 2018, COSEWIC assessed the status of 16 of 28 Chinook Salmon DUs in southern BC (COSEWIC 2019). These DUs were considered to have received no or little artificial supplementation over the past three generations, or were previously considered by DFO to have insufficient data for assessment. This assessment led to the status assignment of 8 DUs as *Endangered*, 4 as *Threatened*, 1 as *of Special Concern,* and 1 as *Not at Risk*. Two DUs were deemed to have insufficient data for assessment. The remaining Chinook Salmon DUs in southern BC will be assessed by COSEWIC in November 2020.

Prior to the COSEWIC (COSEWIC 2019) assessment, the Okanagan DU was the only Canadian Chinook Salmon DU that was evaluated for status, which was assessed as *Endangered* by COSEWIC (COSEWIC 2019). The Okanagan DU is unique because it is currently the only BC Chinook Salmon population in the Columbia River drainage. As such, this DU was evaluated separately and was not included among the DUs reviewed by COSEWIC in 2018.

Subsequent to COSEWIC assessing an aquatic species as *Threatened, Endangered* or *Extirpated*, Fisheries and Oceans Canada (DFO) undertakes a number of actions required to support implementation of the *Species at Risk Act* (SARA). Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery. Formulating this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) within a designated timeframe following the COSEWIC assessment, allowing sufficient time for consideration of peer-reviewed scientific analyses into SARA processes including recovery planning.

This RPA evaluates the status of 11 DUs of Chinook Salmon that spawn in the Fraser River drainage, all of which have been designated as either *Threatened* or *Endangered* by COSEWIC (2019). Specifically, this report addresses the first 11 of 22 elements outlined in the Terms of Reference for completion of RPAs for Aquatic Species at Risk (DFO 2014), which includes:

- summaries of FRC biology, abundance, distribution and life history parameters (Element 1-3);
- descriptions of FRC habitat and residence requirements at all life stages (Element 4-7);
- assessment and prioritization of threats and limiting factors to the survival and recovery of FRC (Element 8-11);
- proposed recovery targets for FRC DUs (Element 12-15);
- discussions of scenarios for mitigation of threats and alternatives to activities (Element 16-21) ;

- an allowable harm assessment to evaluate the maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery (Element 22).

2. BIOLOGY, ABUNDANCE, DISTRIBUTION, AND LIFE HISTORY PARAMETERS

2.1. ELEMENT 1: SUMMARY OF CHINOOK SALMON BIOLOGY

Much of the information presented in this section pertains to Chinook Salmon in general due to limited studies of FRC stocks, particularly for DUs that spawn in the interior Fraser River watershed. A summary of general biological knowledge for Chinook Salmon is reported here, and FRC-specific information is identified and presented when possible.

2.1.1. Morphology

Chinook Salmon is the largest of five anadromous and semelparous Pacific salmon species native to North America (Netboy 1958; Healey 1991). Adult Chinook Salmon are, in general, distinguished from other Pacific salmon species by: (1) the presence of small black spots on both lobes of the caudal fin; (2) black gums at the base of the teeth in the lower jaw; (3) a pointed lower jaw; and (4) a large number of pyloric caeca (>100) (McPhail and Lindsey 1970; Healey 1991; McPhail 2007). Like most other Oncorhynchus species, males grow large kypes (elongation of the upper jaw) and develop a dorsal hump. Chinook Salmon fry and parr can be distinguished by the presence of parr marks extending well below the lateral line (Mcphail and Carveth 1994). The adipose fin is normally edged with black and unpigmented in the middle region (Healey 1991). The anal fin also displays a white leading edge, but is not offset by a dark pigment line as is seen in Coho Salmon (Healey 1991). Chinook Salmon exhibit extreme variation in flesh coloration ranging from bright red to white, with intermediate variants existing across the spectrum (Lehnert et al. 2016).

2.1.2. Glaciation History

Candy et al. (2002) and Beacham et al. (2003) have previously described the importance of historical glaciation patterns and how they have led to the distribution of FRC throughout the entire Fraser River drainage. BC was almost entirely covered by ice 15,000 years ago (Fulton 1969), followed by a period of global warming (Roed 1995). As the ice retreated, much of the Fraser River drained through the Okanagan watershed and entered the ocean via the Columbia River as the Fraser Canyon was blocked with ice near Hells Gate. During this period some Chinook Salmon presumably colonized the interior Fraser watershed via the Columbia River through connections in the Okanagan-Nicola area and by upper mainstem Fraser/Columbia connections.

Multiple colonization events throughout the glaciation history of the contemporary Fraser River watershed led to unique groups of FRC populations (organized into CUs and DUs) within the Fraser watershed that do not readily interbreed. The presence of genetically distinct FRC populations in the lower Fraser River watershed (downstream of Hells Gate) suggests independent colonization events from the Columbia refuge, and from a Pacific coastal (Teel et al. 2000) or northern Beringial (Utter et al. 1989) refuge. Even though some FRC populations (i.e. reproductively isolated groups) are close in geographic proximity, there is often a mixture of populations from different colonization histories (Healey 1991, 2001). These distinct populations have evolved a spectrum of life history strategies, with considerable variation in: age when juveniles disperse from their natal streams; length of freshwater, estuarine and ocean residence; ocean distribution; and age/timing of the spawning migration (Brown et al. 2013).

Life History Variants

The most general variation in Chinook Salmon life history is in the duration of time spent in freshwater before migrating to the ocean, designated as stream-type and ocean-type Chinook Salmon. These descriptions are, however, broad generalizations of an actual behavioural continuum between stream-type and ocean-type. In general, stream-type Chinook Salmon spend one or more years as fry or parr in freshwater before migrating to the ocean. Stream-type Chinook typically perform extensive offshore oceanic migrations and return to their natal streams in the spring or summer several months prior to spawning. Conversely, ocean-type variants migrate to the ocean during the first year of their life, spend most of their life in coastal waters, and return to their natal streams in the fall a few days or weeks prior to spawning.

Evidence suggests these two variants are divergent lineages of Chinook Salmon arising from the Bering refugium to the north (stream-type) and the Cascadia-Columbia refugium to the south (ocean-type). Genetic research indicates there is little to no gene flow between the two variants despite co-migrating through large areas of riverine and ocean habitat, and in some cases, spawning in adjacent systems (Healey 1991; Waples et al. 2004). There has, however, been some suggestion that Chinook Salmon south of the Upper Columbia River Basin exhibit both stream- and ocean-type behaviours yet share the same lineage (Moran et al. 2013). In systems where the two variants are sympatric (i.e. evolved without geographic or temporal separation), stream-type variants are found more frequently in headwater spawning areas and ocean-type variants occur more frequently in downstream spawning areas (Rich 1925; Hallock, Fry, and LaFaunce 1957; Healey and Jordan 1982).

There is also considerable variation in the time of year when sexually mature Chinook initiate their return to freshwater and the upstream migration to spawning grounds. It has been suggested that variation in run timing in salmon is evidence of local adaptation (Waples et al. 2004; Beacham and Murray 1990). Freshwater return migrations can precede actual spawning activity by weeks, or even months in some DUs or populations within DUs. There is also a general latitudinal trend in peak return timing. Peak return timing for FRC DUs generally occurs from July to September, while southern DUs generally range from April to September.

It is important to note that adult return timing is not synonymous with spawn timing as it can precede actual spawning activity by weeks, or even months, for some populations (e.g. there are spring runs that enter the Fraser River in April but do not initiate spawning until August, and summer runs entering in July that do not spawn until October). Waples *et al.* (2004) provided standardized adult run timing definitions that are used to classify southern British Columbia Chinook Salmon (Parken et al. 2008). Adult run timing for FRC is summarized by DU in Table 3. The additional diversity of spawn timing strategies is believed to demonstrate the specificity of thermal requirements for hatching and emergence of fry, as well as the need to synchronize these requirements with other environmental factors such as food availability and hydrographic conditions.

Table 3. Run and migration timing descriptions for the FRC DUs assessed in this RPA.

Run timing designation	Migration timing	Fraser River Chinook DUs
Spring	≥ 50% of the spawners pass through the lower Fraser River by July 15th	DU7 MFR-Nahatlach DU9 MFR-Spring DU11 UFR-Spring DU16 NTh-Spring
Summer	≥ 50% of the spawners pass through the lower Fraser River between July 15th and August 31st	DU4 LFR-Upper Pitt DU5 LFR-Summer DU10 MFR-Summer DU14 STh-Bessette DU17 NTh-Summer
Fall	≥ 50% of the spawners pass through the lower Fraser River after August 31st	DU2 LFR-Harrison DU8 MFR-Portage

2.1.3. Life cycle

Chinook Salmon across North America share similar tendencies in their life cycle. Female Chinook construct several redds in succession upstream, depositing a group of eggs in each that are fertilized by one or more males. The material removed by digging in the new site covers the fertilized eggs in the downstream depression, thereby protecting them from predation and from being washed away by the scouring action of the river or stream (Diewart 2007). Over one to several days, the female deposits four or five such egg pockets in a line running upstream, enlarging the spawning excavation in an upstream direction as she does so. The total area of excavation, including the tailspill, is termed a "redd" (Healey 1991). Redds vary in size and depth across systems, and even within streams, depending on flow velocity and coarseness of the spawning gravels (Vronskiy 1972; Neilson and Banford 1983; Healey 1991). Stream-type Chinook Salmon typically build smaller redds in coarser gravels than do ocean-type Chinook Salmon of the same size (Burner 1951; Diewart 2007). Females defend their redds for days to weeks, with the average length of residence declining throughout the spawning season (Healey 1991). Males are not involved in the construction of redds and move between females to find potential mates until their energetic state no longer permits.

Within a redd, Chinook Salmon eggs develop into alevins. Female Chinook Salmon are the most fecund of all the *Oncorhynchus* species, in addition to having the largest eggs (average single wet egg mass ≈ 300 mg). There is considerable variation in Chinook Salmon fecundity in North America, ranging from less than 2,000 eggs to more than 17,000 eggs (Healey and Heard 1984). Upon hatching, alevins move varying distances within the spaces between the gravel particles depending on gravel size (Diewart 2007). Chinook Salmon alevins are considerably larger during this period than other *Oncorhynchus* species, resulting in fry that are approximately 50% larger than chum salmon fry and more than 200% larger than pink salmon fry (Groot 1995). Studies in North America suggest that survival to emergence averages about 30% (Healey 1991).

Alevins then develop into fry, which spend a variable amount of time in fresh water, depending on their life history variant. Upon emergence from spawning gravels, Chinook Salmon fry swim and/or are passively displaced downstream by flow, distributing themselves among suitable rearing habitats (Healey 1991; Myers et al. 1998). As a result, some Chinook Salmon fry rear in non-natal streams, underscoring the importance of these streams as habitat despite the fact that they are not spawning streams (Scrivener et al. 1994). Downstream dispersal occurs mainly at night, generally concentrated around midnight, although small numbers of fry may move during the day (Healey 1991). Fry dispersal is normally most intense between February and May, with significant year-to-year variation**.** The causes of annual and daily variation in the downstream dispersal are not well understood (Healey 1991), but may be related to the timing of high discharge events (Mains and Smith 1964; Healey 1980; Kjelson, Raquel, and Fisher 1981; Irvine 1986). In addition to discharge, both intra- and interspecific interaction may serve to stimulate the downstream dispersal of young Chinook Salmon (Reimers 1968; Stein et al. 1972; Taylor 1988; Myers et al. 1998), as well as habitat quality (Bjornn 1971; Hillman, Griffith, and Platts 1987; Bradford and Taylor 1997).

Chinook Salmon fry then go through the process of smoltification, which includes a physiological change that prepares them for the ocean environment while they migrate downstream. The major difference between the two life history variants is the amount of time they spend in freshwater before smoltification and their migration to the ocean. Ocean-type Chinook Salmon migrate to the ocean any time between immediately post-emergence and approximately 150 days post-emergence; however, the majority move seaward in 60-90 days. Ocean-type Chinook Salmon are known to use lakes (Brown and Winchell 2004; Rosenau 2014) and estuaries for rearing prior to entering the ocean as smolts. Stream-type variants typically delay migration until the spring following their emergence and sometimes wait for an additional year (Healey 1983). Most stream type variants will migrate out to the ocean as smolts from April to July the following year, however, a smaller (and currently unknown) proportion have been identified to migrate to the ocean as 2 year old smolts.

For all life history variants, the rate of downstream migration appears to be both time and size dependent. Larger Chinook Salmon travel downstream faster than smaller Chinook Salmon, and the rate of migration increases as the season advances (Healey 1991). Downstream travel rates may also be positively related to river discharge (Bell 1958; Raymond 1968), but there has been no systematic study of the triggers (Healey 1991).

After rearing in the ocean for a variable amount of time, Chinook Salmon begin sexual maturation as they migrate towards their natal freshwater systems. For most Chinook Salmon sexual maturation can occur anytime between the second and sixth year, with the average age at maturity varying between populations and DUs (Brown et al. 2019). The oldest known age of maturity for Chinook is seven years (Healey 1986). In general, male salmon (including Chinook) tend to grow faster than females with the exception of Coho Salmon, and vary more in age at maturity (Quinn 2005). Female Chinook generally have an older average age at maturity than males (Healey 1991; Quinn 2005). Chinook Salmon most commonly initiate their return to natal streams within two to four years at sea (Myers et al. 1998), however, most Chinook Salmon populations contain a portion of males that mature precociously during their second year (for ocean-type) or third year (for stream-type), and are referred to as “jacks” (Brown et al. 2019). Precocious maturation can also occur in female Chinook Salmon (referred to as “jills”) within these age categories, yet occurrences tend to be negligible (Brown et al. 2019). Chinook Salmon parr have also been observed to mature precociously in their first (for ocean-type) and second (for stream-type) year in some populations, and are referred to as “jimmies” (Brown et al. 2019). Several studies have shown that genetics and environmental factors can contribute to variation in maturation rates over time (Quinn 2005).

2.1.4. Diet

Juvenile Chinook Salmon rearing in freshwater feed predominantly on invertebrate species, providing up to 95% of the freshwater diet in all seasons. Prey items consist of crustacea, chironomids, corixids, caddisflies, mites, spiders, aphids, corethra larvae, and ants, with chironomids making up a large portion (58-63%) of food items taken (Becker 1973; Scott and Crossman 1973; Healey 1991). Loftus and Lenon (1977) speculated that the increased abundance of insects as a result of freshet conditions is an important factor influencing food use by stream-type Chinook Salmon.

Estuarine diet varies considerably, and consists of a mixture of food from both freshwater and brackish habitats (Macdonald et al.1987). Food items include chironomid larvae and pupae, crab larvae, harpacticoid copepods, Daphnia, *Eogammarus*, *Corophium*, and *Neomysis* (Dunford 1975; Northcote, Johnston, and Tsumura 1979; Levy, Northcote, and Birch 1979; Levy and Northcote 1982). As Chinook grow larger, small fish such as juvenile herring (*Clupea pallasii*), sticklebacks (e.g., *Gasterosteus aculeatus*), and Chum salmon fry (*O. keta*) also become prominent in the diet (Goodman 1975; Healey 1980; Levings 1982).

Juvenile Chinook Salmon rearing in saltwater were historically reported to favour harpacticoid copepods as prey in the Strait of Georgia, yet recent studies indicate predation on copepods is decreasing despite being abundant in zooplankton catch (Schabetsberger et al. 2003; Bollens et al. 2010; Preikshot et al. 2013; Chittenden et al. 2018). The types and quality of copepods living in the Salish Sea have changed over time (El-Sabaawi et al. 2009), potentially as a result of anthropogenic activities (shoreline development, water contamination, log booming) that have significantly altered their habitat and environment (Hetrick et al. 1998; Duffy et al. 2010; Chittenden et al. 2018). Warming ocean conditions are subject to increasing numbers of jellyfish and crab larvae (Mackas et al. 2013), which have been observed in recent years in high proportions of Chinook Salmon diets (Chittenden et al. 2018; Weil et al. 2019).

As juvenile chinook salmon migrate away from coastal waters they eat mainly fish, with invertebrates like pelagic amphipods, squids, shrimp, euphausiids, crab larvae, and insects comprising the remainder of their diet (Scott and Crossman 1973; Healey 1980; Hertz et al. 2016). Subadult Chinook Salmon (27 to 72 cm in length) in the Qualicum River area of the Strait of Georgia have been reported to feed on Chum Salmon fry, larval and adult Herring, Sand Lance (*Ammodytes hexapterus*), and euphausiids (Robinson, Lapi, and Carter 1982). Fish dominate the diet of adult Chinook Salmon, especially herring (Reid 1961; Prakash 1962); other food fish include sand lance, pilchards/sardines, and sticklebacks (Pritchard and Tester 1944). Invertebrate taxa form a relatively small component of the ocean adult diet, although there is considerable regional (and seasonal) variation in diet composition (Healey 1991). Coast-wide data suggest that the prominence of Herring and Sand Lance in the adult diet increases from south to north, whereas the prominence of rockfishes (*Sebastes* sp.) and anchovies (*Engraulis mordax*) decreases (Healey 1991).

2.2. ELEMENT 2: EVALUATION OF RECENT CHINOOK SALMON ABUNDANCE TRAJECTORY, DISTRIBUTION, AND NUMBER OF POPULATIONS

2.2.1. Distribution and Number of Population

The eleven DUs in the report are widely distributed throughout the lower (DUs 2 (LFR-Harrison), 4 (LFR-Upper Pitt), 5 (LFR-Summer)), middle (DUs 7 (MFR-Nahatlatch), 8 (MFR-Portage), 9 (MFR-Spring), and 10 (MFR-Summer)), and upper Fraser River basin (DU11 UFR-Spring), as well as the North (DUs 16 (NTh-Spring) and 17 (NTh-Summer)) and South Thompson River basins (DU14 STh-Bessette). Each of these DUs correspond to a single CU, and hence there are no COSEWIC-recognized sub-populations. Three of the DUs (DUs 2, 7 and 8) have single spawning sites, while the rest of the DUs have spawning occurring in several systems.

COSEWIC (2019) reported an Index of Area of Occupancy (IAO) for FRC DUs based on the distribution of spawning areas using a 2x2 km grid; these metrics are summarized in Table 4. Chinook Salmon spawning extents were provided by the Province's Fisheries Information Summary System (FISS), and are meant to cover the total linear length of known Chinook Salmon spawning habitat within each DU. FISS presently represents the best available data in GIS format, but the database is still lacking as currently there is no comprehensive source of distributional data for FRC (Porter et al. 2013). There is some error associated with the values reported in Table 4, particularly for those with large geographical areas such as DUs 9, 10, and 11. Table 5 lists persistent spawning streams used for trend analysis within each DU, and does not necessarily contain all FRC-bearing streams within that DU. A full list of known streams within each DU is located in Appendix A.

Table 4. Data quality and stream characteristics for FRC DUs assessed in this RPA.

Designatable Unit	Data Quality	IAO (km^2)	Stream	% of total stream
DU2 LFR-Harrison	Absolute Abundance	175	87	0.86
DU4 LFR-Upper Pitt	Relative Abundance	191	95	0.94
DU5 LFR-Summer	Relative Abundance	645	323	3.21
DU7 MFR-Nahatlatch	Relative Abundance	103	52	0.52
DU8 MFR-Portage	Relative Abundance	63	32	0.32
DU9 MFR-Spring	Relative Abundance	4490	2245	22.32
DU10 MFR-Summer	Relative Abundance	2616	1308	13
DU11 UFR-Spring	Relative Abundance	4065	2033	20.2
DU14 STh-Bessette	Relative Abundance	70	35	0.35
DU16 NTh-Spring	Relative Abundance	291	146	1.45
DU17 NTh-Summer	Relative Abundance	714	357	3.55

Table 5. List of persistent spawning sites used in trend analysis for each FRC DU, with the CU number for additional reference.

DU	DU Name	CU	Stream Name(s)
DU2	Lower Fraser River Ocean Fall	CK-03	Harrison R
DU4	Lower Fraser River Stream Summer-Upper Pitt	CK-05	Pitt R (Upper)

DU	DU Name	CU	Stream Name(s)	
DU5	Lower Fraser River Stream Summer	CK-06	Big Silver Cr	
DU7	Middle Fraser River Stream (Nahatlach)	CK-08	Nahatlatch R	
DU8	Middle Fraser River Stream Fall (Portage)	CK-09	Portage Cr	
DU9	Middle Fraser River Stream Spring	CK-10	Ahbau Cr	Endako R
			Baezaeko R	Horsefly R
			Bridge R	Lightning Cr
			Chilako R	Nazko R
			Chilcotin R (Lower)	Swift R
			Chilcotin R (Upper)	West Road (Blackwater) R
DU10	Middle Fraser River Stream Summer	CK-11	Cariboo R (Lower)	Pinchi Cr
			Chilko R	Quesnel R
			Kuzkwa R	Stellako R
			Nechako R	-
DU11	Upper Fraser River Stream Spring	CK-12	Antler Cr	James Cr
			Bowron R	McKale Cr
			Captain Cr	Morkill R
			Dome Cr	Nevin Cr
			East Twin Cr	Salmon R (PG)
			Fontoniko Cr	Seebach Cr
			Forgetmenot Cr	Slim Cr
			Fraser R - Tete Jaune	Small Cr
			Goat R	Swift Cr
			Haggen Cr	Torpy R
			Holliday Cr	Walker Cr
			Holmes R	Wansa Cr
			Horsey Cr	West Twin Cr
			Ice Cr	Willow R
			Indianpoint Cr	-
DU14	South Thompson Stream Summer (Bessette)	CK-16	Bessette Cr	
			Creighton Cr	
			Duteau Cr	
DU16	North Thompson Stream Spring	CK-18	Blue R	
			Finn Cr	

DU	DU Name	CU	Stream Name(s)
DU17	North Thompson Stream Summer	CK-19	Barriere R
			Clearwater R
			Lemieux Cr
			Mahood R
			North Thompson R
			Raft R

2.2.2. Trends in Productivity and Abundance

The information provided in this section is an update from the COSEWIC report, using additional data for 2016 to 2018. A brief review of the data treatment process is provided below. Additional details of the process can be found in the COSEWIC report (COSEWIC 2019). Any differences in the data treatment methods between the COSEWIC report and the RPA will be described below.

Annual escapement estimates for many FRC DUs are difficult to assess due to the large geographic range and remote spawning locations for these populations. Ten of eleven DUs assessed in this report are heavily reliant on relative escapement estimates rom visual survey data, and in some cases not all spawning areas are surveyed within a DU. DU2 (LFR-Harrison) is the only DU covered in this RPA that has absolute abundance data, as a result of the long standing mark recapture program.

Escapement estimates exist in most systems prior to the start of the time series presented in this report, but were excluded due to the quality filtering process. Quality filtering is based on the methods used to produce the estimate that year, and ensures that only reliable estimates are used. Estimates are classified into six different quality categories from presence absence to absolute abundance. Consistent with the COSEWIC report and the Wild Salmon Policy Assessments, only moderate to high quality estimates are used for assessment. The time series used for assessment start when moderate or high quality estimates are available for the system(s) in a DU. All time series datasets start after 1994 as data has increased in quality and consistency since then, with the exception of DU2 which begins in 1984. Infilling of missing years occurs for DUs with escapement estimates from multiple systems, where the infilled estimate is based on the proportion that the system represents at the DU level through time (English et al. 2006). Appendix B has survey quality plots for each of the DUs, that show the years with surveys for each stream, the quality of the estimates, and the years that were infilled.

A minimum proportion of streams must have estimates to allow for infilling. This proportion was set at 50% for the COSEWIC report, but for this RPA it was reduced to 25%, to allow for infilling in 1995 and 1997 in DU9 (MFR-Spring) and in 2016 in DU14 (STh-Bessette). While the difference in the overall estimate is low for DU14 in 2016 (an increase of 2 spawners), the infilling represents 36% and 51% of the 1995 and 1997 estimates respectively for DU9, as only 4 of the 12 systems surveyed in DU9 had estimates for those years. Without infilling those years, it would appear that 1995 and 1997 had lower abundances, when in reality fewer streams were surveyed. While the infilled estimates are not completely accurate, it is likely a more realistic estimate of relative abundance than missing data. Appendix C shows the difference in time series and probabilities of decline between infilling and not infilling in DU9.

Data quality review is ongoing, and as such there have been two changes to the time series since the COSEWIC report. Further investigations in the data quality of DU7 (MFR-Nahatlatch) back to 1999, found that these estimates were of moderate quality, rather than unknown, and hence they are now included in this report. The additional data enables a trend analysis that was not possible in the COSEWIC report due to the previous short time series. Review of estimates from DU14 indicated that some of the early estimates were in fact low, not moderate quality, so they were removed. Accordingly, the start year for DU14 was moved to 1999 to coincide with the start of the higher quality estimates.

To update the information from the COSEWIC report, the trend in spawner abundances were calculated over two different ranges:

1. The rate of change over the last three generations based only on the last three generations of data
2. The rate of change over the last three generations based on the trend over the whole time series.

The latter is shown because indicators of changes in abundance based on the rate of change over entire time series have been shown to be more reliable than shorter time series (Porszt et al. 2012; D'Eon-Eggertson et al. 2015). Consistent with the COSEWIC report, the length for the three generation trend, was in fact three generations plus one year, such that the selected data spanned the last three generations (i.e. 13 years for a DU with a 4 year generation time).

Rates of change in logged spawner escapement over time were calculated using a Bayesian estimation framework. Doing so enabled the presentation of probabilities associated with estimated changes in abundance, and is consistent with the COSEWIC report. Bayesian modeling and parameter estimation was conducted in R using JAGS software (Plummer 2018[2]; R Core Team 2019[3]) with the package R2jags (Su and Yajima 2015[4]). Uninformative priors were assumed for slope (β), intercept (α) and standard deviation (σ). The natural log linear model for a single chain used a burn-in of 2,000 observations, and retaining 10,000 samples after burn-in. Only every 10th observation was saved to reduce autocorrelation (thin=10).

The median trend in spawner abundance are negative for all of the DUs using both the short and long term trends. In 8 out of 11 DUs, the recent and long term trends are steeper declines than in the COSEWIC report due to the addition of three new years of data. DU4 (LFR-Upper Pitt) is the only case where there is a lower probability of decline using the whole time series trend than the COSEWIC report. This can be attributed to the 2018 return which, although still under 200 fish, is higher than recent years. The recent trend of decline for DU2 (LFR-Harrison) and DU16 (NTh-Spring) has become more gradual compared to the COSEWIC report because the recent trend no longer captures the higher abundances in the early 2000's. The recent trend is steeper than the trend over the whole time series for half the DUs. For DUs 2, 7 (MFR-Nahatlatch), 8 (MFR-Portage) and 17 (NTh-Summer), the trend over the whole time series is not as steep as the recent trend due to low abundance estimates near the beginning of the time series. The steeper recent trend for DUs 10 (MFR-Summer) and 11 (UFR-Spring) results from the start of the trend (2003) being the highest abundance in the time series, dragging the trend line upwards at the beginning and causing a more negative estimate of the slope (steeper

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[2] Plummer, M. 2018. rjags: Bayesian Graphical Models using MCMC. (Accessed July 22, 2020)

[3] R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. (Accessed July 22, 2020)

[4] Su, Y.-S., and Yajima, M. 2015. R2jags: Using R to Run "JAGS." (Accessed July 22, 2020)

decline). There is less uncertainty in the trend over the whole time series, with the exception of DU8.

When considering the trend data presented in this report, it is imperative to remember that DU2 (LFR-Harrison) is the only DU with absolute abundance estimates, while estimates for the other 10 DUs rely on relative abundance data. Thus for most of the DUs, the trend represents partial counts from only a portion of the spawning systems in that DU. In the case of DU4 (LFR-Upper Pitt), DU5 (LFR-Summer) and DU16 (NTh-Spring), the trends are based on counts from one or two systems in a very large area. The trends in spawning abundance for these three DUs are particularly uncertain due to the lack of data, and may or may not be representative of the trend in the DU as a whole. The trends presented below represent the best available time series of abundance for these DUs, however it is possible that estimates of relative abundance in any year could significantly differ from the actual population level. So while these trends may be an indication of the DU-level population trajectories, they are by no means certain.

In each of the DU headings below there is a plot of the current trends in abundance for each DU and a table with the median percent change and probability of decline based on the trend over both the last three generations and the whole time series. The previous calculations from the COSEWIC report are also included in the tables for comparison. For easier cross comparison among DUs, Appendix D has smaller figures of the trends presented in rows. Histograms of the percent change distributions are provided in Appendix E.

DU2 – Lower Fraser, Ocean, Fall (Harrison)

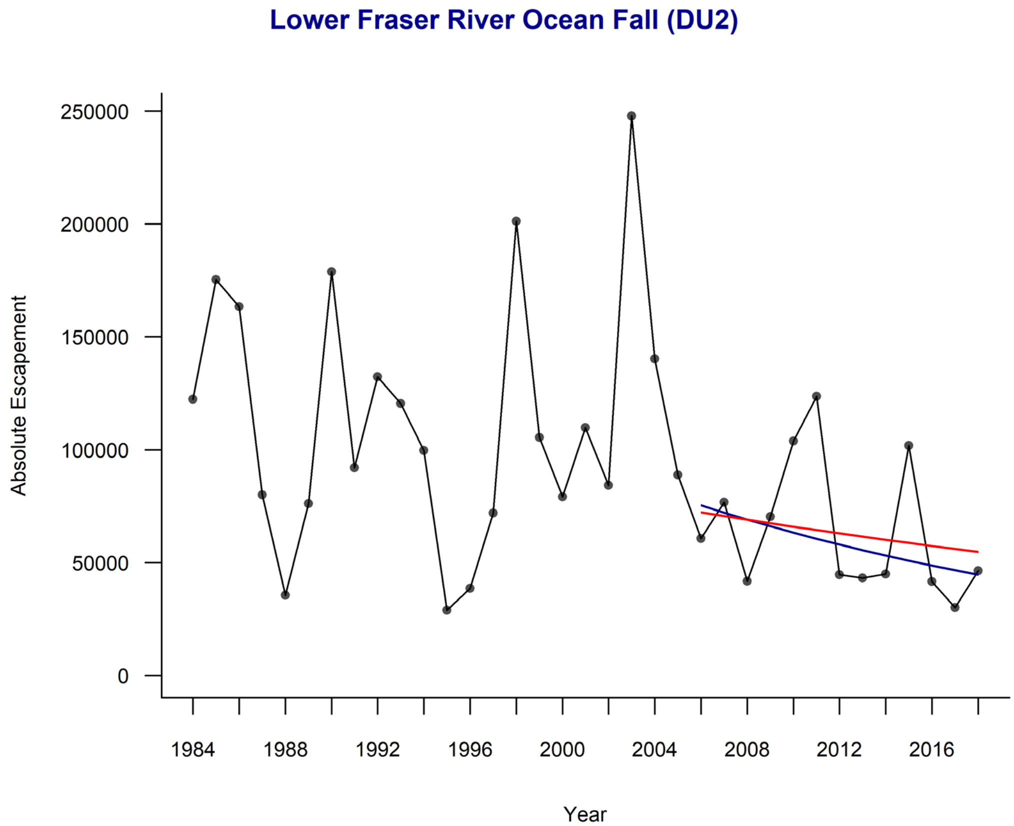

Figure 1. DU2 LFR-Harrison: time series of absolute escapement from 1984 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 6. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU2	LFR-Harrison	COSEWIC	3 Gens	2003-2015	-57	-84, 17	0.85	0.53	0.22
			All Years	1984-2015	-17	-35, 7	0.09	0.00	0.00
		RPA	3 Gens	2007-2018	-40	-73, 33	0.65	0.31	0.04
			All Years	1984-2018	-24	-39, -6	0.21	0.00	0.00

DU4 – Lower Fraser Stream, Summer (Upper Pitt)

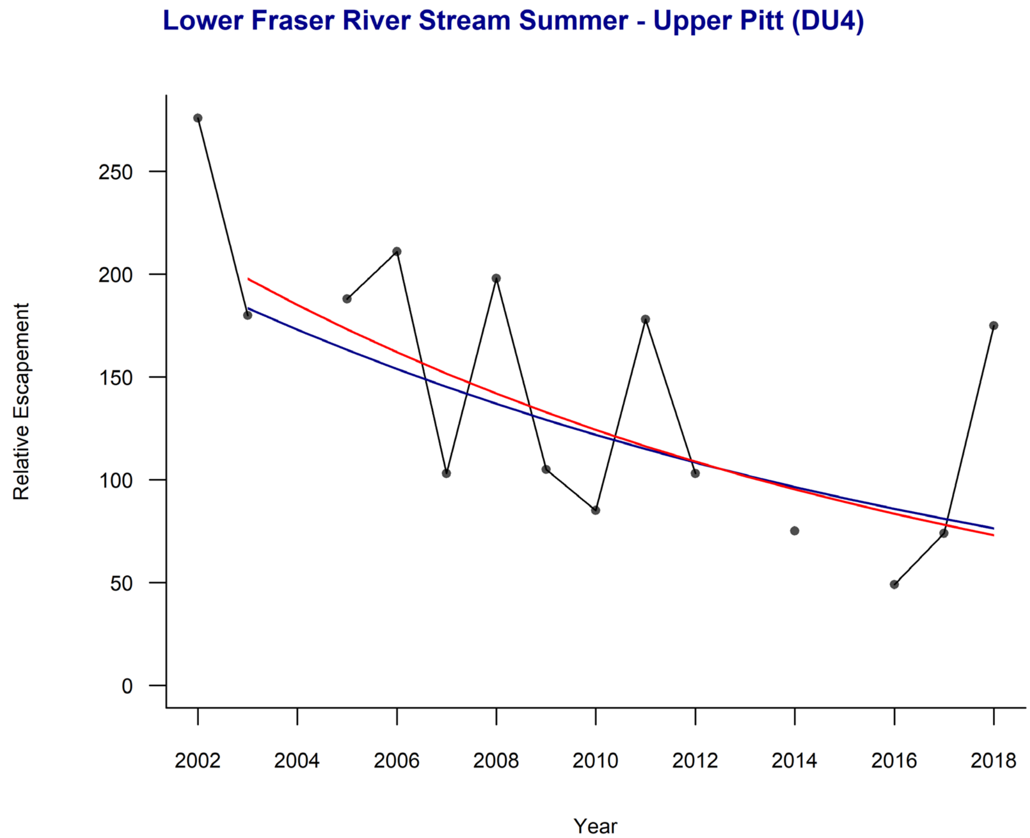

Figure 2. DU4 LFR-Upper Pitt: time series of relative escapement from 2002 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 7. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU4	LFR-Upper Pitt	COSEWIC	3 Gens	Not enough data for three generations					
			All Years	2002-2014	-73	-89, -32	0.98	0.92	0.60
		RPA	3 Gens	2003-2018	-57	-80, -2	0.89	0.66	0.17
			All Years	2002-2018	-62	-81, -25	0.96	0.80	0.25

DU5 – Lower Fraser Stream, Summer

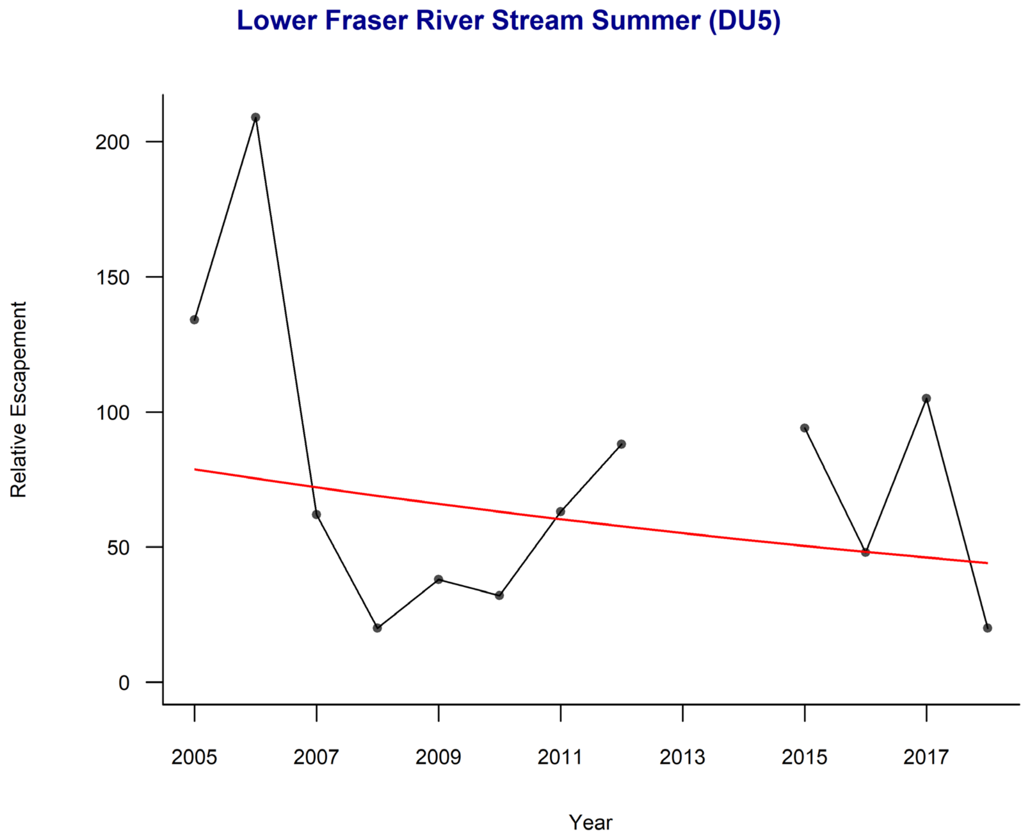

Figure 3. DU5 LFR-Summer: time series of relative escapement from 2005 to 2018 with an estimate of the rate of change in logged escapement through time over the last three generations based on all available data (red).

Table 8. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU5	LFR-Summer	COSEWIC	3 Gens	Not enough data for three generations					
			All Years	2005-2015	-36	-98, 1689	0.52	0.43	0.30
		RPA	3 Gens	Not enough data for three generations					
			All Years	2005-2018	-43	-87, 139	0.63	0.42	0.17

DU7 – Mid Fraser Stream, Spring (Nahatlatch)

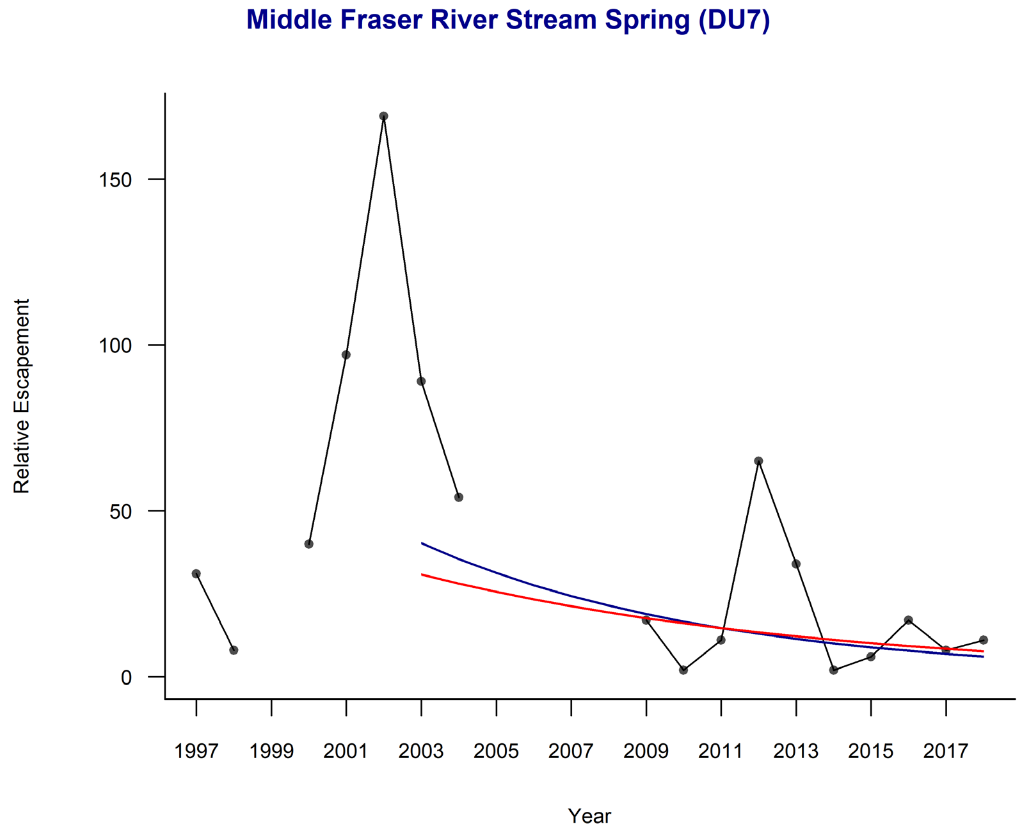

Figure 4. DU7 MFR-Nahatlatch: time series of relative escapement from, 1997 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 9. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline:		
							>30	>50	>70
DU7	MFR-Nahatlach	COSEWIC	3 Gens All Years	Not completed					
		RPA	3 Gens	2003-2018	-83	-98, 74	0.90	0.85	0.71
			All Years	1997-2018	-74	-94, -3	0.93	0.85	0.59

DU8 – Mid Fraser Stream, Fall (Portage)

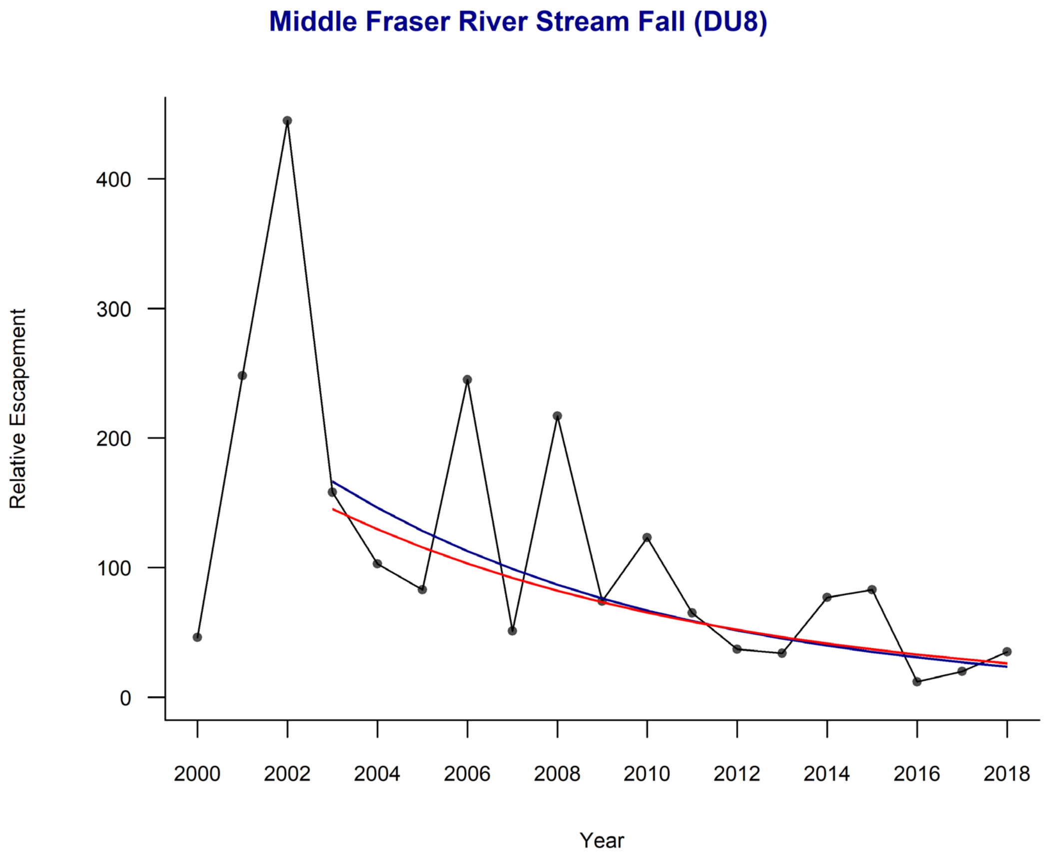

Figure 5. DU8 MFR-Portage: time series of relative escapement from 2000 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 10. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU8	MFR-Portage	COSEWIC	3 Gens/ All Years	2000-2015	-67	-90, 13	0.90	0.77	0.44
		RPA	3 Gens	2003-2018	-84	-94, -53	0.99	0.98	0.89
			All Years	2000-2018	-80	-92, -50	0.99	0.98	0.81

DU9 – Mid Fraser Stream, Spring

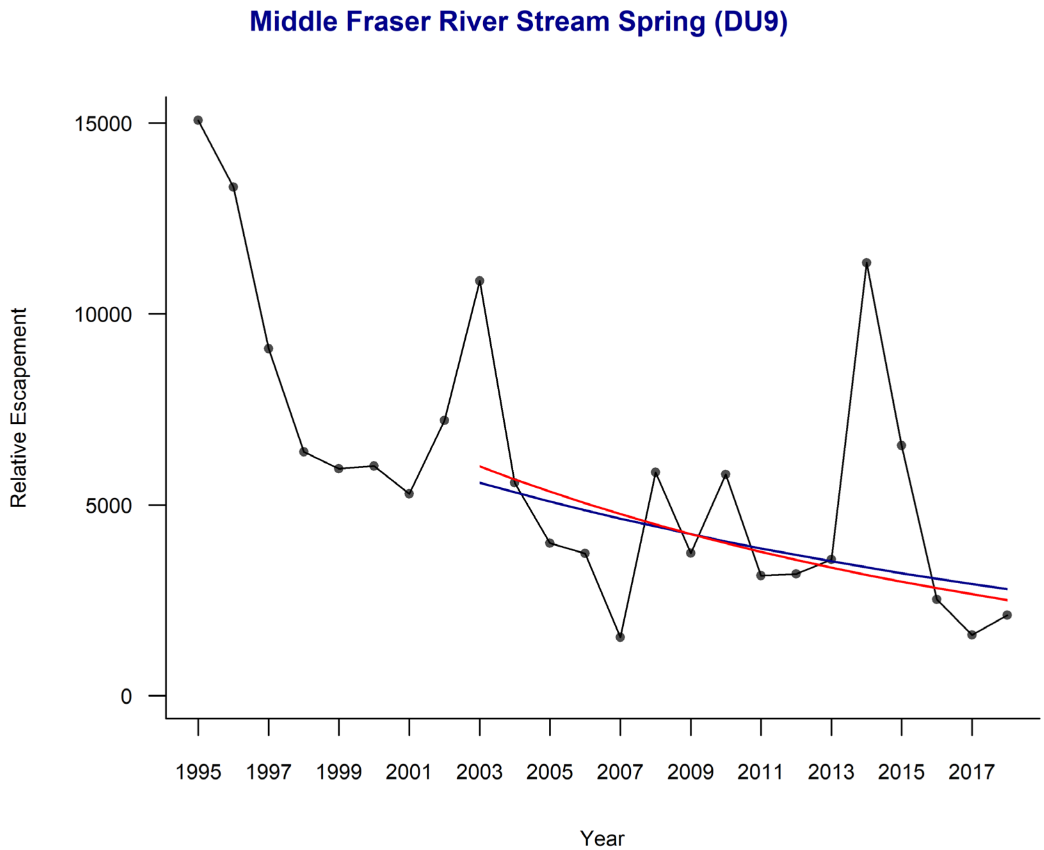

Figure 6. DU9 MFR-Spring: time series of relative escapement from 1995 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 11. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU9	MFR-Spring	COSEWIC	3 Gens	2000-2015	-28	-73, 97	0.48	0.22	0.04
			All Years	1995-2015	-49	-72, -9	0.87	0.47	0.04
		RPA	3 Gens	2003-2018	-49	-81, 45	0.77	0.48	0.14
			All Years	1995-2018	-57	-72, -32	0.98	0.76	0.06

DU10 – Mid Fraser Stream, Summer

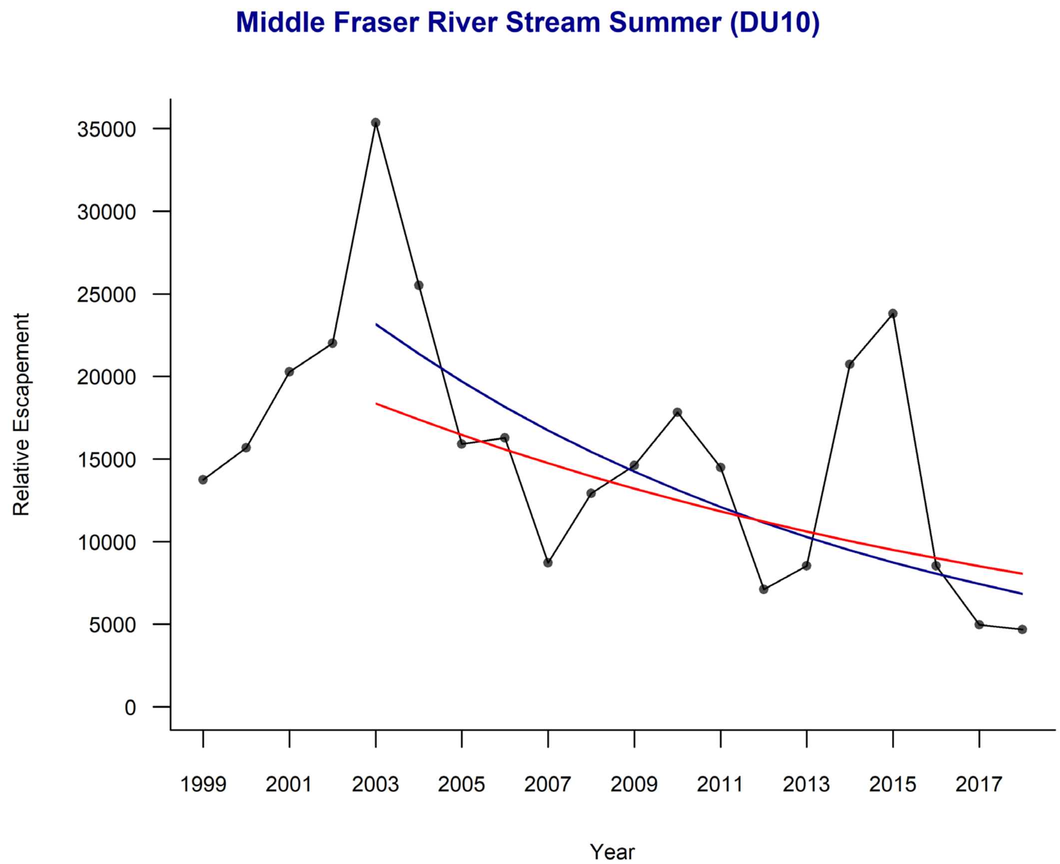

Figure 7. DU10 MFR-Summer: time series of relative escapement from 1999 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 12. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU10	MFR-Summer	COSEWIC	3 Gens	2000-2015	-38	-70, 28	0.64	0.26	0.03
			All Years	1999-2015	-29	-63, 39	0.48	0.14	0.01
		RPA	3 Gens	2003-2018	-69	-86, -32	0.98	0.88	0.47
			All Years	1999-2018	-55	-74, -22	0.95	0.66	0.07

DU11 – Upper Fraser Stream, Spring

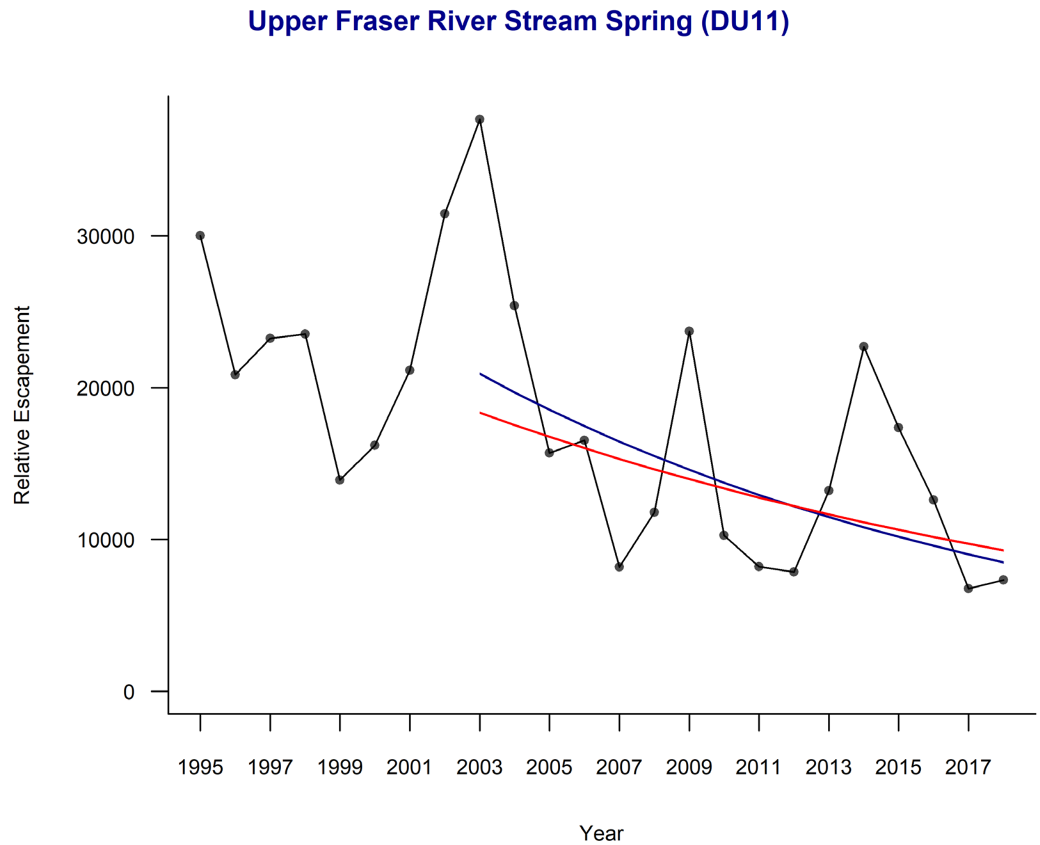

Figure 8. DU11 UFR-Spring: time series of relative escapement from 1995 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 13. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU11	UFR-Spring	COSEWIC	3 Gens	2000-2015	-49	-77, 15	0.79	0.48	0.09
			All Years	1995-2015	-43	-64, -8	0.81	0.28	0.00
		RPA	3 Gens	2003-2018	-58	-80, -12	0.92	0.69	0.18
			All Years	1995-2018	-49	-65, -26	0.95	0.44	0.00

DU14 – South Thompson Stream, Summer 1.2

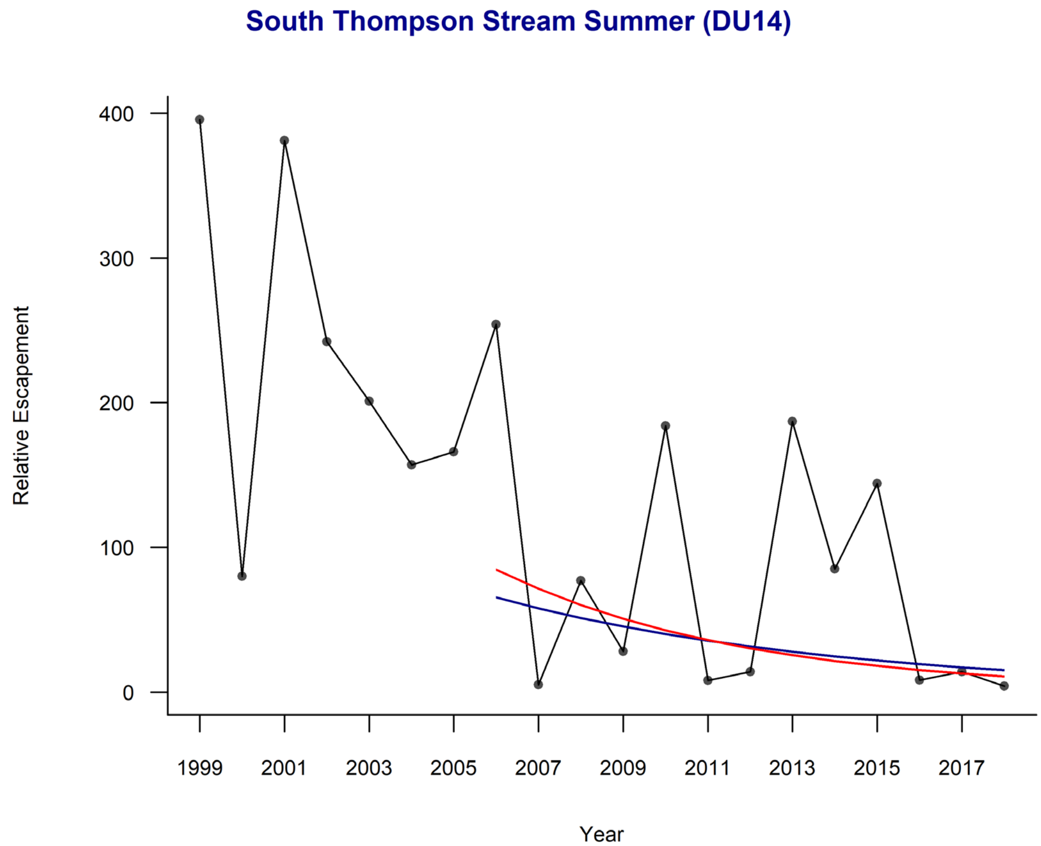

Figure 9. DU14 STh-Bessette: time series of relative escapement from 1999 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 14. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU14	STh-Bessette	COSEWIC	3 Gens	2003-2015	-47	-96, 705	0.59	0.48	0.33
			All Years	1995-2015	-76	-92, -31	0.98	0.92	0.67
		RPA	3 Gens	2007-2018	-75	-98, 310	0.77	0.70	0.56
			All Years	1999-2018	-85	-95, -51	0.99	0.98	0.88

DU16 – North Thompson Stream, Spring

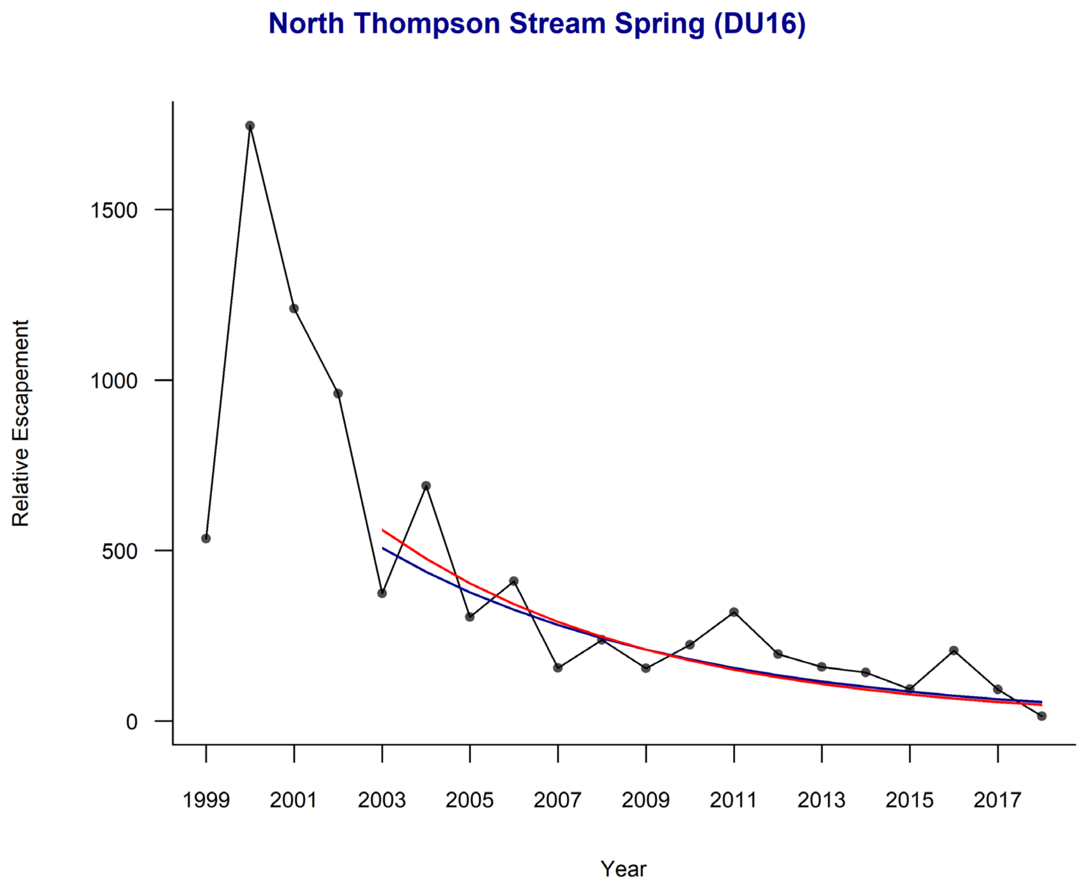

Figure 10. DU16 NTh-Spring: time series of relative escapement from 1999 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 15. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU16	NTh-Spring	COSEWIC	3 Gens	2000-2015	-91	-95, -81	1.00	1.00	1.00
			All Years	1999-2015	-88	-94, -76	1.00	1.00	0.99
		RPA	3 Gens	2003-2018	-87	-95, -64	1.00	0.99	0.96
			All Years	1999-2018	-90	-95, -79	1.00	1.00	1.00

DU17 – North Thompson Stream, Summer

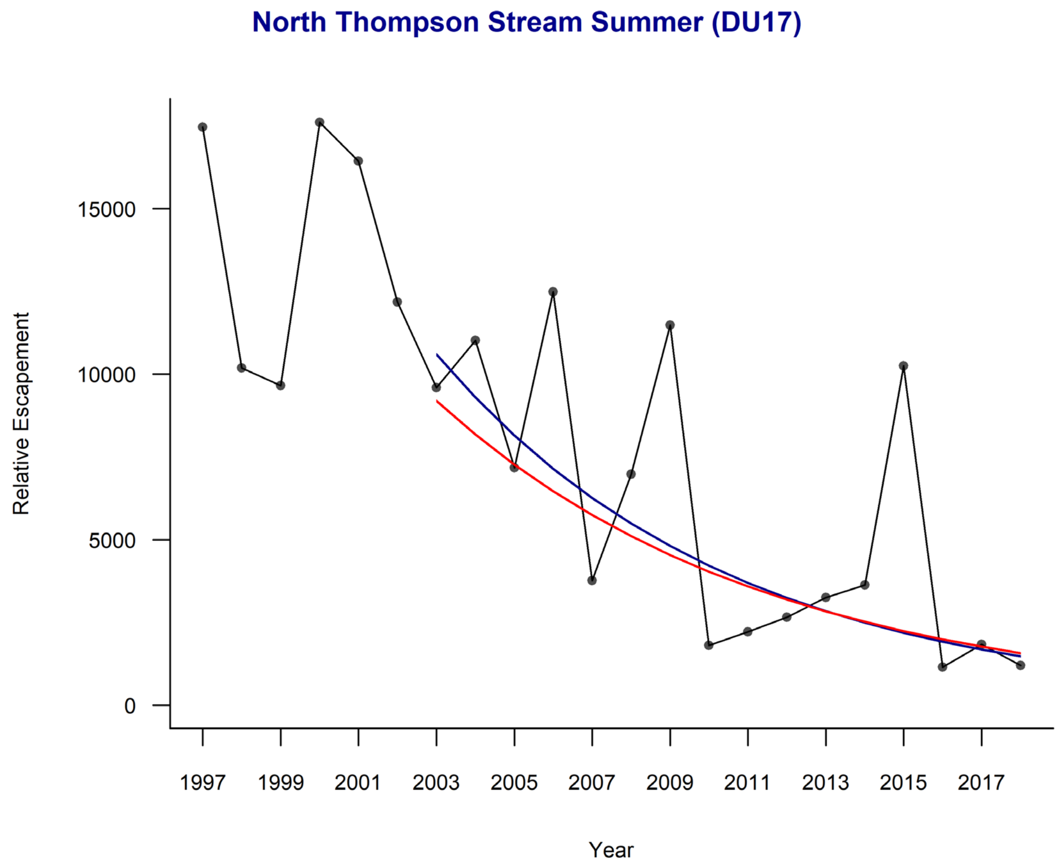

Figure 11. DU17 NTh-Summer: time series of relative escapement from 1997 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table 16. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) from the COSEWIC report and the updated values. Rates of change over the last three generations are provided based on analysis of the last three generations of data as well as the entire time series.

DU	DU Name Short	Report	Time Series Length	Years	Median % Change	95% CI	Probability of Decline: >30	>50	>70
DU17	NTh-Summer	COSEWIC	3 Gens	2000-2015	-62	-84, -10	0.93	0.75	0.29
			All Years	1997-2015	-64	-80, -33	0.98	0.86	0.26
		RPA	3 Gens	2003-2018	-84	-95, - 55	0.99	0.99	0.89
			All Years	1997-2018	-81	-90, -66	1.00	1.00	0.95

2.3. ELEMENT 3: RECENT LIFE HISTORY PARAMETERS

There are eleven Canadian coded-wire tags (CWT) indicator stocks distributed among all 28 Chinook Salmon DUs in BC, yet for the DUs covered in this report, only DU2 (LFR-Harrison) is an indicator stock. DU14 (STh-Bessette) is part of the Fraser Spring 4_2 Management unit, which uses Nicola as the indicator. Prior to ending in 2002, the Dome Creek system served as an indicator stock for DU11 (UFR-Spring) and as a proxy indicator for 8 of 11 DUs covered in this report (Table 17). Chilko River is under development as an indicator for DU10 (MFR-Summer), and it may subsequently act as an indicator for DUs 4 (LFR-Upper Pitt), 5 (LFR-Summer), 8 (MFR-Portage), and 17 (NTh-Summer). Consequently, there is limited data available at the DU level for life history characteristics such as marine survival and productivity at this time.

Productivity is an important life history parameter in the context of recovery. In salmon, productivity is often represented by the number of adult recruits produced per adult spawner. Broad patterns of declining Chinook Salmon productivity have been observed from Alaska to Oregon, and have been shown to be associated with the North Pacific Gyre Oscillation and North Pacific Current (Dorner et al. 2018). It has been suggested that this decline in productivity is associated with shifting population demographics, such as younger-age-at-maturity, reduced size-at-age, and reduced fecundity of female spawners (Ohlberger et al. 2018). A study of 10 Alaskan Chinook Salmon populations found that these populations' body sizes has decreased over the past 30 years on average, likely due to a decline in the age-at-maturity *and* a decrease in age-specific length (Lewis et al. 2015). All populations had a reduced proportion of older and larger ocean age-4 fish, and 9 out of 10 saw trends of declining length-at-age for ocean age-4 fish, and there is some evidence that this was driven by size-selective fisheries (Lewis et al. 2015). Declining trends of older and large fish are important to note for species recovery, because these life history parameters can influence productivity potential through reduced fecundity and egg survival (Healey 2001; Quinn et al. 2011).

Recently it was estimated that across BC Chinook Salmon indicator stocks, productivity has declined by 25-40% since the early 1980s (DFO 2018). Along with declining productivity, there is evidence that specific life history parameters such as generation timing, length-at-age, and survival have decreased in Fraser Chinook DUs (Table 18). DU2 (LFR-Harrison) is experiencing reduced survival, generation timing and age-at-length (Table 18). The long term trend for Nicola, the CWT indicator stock for the Spring 4.2s, did not show a decline in the generation length. The recent Chinook 5 Year Review found that there has been a decline in length-at-age at Albion for 5.2 fish, but not 4_2 fish (Dobson et al. 2019). A reduction in length-at-age has been observed in samples from Chilko (DU10) since 2014, however, due to the short and patchy time series, this trend is statistically uncertain and may be due to natural variability (Dobson et al. 2019). There is no current information available for the Fraser Spring 5_2 to assess trends. The trend in fecundity is currently unknown for all DUs.

Due to the lack of indicator stocks, with the exception of Harrison, current survival and absolute productivity data are not available at the DU level. The Dome CWT indicator smolt-age-3 survival data is from 1998 to 2002 (Table 19), thus it is unlikely to accurately represent recent marine survival due to changes in both freshwater and ocean productivity, ecosystem dynamics and trends observed for other Chinook stocks (Morrison et al. 2002; Nelitz and Porter 2009; Healey 2011; Irvine and Fukuwaka 2011). Due to limited direct information, many of the parameters used for the forward projections in the report that addresses Elements 12-22 will have to be estimated using proxy stocks or indirect information. Producing representative life history parameters is ongoing for the second part of this RPA, and will be more fully discussed in Part 2 (Elements 12-22).

Table 17. Summary of life history parameters for FRC DUs, including average generation time, fecundity, and fork length at age. Average generation times were estimated as the average of spawners in the absence of fishing mortality. General ranges in fecundity reported for age classes are reported in (Healey 1986). Average fork lengths were estimated for FRC DUs (data permitting) based on fisheries CWT recoveries data collected between 1967 - 2012 (Brown et al. 2019).

Designatable Unit	CWT Stock or Proxy	Juvenile Life History	Adult Run Timing	Age Class	Avg. Gen Time	Range in Fecundity	Fork Length by Age (mm)			
							Age-2	Age-3	Age-4	Age-5
DU2 LFR-Harrison	HAR	Ocean	Fall	4_1	3.8	2,648-4,462	653.8	797.8	879.3	-
DU14 STh-Bessette	NIC	Stream	Summer	4_2	3	4,018	-	-	-	-
DU4 LFR-Upper Pitt	DOM	Stream	Summer				675.2	804.4	912	-
DU5 LFR-Summer	DOM	Stream	Summer				645.6	804.9	888.6	-
DU7 MFR-Nahatlatch	DOM	Stream	Spring				-	-	-	-
DU8 MFR-Portage	DOM	Stream	Fall				-	-	-	-
DU9 MFR-Spring	DOM	Stream	Spring	5_2	4.5	5,388-9,063	665.2	738.9	846.8	-
DU10 MFR-Summer	DOM	Stream	Summer				629.7	766.9	869.7	895.2
DU11 UFR-Spring	DOM	Stream	Spring				601.2	741.5	798.0	870.0
DU16 NTh-Spring	DOM	Stream	Spring				696.5	786.8	869.8	-
DU17 NTh-Summer	DOM	Stream	Summer				661.3	796.1	889	992

Table 18. Summary of recent trends in characteristics for three BC management units (from DFO 2018). It should be noted the Nicola stock was included as it serves as a proxy indicator for DU14 (STh-Bessette).

Management Unit	Population	Survival	Generation Time	Female Length	Fecundity
		(2007-2011 brood year avg relative to 1980- 1990 avg)	(Decline rate)	(Trend)	(Trend)
Fraser Spring 4_2	Nicola	-55%	stable	Declining, Age-4	Unknown
Fraser Spring 5_2	-	Unknown	Unknown	Unknown	Unknown
Fraser Summer 5_2	Chilko	Unknown	Unknown	Declining, Age-3,-4,-5	Unknown
Fraser Fall 4_1	Harrison	-45%	-0.016	Declining, Age-3,-4,-5	Unknown

Table 19. Smolt- to age-3 survival rates for Dome and Nicola indicator stocks, and for smolt to age-2 survival rates for the Harrison indicator stock.

	Smolt to Age-3 Survival	Smolt to Age-3 Survival	Smolt to Age-2 Survival
Brood Year	Fraser Spring 5_2	Fraser Spring 4_2	Fraser Fall 4_1
	DOM CWT Indicator	NIC CWT Indicator	HAR CWT Indicator
1981	-	-	24.0%
1982	-	-	3.8%
1983	-	-	1.1%
1984	-	-	1.1%
1985	-	3.1%	1.4%
1986	0.4%	0.6%	7.2%
1987	1.1%	2.6%	2.6%
1988	2.0%	1.3%	10.9%
1989	0.8%	2.7%	7.2%
1990	2.5%	7.7%	2.2%
1991	1.7%	5.5%	0.4%
1992[5]	1.8%	0.1%	0.6%
1993	2.4%	0.8%	2.0%
1994	0.1%	1.1%	3.8%

[5] The low survival reported in 1992 (0.1%) for the Nicola River stock was due to a disease outbreak at the Nicola hatchery, which led to high levels of fish mortality. It should be noted survival in this year is not a good representation of natural fish survival for this stock.

	Smolt to Age-3 Survival	**Smolt to Age-3 Survival**	**Smolt to Age-2 Survival**
Brood Year	**Fraser Spring 5_2**	**Fraser Spring 4_2**	**Fraser Fall 4_1**
	DOM CWT Indicator	**NIC CWT Indicator**	**HAR CWT Indicator**
1995	0.3%	5.8%	1.0%
1996	0.9%	4.6%	2.3%
1997	1.4%	6.3%	0.8%
1998	1.3%	12.5%	0.9%
1999	-	6.3%	2.1%
2000	0.3%	0.8%	1.4%
2001	0.4%	1.4%	2.4%
2002	0.4%	1.3%	0.9%
2003	-	0.2%	1.4%
2004	-	2.0%	N/A
2005	-	0.4%	6.8%
2006	-	3.9%	0.8%
2007	-	1.1%	5.7%
2008	-	1.3%	2.0%
2009	-	1.9%	1.0%
2010	-	0.5%	4.7%
2011	-	1.8%	3.5%
2012	-	1.2%	0.7%
2013		1.5%	1.9%
2014	-	1.4%	2.4%
2015	-	0.6%	11.7%

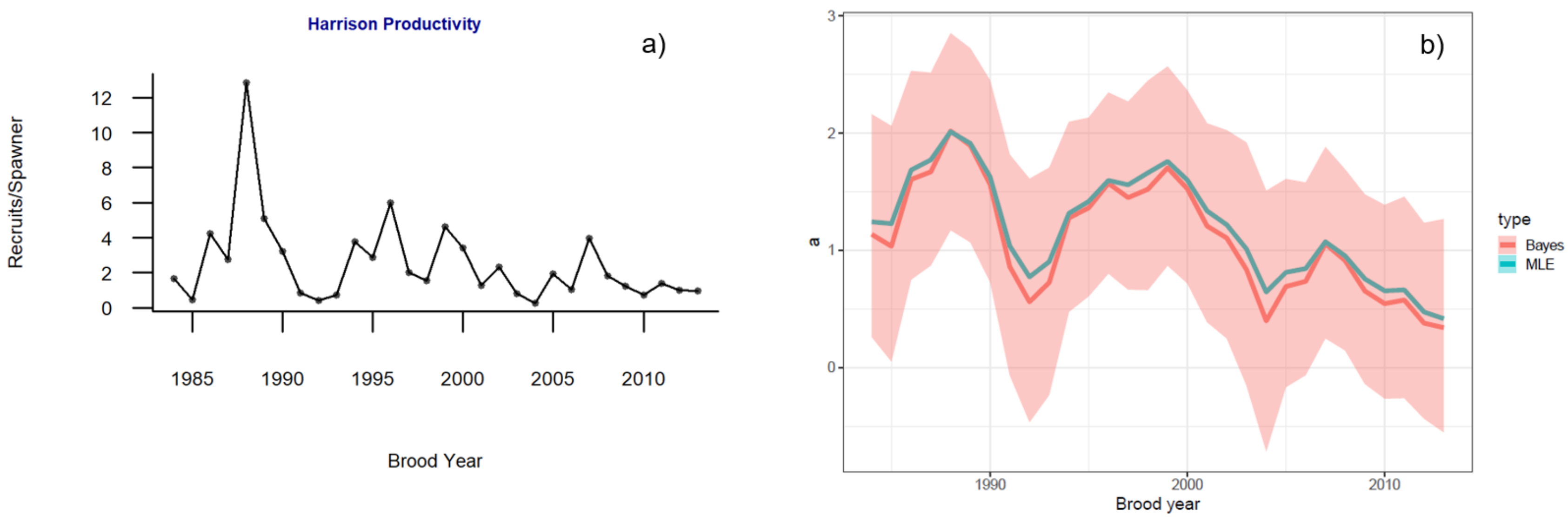

Figure 12. a) productivity as estimated recruits per spawner for DU2 (LFR-Harrison) by brood year from 1984 to 2013; and b) the trajectory of a (ln(alpha)) using the recursive Bayes model: the red lines is the median posterior and the maximum likelihood estimate is in blue (shaded area is 95% credible interval for the Bayes estimate).

3. HABITAT AND RESIDENCE REQUIREMENTS

3.1. ELEMENT 4: HABITAT PROPERTIES THAT CHINOOK SALMON NEED FOR SUCCESSFUL COMPLETION OF ALL LIFE-HISTORY STAGES

Chinook Salmon use a diverse range of habitats throughout their life cycle. Ocean-type and stream-type Chinook Salmon life history variants generally use different freshwater and ocean habitats, and exhibit different migration timing. Much of the variation in freshwater habitat use can be linked to differences in the hydrology of the spawning habitat and the nearby stream network. Coastal streams and rivers with rain-dominated hydrology tend to give rise to ocean-type Chinook Salmon that typically migrate to the ocean in their first year of life, while interior watersheds with snow-dominated hydrology tend to give rise to stream-type individuals that overwinter for one year or more in freshwater. Mixed rain and snow-dominated headwaters of some coastal streams also may support stream-types, as occurs in DU4 (LFR-Upper Pitt) and DU5 (LFR-Summer). Differences in habitat use and conditions between ocean- and stream-type Chinook Salmon are reviewed below and draw heavily from previous summaries of Chinook habitat (Healey 1991; Brown 2002; COSEWIC 2019; Brown et al. 2019).

3.1.1. Spawning and Egg Incubation Habitat

The habitat required for Chinook Salmon to carry out reproduction includes spawning and incubation habitat, which occurs in a range of different systems from small streams to the mainstem of large rivers. Females generally select spawning sites that have good circulation of well-oxygenated water (Healey 1991). Specific habitat features associated with Chinook Salmon spawning locations are the areas upstream of riffles, pool tail-outs especially below log jams and on the upstream side of large gravel dunes in large rivers (Table 20). These habitats are particularly important because they are associated with higher subsurface flows relative to other habitats.

The habitat attributes of Chinook Salmon redds have been shown to be highly variable (Healey 1991), although generally suitable spawning water depths are > 30 cm and suitable substrate sizes for redd construction are between 1.3 and 10.2 cm (Table 20). Large gravel and good inter-gravel flows (greater than 0.03 $cm \cdot s^{-1}$ percolation rate) are associated with high egg to fry survival for Chinook (87%) (Shelton 1955). Variability in suitable substrate sizes are in part due to variation in female length. Riebe et al. (2014) showed that the maximum substrate size a female can move during redd construction increases with female size. Female length also influences the size of redds, which can range from roughly 4.7 and 10.7 m^2 for females 700 to 1000 mm in fork length. For specific examples from FRC populations, average redd size for stream-type Chinook was 9.1-10 m^2 in the Nechako River (Neilson and Banford 1983) and 8.7 m^2 in the Nicola River (n=124, CV=24%; Chuck Parken, DFO, Kamloops, BC, unpub. data).

Spawning and incubation habitat conditions change between the time when adults arrive on the spawning grounds and when fry emerge from the gravel. Large changes in flows and temperature during spawning and incubation can affect the quality and quantity of habitat. Interior Fraser streams generally experience declining discharges during the autumn and winter as temperatures drop below freezing, creating a risk of redds dewatering and freezing if spawning occurs too early. In many interior systems, females seek out a mix of groundwater and surface water for their redd site. Groundwater is warmer and protects against freezing, however it is typically anoxic, thus a mix is required to ensure sufficient oxygen without risk of freezing. In coastal systems, scouring from fall and winter flooding is an important source of incubation mortality through direct removal of redds and/or the deposition or the infiltration of fine sediment into redds (Roni et al. 2016). Similarly, in interior systems, scouring during rain-on-snow events is thought to be a source of mortality during incubation (R. Bailey, pers. comm. 2019)

While habitat quality associated with this life stage has important consequences for recruitment, the amount of spawning habitat generally does not limit the number of fish that leave the freshwater environment as smolts.

3.1.2. Fry and Juvenile Rearing Habitat

Upon hatching, juvenile Chinook Salmon, called alevins, remain in the gravel and continue to develop before emerging from the substrate. Alevins move within the interstitial spaces between substrate particles and are particularly vulnerable to the presence of fine sediment or bedload movement. Alevins eventually move up through the gravel to emerge as fry when the yolk sac has been completely absorbed. Emergence generally occurs at night, helping to minimize predation.

Once juveniles emerge, there is large variation in freshwater habitat use among populations. Ocean-type juvenile Chinook Salmon from DU2 (LFR-Harrison) tend to outmigrate to the ocean immediately after emergence. They spend approximately six weeks rearing in the Fraser estuary. Juveniles from other ocean-type DUs may spend longer rearing in freshwater prior to migration to the estuary and the marine environment, however, none of those DUs are under consideration in this assessment.

Stream-type juvenile Chinook Salmon from interior snow-melt dominated systems typically rear for 1 year (over winter) in freshwater and outmigrate to the ocean as yearlings. For Chinook Salmon spawning in upstream areas of watersheds, the downstream migration to non-natal streams and rivers distributes fry into suitable rearing habitats (Bradford and Taylor 1997). Three commonly observed strategies for stream-type juvenile Chinook Salmon from snow-dominated Interior Fraser and Thompson rivers are:

1. juveniles rear in their natal stream from emergence until smolting;
2. juveniles rear in their natal stream from emergence to late summer and then migrate into a larger mainstem river such as the Thompson or Fraser where they overwinter and before smolting the following spring; or
3. juveniles immediately leave their natal stream after emergence and migrate (actively and passively) downstream to overwinter in the mainstem, side channels, and small tributaries of the lower Fraser River and the estuary.

Irrespective of the habitats they use, Chinook Salmon fry are most often found in habitats with small substrate, relatively low velocity and shallow depth (Table 20). They are most often observed in main river channels and are found less often in off-channel habitat than Coho salmon, however, there are many observations of juvenile Chinook Salmon rearing in small non-natal streams throughout the Fraser and Yukon rivers (Murray and Rosenau 1989; Scrivener et al. 1994). Brown (2002) provides a comprehensive review of the freshwater rearing habitat required for Chinook Salmon, in both coastal and interior British Columbia watersheds; a summary is provided below (Table 21). It should be noted the reported limit of <25 NTUs (Nephelometric Turbidity Units) in Table 21 may be unreasonable for FRC, as the mainstem Fraser River and a variety of its tributaries, where juveniles are known to rear, exceed this threshold. This may be a misrepresentation of useable habitat for FRC within the Fraser drainage, and in particular, undervaluing the importance of the mainstem Fraser River as rearing habitat.

Juvenile Chinook Salmon have been captured in isolated flood channels of major rivers (Bustard 1986; Brown et al. 1989), non-natal tributaries during spring freshet (Scrivener et al. 1994), and along lake margins (Graham and Russell 1979; Fedorenko and Pearce 1982; Lewis and Levings 1988). FRC fry densities (April-July) were higher in the mainstem North Thompson than in its tributaries (Stewart et al. 1983). Juvenile chinook densities (captured in November by electroshockers) were estimated at 0.011 fish·m^{-2} for the Salmon River (Shuswap Lake) and 0.245 fish·m^{-2} for the Quesnel River. Reported densities from these habitats are much lower than the estimated median of 5000 ha^{-1} (0.5 m^{-2}) interior Columbia Rivers tributaries (Thorson et al. 2014).

While in freshwater, juvenile Chinook Salmon primarily feed on adult and larval insects, particularly those floating on the surface of the stream (Raleigh et al. 1986). During their limited period of freshwater rearing, ocean-type Chinook juveniles require stream habitats that are moderate in temperature and flow, and that support healthy and productive insect communities. Stream-type Chinook juveniles also have similar habitat requirements, and in addition, require water of sufficient quantity and quality to allow overwintering. These criteria are met in natural systems with healthy streamside vegetation, low sediment loads, high dissolved oxygen levels, and variable substrates. Groundwater inputs are required in many interior systems to counter anchor ice formation in overwintering habitats, and moderate warm summer temperatures.

A critical component of fry and juvenile rearing is access to ephemeral habitats, which plays an important role for both ocean and stream-type Chinook. Junk et al. (1989) proposed the flood pulse concept, which predicts that annual inundation is the driving force for productivity and biotic interactions in river–floodplain systems. Floodplain habitats are particularly important to juvenile Chinook Salmon as they have higher biological diversity and increased production of invertebrates when compared to adjacent river channels (Junk et al. 1989; Gladden and Smock 1990), and provide a seasonal source of food during and following the freshet. While not FRC-specific, Jeffres et al. (2008) report off-channel floodplain habitats in the Cosumnes River provide significantly better rearing habitat than the intertidal river channel supporting higher growth rates. When juvenile Chinook salmon leave fresh water at a larger size, as seen in fish reared on floodplains, overall survivorship to adulthood is increased (Unwin 1997; Galat and Zweimüller 2001; Jeffres et al. 2008). Degradation of these seasonally inundated habitats, or features that limit access to these habitats, may therefore indirectly influence important habitat properties for FRC.

The amount of rearing habitat available to coastal and interior populations have been shown to be limiting (Thorson et al. 2014; David et al. 2016). While not FRC specific, strong negative density dependence in juvenile survival has been indicated for freshwater (Thorson et al. 2014) and estuarine (David et al. 2016) rearing environments. The degradation and loss of freshwater and estuarine rearing habitat will have negative impacts on population productivity and may mediate negative density effects on production when habitat is lost (David et al. 2016).

3.1.3. Juvenile Freshwater Outmigration Habitat

Ocean-type Chinook from populations from the lower Fraser and South Thompson Rivers encounter snowmelt-induced flooding in May, June and July and may use seasonal flood cycles as a queue to begin downstream emigration (Healey 1991). After one year in freshwater, juvenile stream-type Chinook Salmon from the interior and lower Fraser systems migrate downstream in the spring and early summer and enter the Strait of Georgia. Tagging studies indicate that it takes hatchery Chinook smolts from the Nicola watershed (Nicola, Spius, Coldwater) between 3.4 and 19.2 days (median) to travel from interior release sites to the mouth of the Fraser River (Welch et al. 2008). Similar data are not available for smolts from other interior DUs.

3.1.4. Ocean Rearing Habitat

Ocean rearing habitat for juvenile Chinook Salmon range from estuaries to the open ocean. These habitats are critical as they are where Chinook Salmon gain most of their biomass and begin to develop their gametes for subsequent reproduction.

Estuaries are important as they provide extensive opportunities for feeding and growth, and refuge from predators. They are also environmental transition zones that allow Chinook juveniles the opportunity to acclimate from freshwater to saltwater from freshwater, and between waters of differing temperatures (Macdonald et al. 1988). Levings et al. (1986) found that Chinook Salmon that reared in estuaries longer grew faster and survived better than individuals that quickly migrated through. Estuaries also provide refuge from predators (Healey 1991). The higher turbidity and extensive aquatic vegetation that provides important structural cover associated with estuarine areas limits the ability of visual predators to key on salmon juveniles (Gregory and Levings 1996, 1998).

The main habitat used by both sub-yearling and yearling Chinook Salmon in the lower Fraser River estuary was marsh habitat (Chalifour et al. 2019) and patches with higher temperatures tended to result in higher catches of juvenile Chinook Salmon. Catches in eelgrass and sand flats were consistently lower than in marsh habitat in both years of the study.

In general, ocean-type Chinook Salmon smolts remain for varying periods in estuaries, ranging from a few weeks to several months. Estuarine habitat is particularly important for ocean-type Chinook given their prolonged residence time (Quinn 2005). As they continue to grow, ocean-type Chinook smolts begin to disperse throughout the nearby coastal areas, preferring sheltered surface waters during early marine residence. Stream-type Chinook smolts appear to spend less time in the estuary of their home rivers. When observed in estuaries, they concentrate in the outer delta areas and residence times tend to be relatively short.

Chinook Salmon require productive nearshore marine habitats. Nearly all Chinook from the Fraser River spend the first few months in the Salish Sea (Tucker et al. 2011) and tend to remain within 200-400 km of their natal rivers for the first year at sea, irrespective of life history type (Trudel et al. 2009). Chinook Salmon generally rear in sheltered, near-shore environments for varying periods depending on factors such as food availability, competition, predation and environmental conditions. Throughout this period, kelp and other shoreline vegetation provide an important refuge from predators as well as a productive environment for insects and plankton, both major dietary components for juvenile Chinook (Healey 1991).

Following the first few months at sea, patterns of marine habitat use, including exit timing from the Salish Sea and subsequent distribution along the coast of BC and Southeast Alaska, tend to diverge between ocean- and stream-type life histories for Fraser River Chinook Salmon (Trudel et al. 2009; Tucker et al. 2011). Distributional data suggest that ocean- and stream-type Chinook Salmon may experience different ocean conditions due to differences in migration timing. For example, surface trawl surveys in coastal waters indicate that subyearlings from the South Thompson DU tend to exit the Salish Sea earlier (first fall and winter at sea) than subyearlings from the lower Fraser River that appear to exit Salish Sea the following summer (Tucker et al. 2011). It also appears that all ocean-type Chinook exit the Salish Sea via the Strait of Juan de Fuca (Tucker et al. 2011), whereas yearling Chinook may exit through the Strait of Juan de Fuca or Johnstone Strait.

Catches of Chinook Salmon also suggested that the lower Fraser River subyearlings (DU2 LFR-Harrison) have the narrowest distribution during their first two years at sea and is restricted to the south of northern West Coast of Vancouver Island. Yearling Chinook Salmon tend to have the broadest marine distribution in their first two years at sea and are generally found more northerly and westerly than subyearlings. In contrast to subyearling Chinook Salmon, yearlings tend to be found in deeper waters. These finer scale patterns of habitat use may contribute to differences in dynamics among life histories and populations (Braun et al. 2016).

Primary prey items consumed during the early marine phase include various zooplankton species as well as adult and larval insects. The variety of food items consumed varies over time and location but fish (primarily herring and sandlance) dominate the diet with crab larvae, squid and large zooplankton also contributing.

Ocean-type Chinook Salmon rear in coastal waters for most of their life at sea. Data suggests that in general, ocean-type do not disperse more than 1,000 km throughout their life (Healey 1991). In general, stream-type Chinook Salmon are thought to disperse widely throughout the North Pacific and comprise the majority of Chinook Salmon intercepted on the high seas. They feed mainly on small fish (primarily herring and sandlance), with crab larvae, squid and large zooplankton also contributing to their diet (Healey 1991).

Factors that impact the productivity of coastal regions also have an impact on Chinook Salmon. For example, correlations between sea-surface temperatures and coastal upwelling during their first year at sea and the survival of Fraser River hatchery Chinook populations have been observed, although the analyses should be considered exploratory (Braun et al. 2016). Correlations suggested different responses to coastal marine conditions by life history type. This response diversity indicates changes to the marine environment may affect Fraser Chinook DUs differently and may be complex.

3.1.5. Adult Freshwater Migratory Habitat

The adult freshwater migratory timing is one of the most variable Chinook Salmon life history traits. Each DU experiences a unique combination of temperatures and flows, as well as different travel distances and migration rates as they migrate upstream to their spawning grounds. Environmental thresholds used in Hague and Patterson (2009) were used for assessing the encounter rates of Fraser Chinook populations to adverse upstream migration conditions. The environmental thresholds used by Hague and Patterson (2009) for Fraser Chinook Salmon were taken from other systems, mainly adult Chinook Salmon migration studies from the Columbia River basin suggest optimal temperatures for swimming are 16.3°C and lethal temperatures are > 21°C. Studies of Fraser River sockeye salmon suggest discharges > 8000 $m^3 \cdot s^{-1}$ may be cause for concern, however the threshold of 8000 $m^3 \cdot s^{-1}$ used for sockeye salmon is likely to be low for Chinook Salmon due to their larger size and potentially greater swimming ability.

Hague and Patterson (2009) reconstructed thermal and flow histories of five Fraser River Chinook Salmon populations and evaluated the historical temperatures and flows encountered and the likelihood of exceeding temperature and flow thresholds. The results of the reconstructions are summarized in Table 22. All five populations are unlikely to encounter temperatures that exceed the assumed lethal limit of 21°C, however three populations (Slim Creek and Tete Jaune (DU11); Nechako (DU10); South Thompson River (DU14)) were likely to encounter temperatures above the assumed optimum temperature for swimming of 16.3°C. Only two of the five populations (Upper Chilcotin River (DU9); Slim Creek (DU11)) had encountered discharges > 8000 $m^3 \cdot s^{-1}$, which was due to their early entry into freshwater that corresponded with Fraser River freshet.

Returning adults from the Upper Chilcotin River and Chilako River in DU9 arrive at the lower areas of their natal streams at the time of peak spring freshet. Returning adults need to ascend these systems on the freshet to gain access to spawning habitats that otherwise would be inaccessible. Upon ascending these systems, the fish remain in deep holding habitats for an extended period and only emerge from those habitats to spawn two to three months later (R. Bailey, pers. comm).

Table 20. Overview of habitat requirements for Chinook Salmon by life stage. Most attribute values are taken from reviews of habitat requirements by (Healey 1991) and Bjornn and Reiser (1991).

Life Stage	Function	Feature(s)	Attributes
Spawning and egg incubation	Spawning, incubation	Redds are often constructed at the heads of riffles, in pools, and upstream of gravel dunes in large rivers, where the gravel is less than 15-cm diameter and has good circulation of well-oxygenated water.	Particle size 1.3-10.2 mm Fall Chinook spawning water depth ≥ 24 cm Summer Chinook spawning water depth ≥ 24 cm Spring Chinook spawning water depth ≥ 30 cm Velocity: 0.3-1.09 $m \cdot s^{-1}$ DO_2: 7-12 $mg \cdot L^{-1}$ Temperature: 5.0-14.4°C Mean redd area: 9.1-10.0 m^2
Fry and juvenile rearing	Feeding, cover	Mainstem habitats Floodplain habitats Off-channel habitats Side channels small streams With cover Non-natal streams and side channels Complex habitat As juveniles grow they move from shallow habitats such as stream margins, side channels, and backwaters to deeper pool habitat	Temperature range: 12-14°C DO_2: 7-12 $mg \cdot L^{-1}$ Turbidity: < 25 NTU[6] Cover: high amounts of overhanging vegetation and undercut banks Gradient: < 3% Pool size range: 50-250 m^2 Pool density: > 1500 $sm^2 \cdot km^{-1}$ Large woody debris density: > 100 $pieces \cdot km^{-1}$
Juvenile freshwater outmigration	Outmigration, feeding	Large rivers, non-natal tributaries	
Juvenile - Ocean rearing	Feeding	Estuaries, coastal and off-shore waters	Estuaries (e.g. Marsh, eelgrass): abundant aquatic vegetation, high turbidity. Coastal: near-shore sheltered habitats, abundance of kelp and other shoreline vegetation.

[6] Note: The reported value of <25 NTU for Chinook may be not be appropriate for FRC, as the mainstem Fraser River and a variety of its tributaries exceed this value.

Life Stage	Function	Feature(s)	Attributes
			Depth in coastal waters: ocean-type ~40-60 m, stream-type depth: ~60-80 m
Adult – freshwater migration	Upstream migration	Large rivers	Fall Chinook Temperature range: 10.6-19.4°C Summer Chinook Temperature range: 13.9-20.0°C Spring Chinook Temperature range: 3.3-13.3°C All populations - optimal swim temperature: 16.3°C All populations - lethal temperature: 21°C Water depth: > 24 cm Velocity: < 2.44 $m \cdot s^{-1}$

Table 21. Habitats used by Chinook Salmon in watersheds with snow-dominated hydrology. Adapted from Brown 2002.

Habitat Type	Water Level and Location	Substrate and Vegetation	Examples of Possible Fish Use
Permanent water	Flowing or open standing water all year (rivers, ponds, lakes, terrace tributaries, and channelized streams).	Variable substrates and vegetation, dependent on water velocity	Chinook may use these habitats all year and typically found overwintering in habitats with coarse gravel (Swales et al. 1986; Levings and Lauzier 1991)
Ditches	Water levels are variable (dry to flowing). Ditches are used for drainage and irrigation.	Substrate may be mud and/or clay. Aquatic vegetation may re-colonize abandoned ditches	May trap Chinook fry in the spring. Use and survival is dependent on access and water quality (Fleming et al. 1987)
River side-channels	Water velocity and level are variable. Isolated pools may form when water level drop. Braids, capped side channels, percolation and overflow channels.	Substrate may be sand, gravel, and/or cobble. No instream vegetation, riparian vegetation composed of willows and cottonwoods.	Chinook dominate (Brown et al. 1989)
Runoff tributary and floodplain tributaries	Small, may be steep tributaries that flow into large rivers.	Substrate may be sand, gravel and/or boulder. Typically, no instream vegetation. Riparian vegetation is important.	Used by Chinook during downstream migration (Scrivener et al. 1994). lower Fraser tributaries provide important habitat for Chinook (Murray and Rosenau 1989).

Habitat Type	Water Level and Location	Substrate and Vegetation	Examples of Possible Fish Use
Estuarine drainages, sloughs, and marshes	May be ephemeral habitats but typically flooded in the summer. Access may be dependent on tide cycles. This type of habitat is prevent in the lower Fraser River.	Substrate is variable but usually consists of a high percentage of fines. Aquatic vegetation is variable and may consist of Carex Lyngbyei, Scripus spp, and Typha spp. Also riparian shrubs are present.	Used by Chinook fry in the spring (Birtwell et al. 1987). Access may be limited by flood gates.
Riverine ponds and swamps	Permanent water. Water levels must be adequate to support fish over winter. Often located in abandoned side-channels and may be associated with beavers.	Surface consists of a blanket of organics. Aquatic vegetation often present in ponds and swamps.	Low densities of Chinook have been observed in side channels on the Nicola (Swales et al. 1986)
Lake margins	Flooded in late spring throughout summer and dry in the winter.	Substrate variable and dependent on slope and wave action. May flood into riparian vegetation and swampy alcoves.	Heavily used by Chinook fry when flooded and at night (Graham and Russell 1979; Russell et al. 1980); Brown and Winchell 2002).
River margins	Flooded in late spring throughout summer and dry in the winter.	Substrate may be sand and/or gravel. River may flood into riparian vegetation	Fish may move laterally on to river margins during high water but use is temporary (Tutty and Yole 1978; Brown et al. 1994). Juvenile Chinook tend to move from shallow low velocity margins into deeper, higher velocity main-channel waters as they grow. Use appears to be nocturnal.

Table 22. Summary of thermal and flow reconstructions for four Fraser River Chinook Salmon populations evaluated in (Hague and Patterson 2009).

DU	Populations	Peak River Entry timing	Peak spawn timing	Travel (days)	Likely to encounter high river temps	Likely to encounter high flows	Number of days during migration Fraser River flows at Texas Creek are > 2500 $m^3 \cdot s^{-1}$
DU9 –Middle Fraser River Stream Spring	Upper Chilcotin River	Early May	Mid August	102	Unlikely to encounter river temps ≥ 16.3°C but unable to assess due to lack of thermal records	15% of flows for late-timed fish will encounter > 8000 $m^3 \cdot s^{-1}$	Mean = 39 (51% of days); range = 9-62
DU11 – Upper Fraser River Stream Spring	Slim Creek	Late June	Late August	64	60% of late entry and 25 % of peak entry fish will encounter ≥ 16.3°C. Unlikely to encounter river temps > 21°C	Early and peak entry fish will occasionally encounter > 8000 $m^3 \cdot s^{-1}$	Mean = 55 (79% of days); range = 4-71
DU10 – Middle Fraser River Stream Summer, and DU11 – Upper Fraser River Stream Spring	Nechako River and Tete Jaune Creek	Mid July	Early September	48	The majority of fish would encounter river temperatures ≥ 16.3°C. Unlikely to encounter river temps > 21°C	Unlikely to encounter flows > 8000 $m^3 \cdot s^{-1}$	Mean = 42 (68% of days); range = 0-63
DU2 – Lower Fraser River Ocean Fall	Harrison River	Early October	Early November	32	Unlikely to encounter river temps ≥ 16.3°C	Unlikely to encounter flows > 8000 $m^3 \cdot s^{-1}$	Spawn below the slide

3.2. ELEMENT 5: INFORMATION ON THE SPATIAL EXTENT OF THE AREAS IN CHINOOK SALMON DISTRIBUTION THAT ARE LIKELY TO HAVE THESE HABITAT PROPERTIES

3.2.1. Freshwater Habitat Distribution

FRC are widespread throughout the Fraser River all of its major tributaries. The distribution of each DU are presented in the following maps. Most of the streams and rivers mapped have the habitat features and attributes summarized in Element 4. Mapped distributions are based on spawner surveys, which may underestimate the full extent of the distribution of Chinook in the Fraser River due to constraints in conducting annual spawner surveys over such a broad geographical area.

The maps provided in this section are updated from the COSEWIC (2019) review. The following changes have been made to the COSEWIC maps to better reflect the freshwater distribution of FRC DUs covered in this RPA:

- DU7 (MFR-Nahatlatch) map was altered to remove Anderson River on the east side of the Fraser Canyon, south of Boston Bar. DFO (2013) listed the Anderson River to be excluded from the Fraser Canyon – Nahatlatch CU (CK-08) based on its geography and a lack of evidence to suggest current FRC presence;
- DU9 (MFR-Spring) map was altered to include the Coglistiko, Euchiniko, and Nadina rivers;
- DU10 (MFR-Summer) map was altered to remove Dog Creek on the east side of the Fraser Canyon, northeast of the Gang Ranch. DFO (2013) listed Dog Creek to be removed from the Middle Fraser River – summer timing CU (CK-11) based on local expert and aboriginal traditional knowledge of FRC.

DU2 – Lower Fraser River Ocean Fall (Harrison)

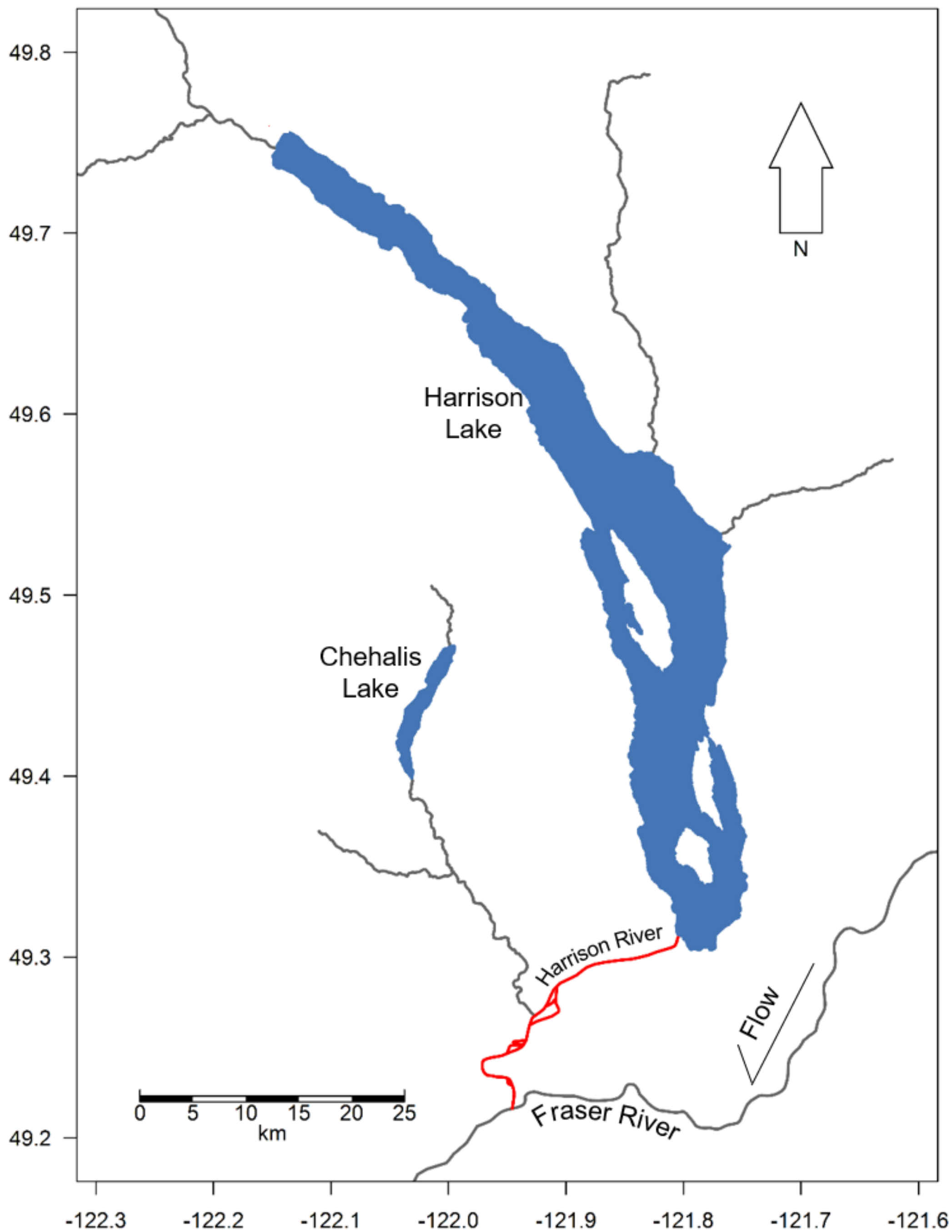

Figure 13. Map of DU2 - Lower Fraser River Ocean Fall (Harrison). The river length in red denotes the distribution of potential spawning area.

DU4 – Lower Fraser River Stream Summer (Upper Pitt)

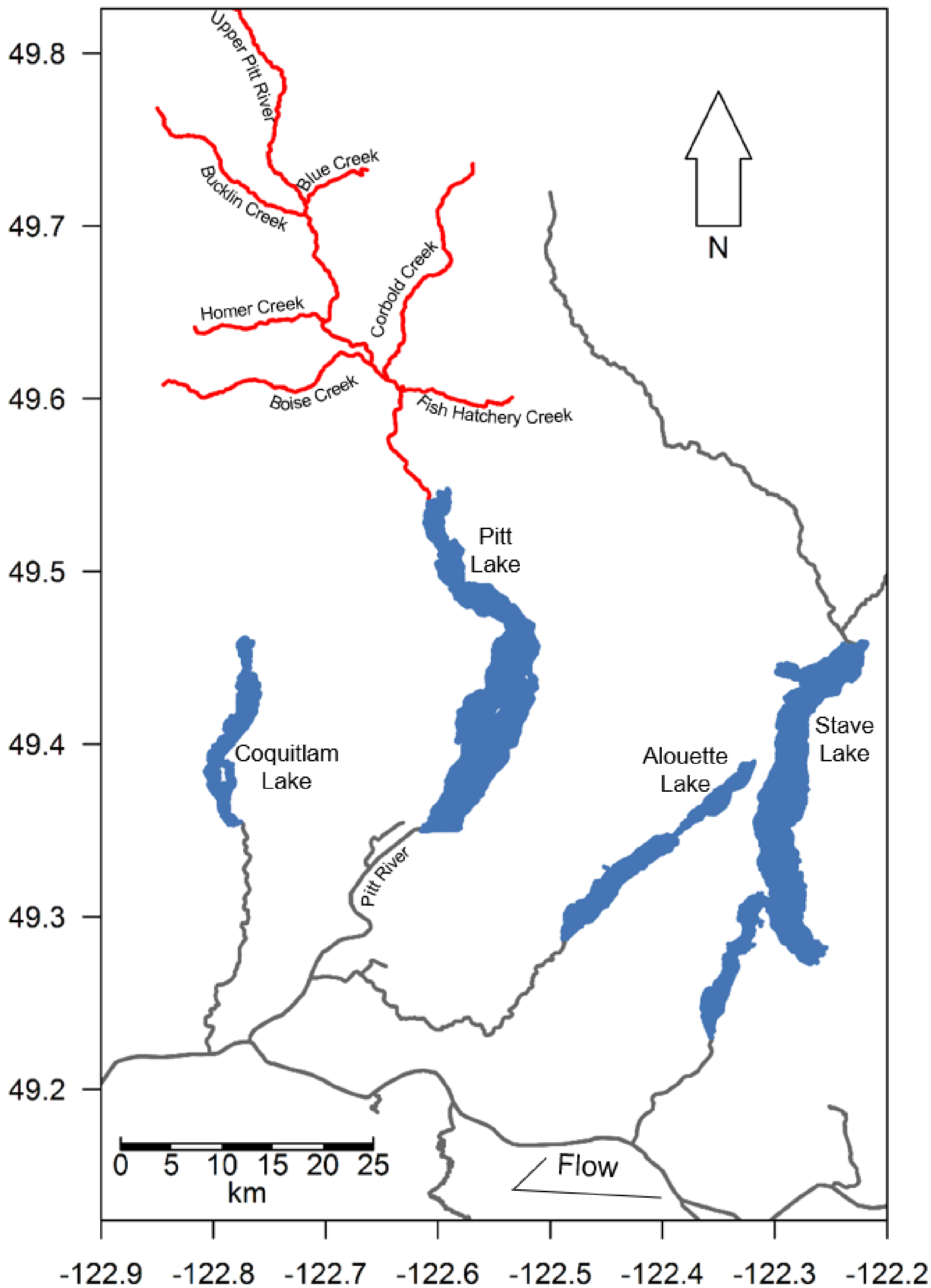

Figure 14. Map of DU4 - Lower Fraser River Stream Summer (Upper Pitt). The river length in red denotes the distribution of potential spawning area.

DU5 – Lower Fraser River Stream Summer

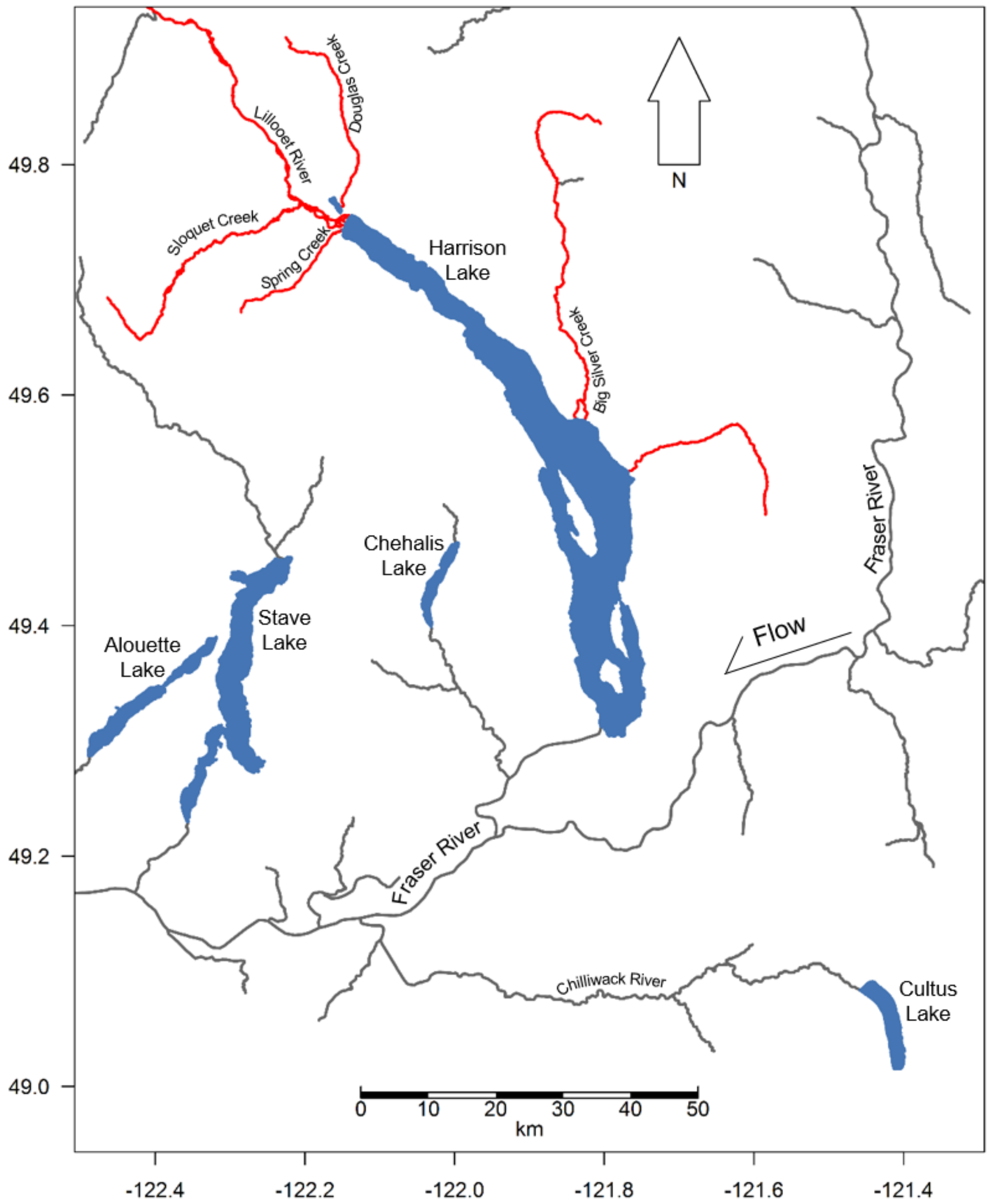

Figure 15. Map of DU5 - Lower Fraser River Stream Summer. The river length in red denotes the distribution of potential spawning area.

DU7 – Middle Fraser River Stream Spring (Nahatlatch)

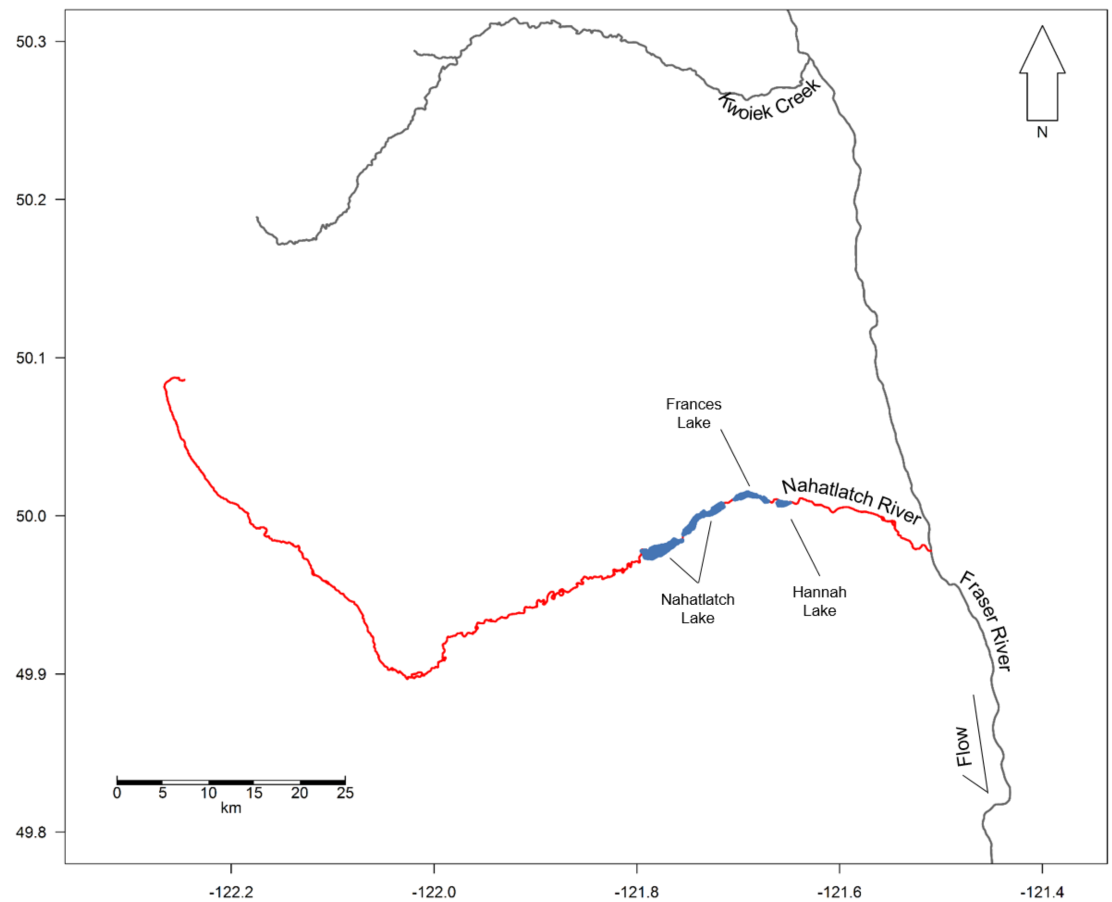

Figure 16. Map of DU7 - Middle Fraser River Stream Spring (Nahatlatch). The river length in red denotes the distribution of potential spawning area.

DU8 – Middle Fraser River Stream Fall (Portage)

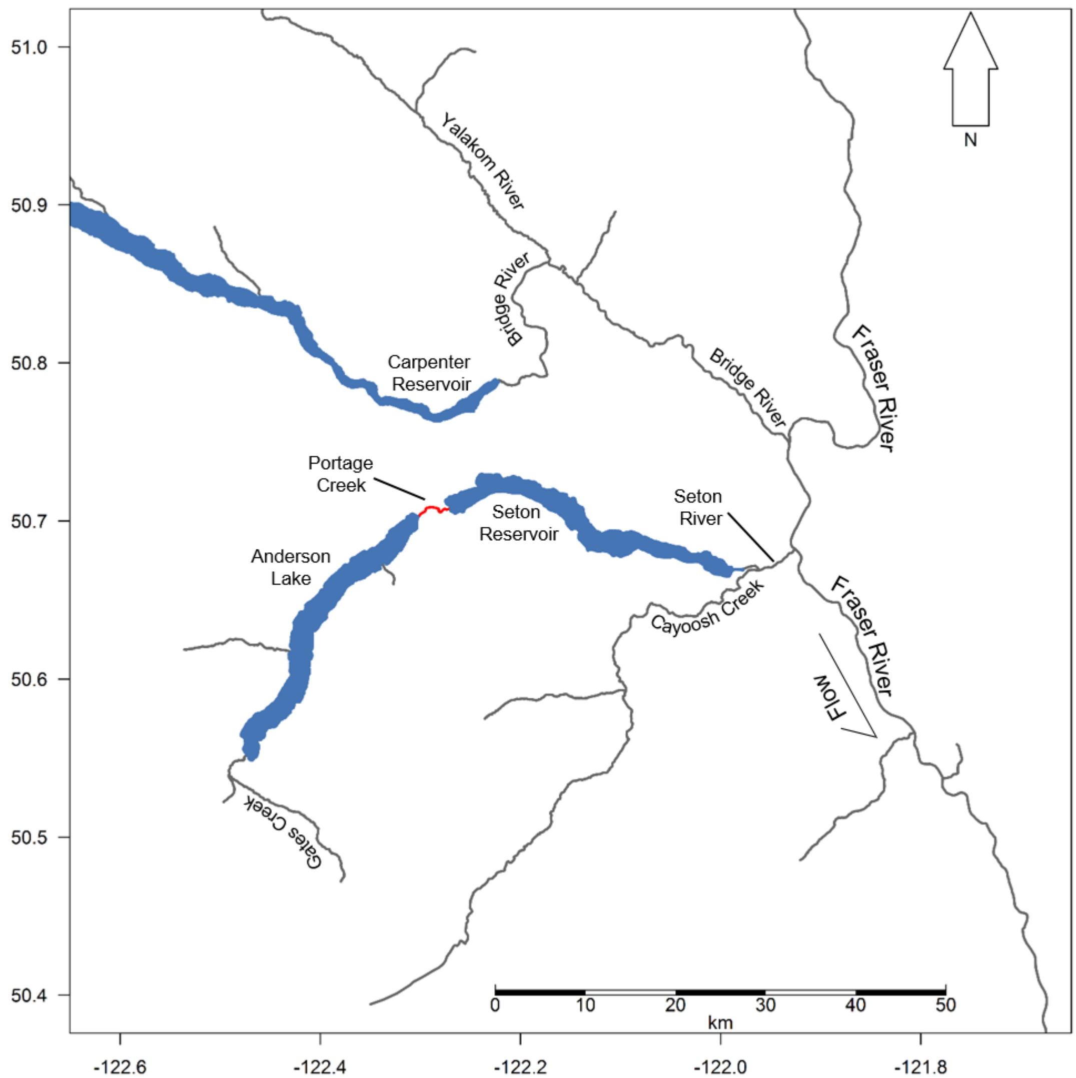

Figure 17. Map of DU8 - Middle Fraser River Stream Fall (Portage). The river length in red denotes the distribution of potential spawning area.

DU9 – Middle Fraser River Stream Spring

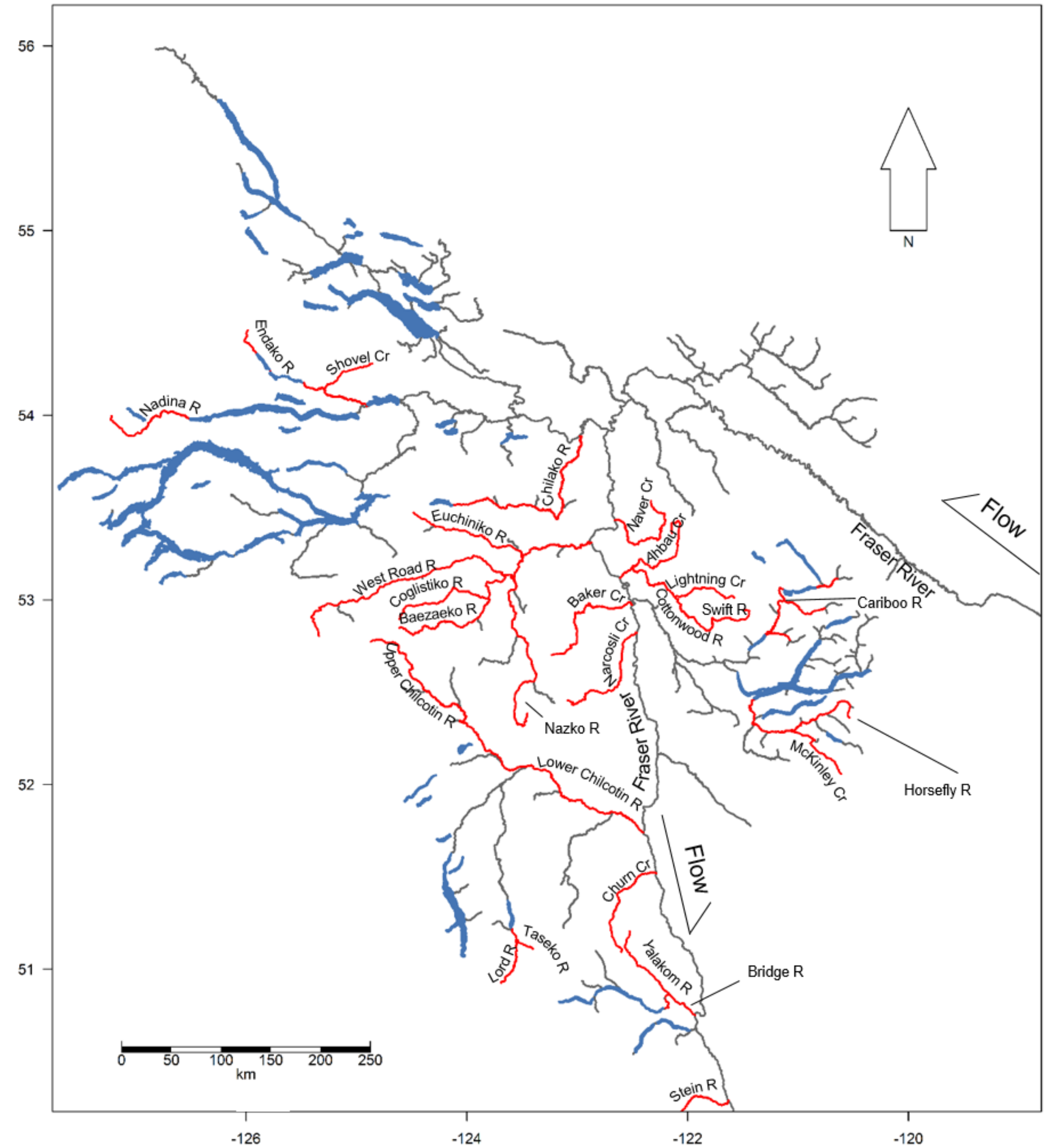

Figure 18. Map of DU9 Middle Fraser River Stream Spring. The river length in red denotes the distribution of potential spawning area.

DU10 – Middle Fraser River Stream Summer

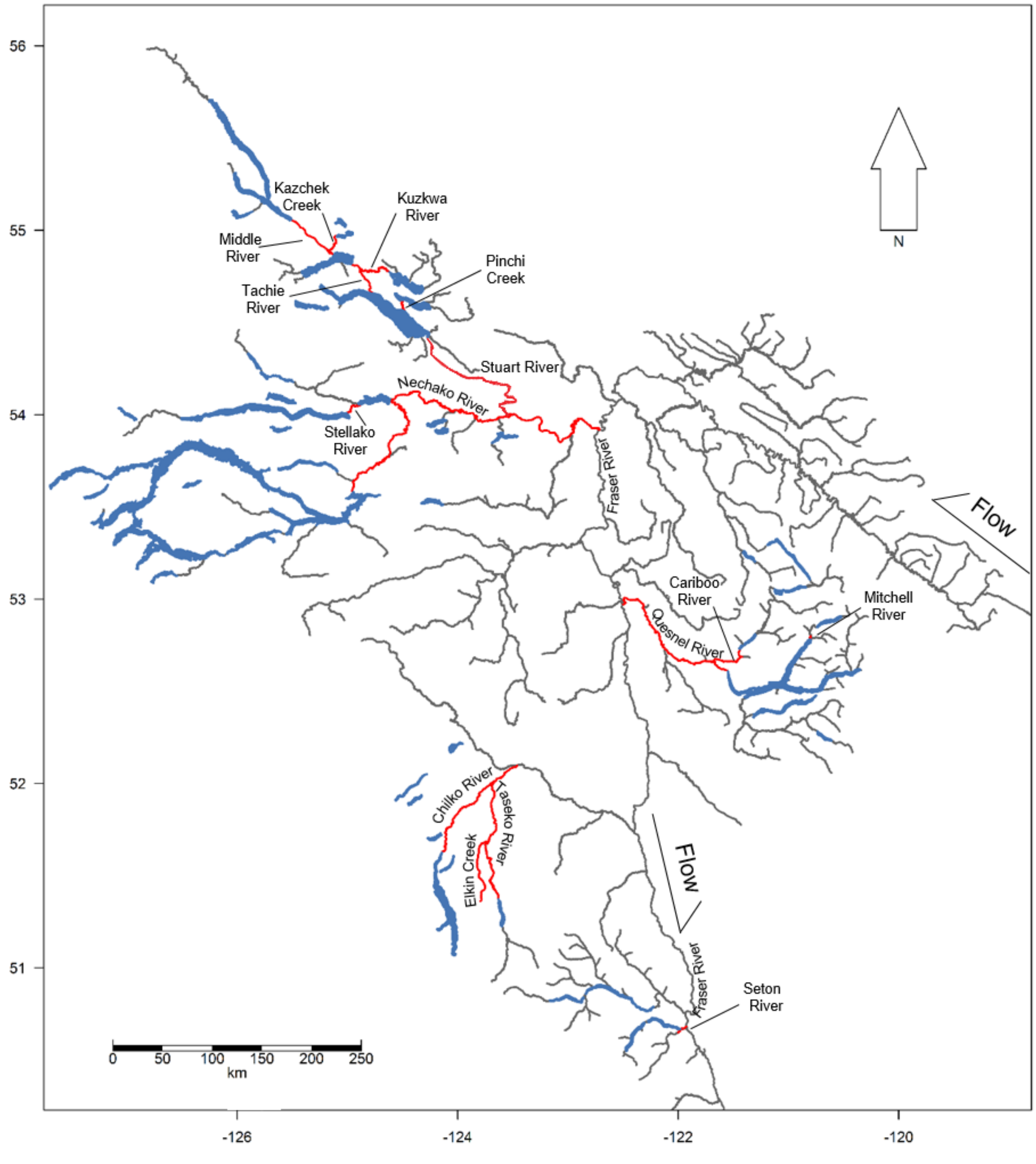

Figure 19. Map of DU10 - Middle Fraser River Stream Summer. The river length in red denotes the distribution of potential spawning area.

DU11 – Upper Fraser River Stream Spring

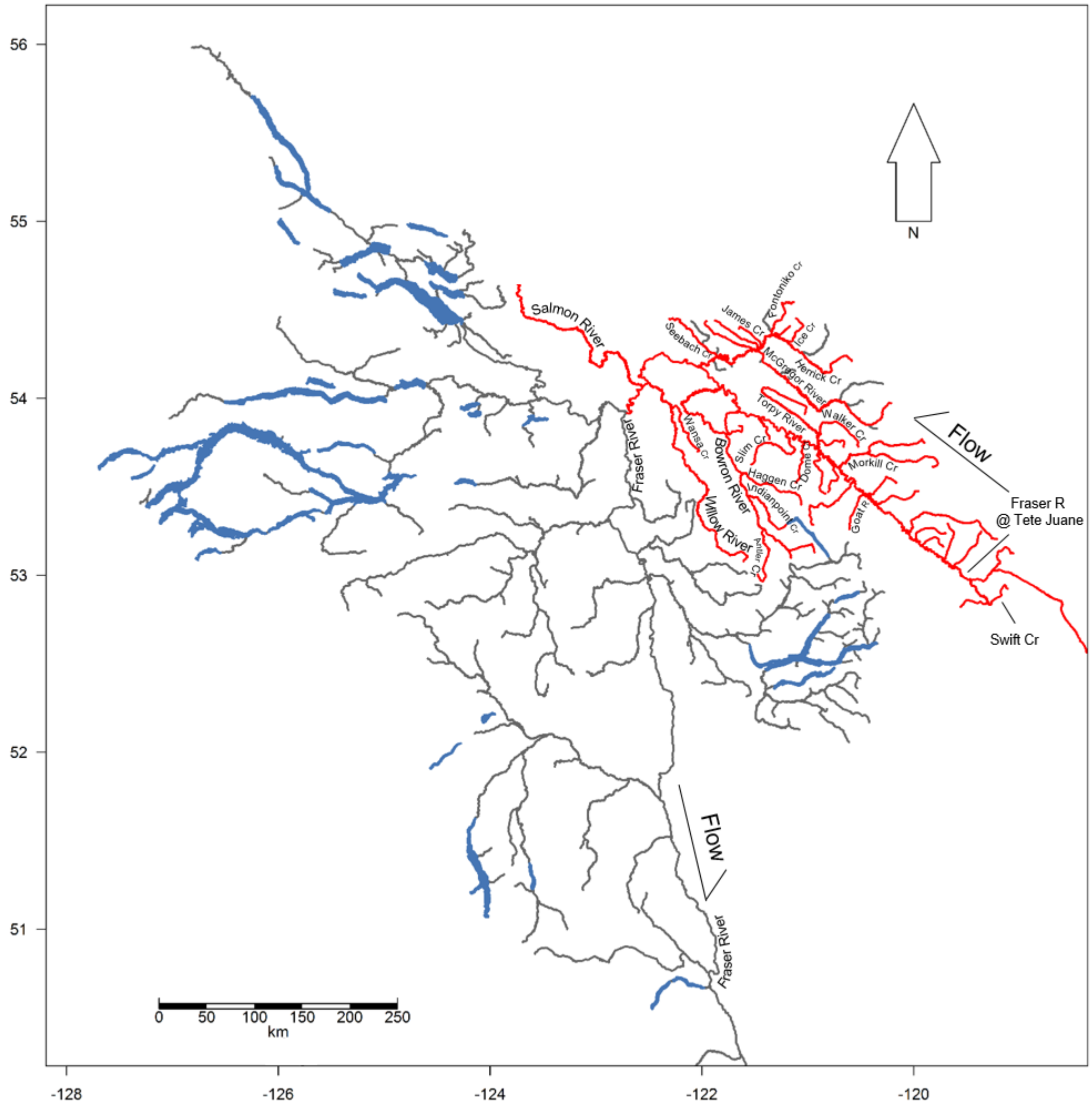

Figure 20. Map of DU11 - Upper Fraser River Stream Spring. The river length in red denotes the distribution of potential spawning area.

DU14 – South Thompson Stream Summer (Bessette)

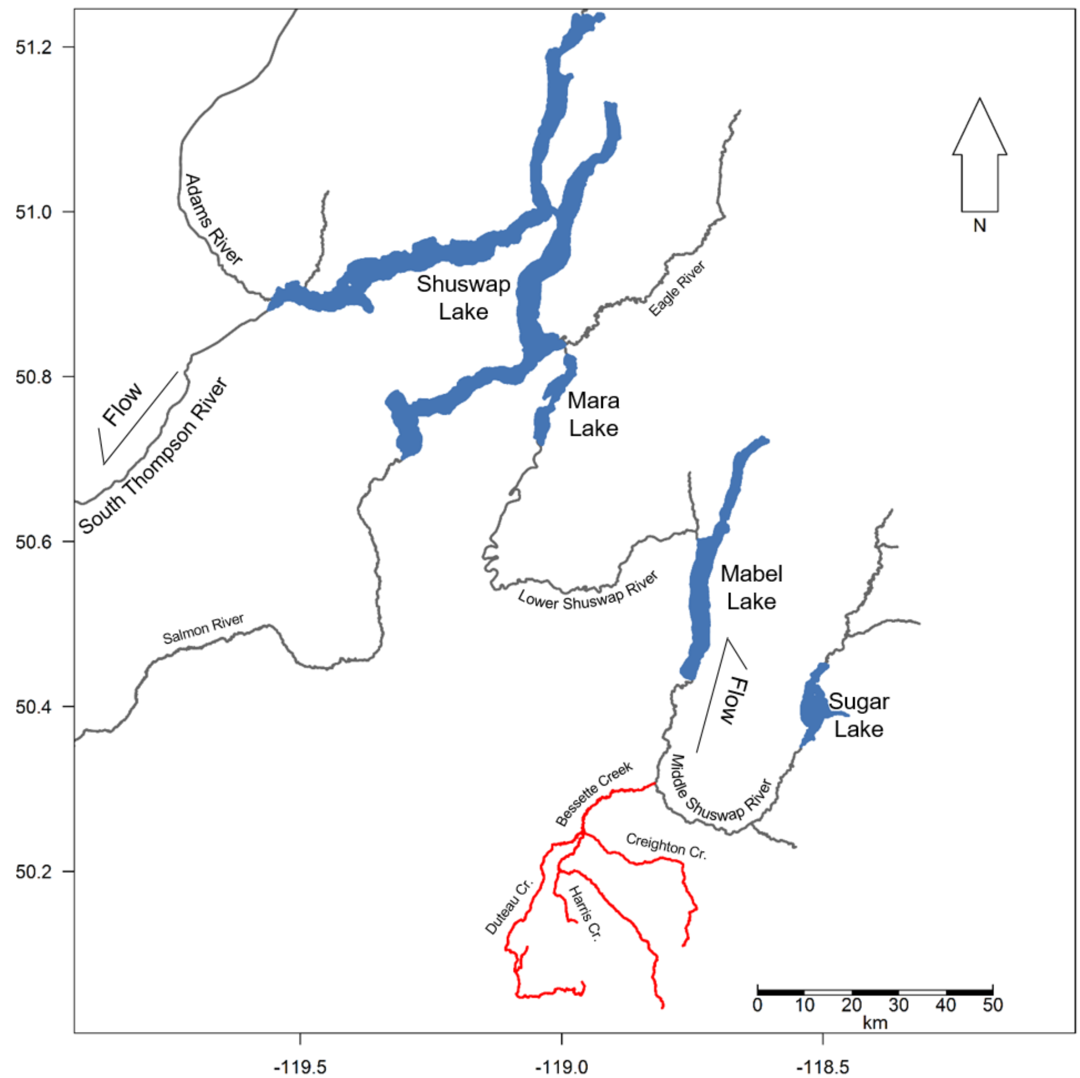

Figure 21. Map of DU14 - South Thompson Stream Summer (Bessette). The river length in red denotes the distribution of potential spawning area.

DU16 – North Thompson Stream Spring

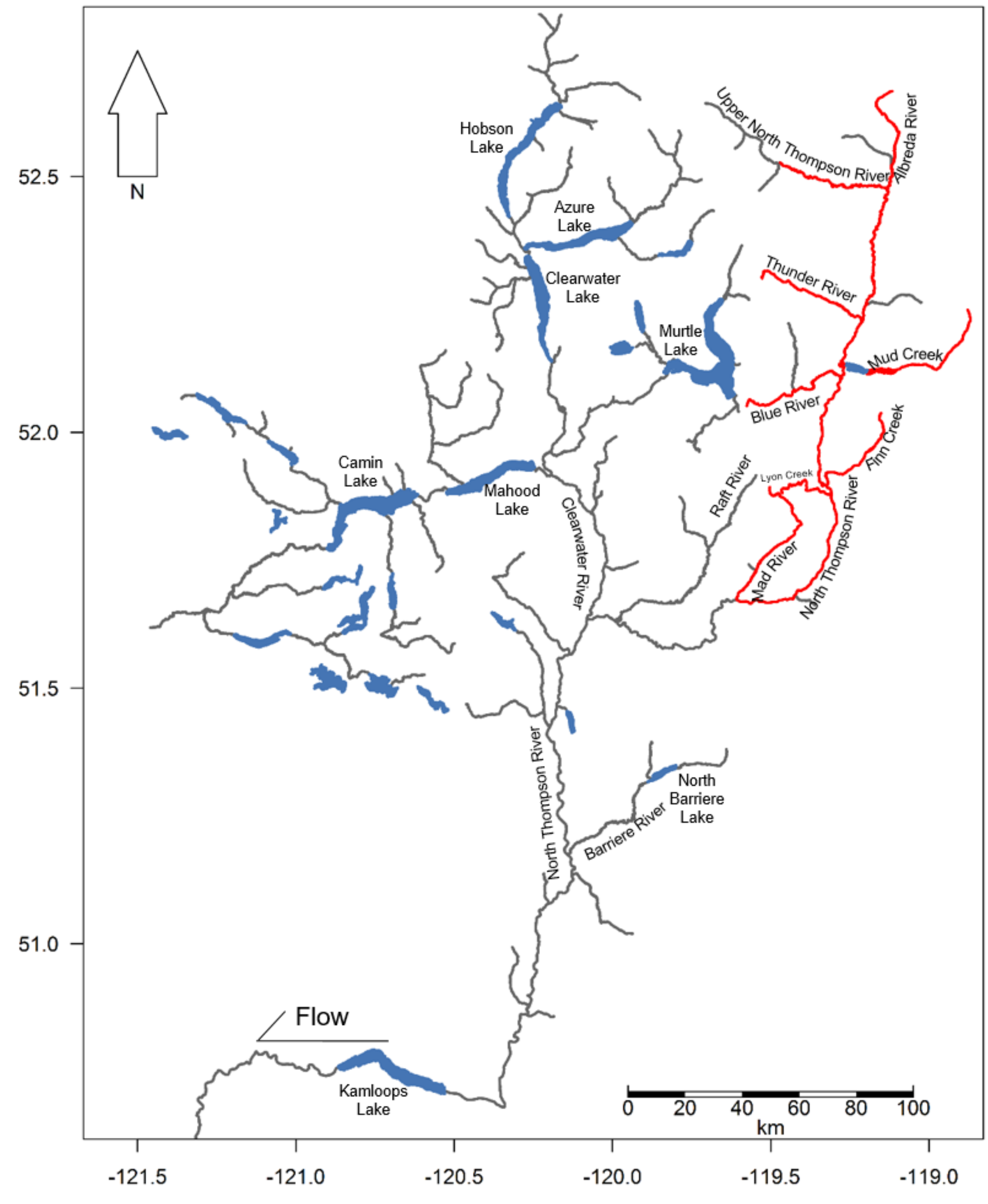

Figure 22. Map of DU16 - North Thompson Stream Spring. The river length in red denotes the distribution of potential spawning area.

DU17 – North Thompson Stream Summer

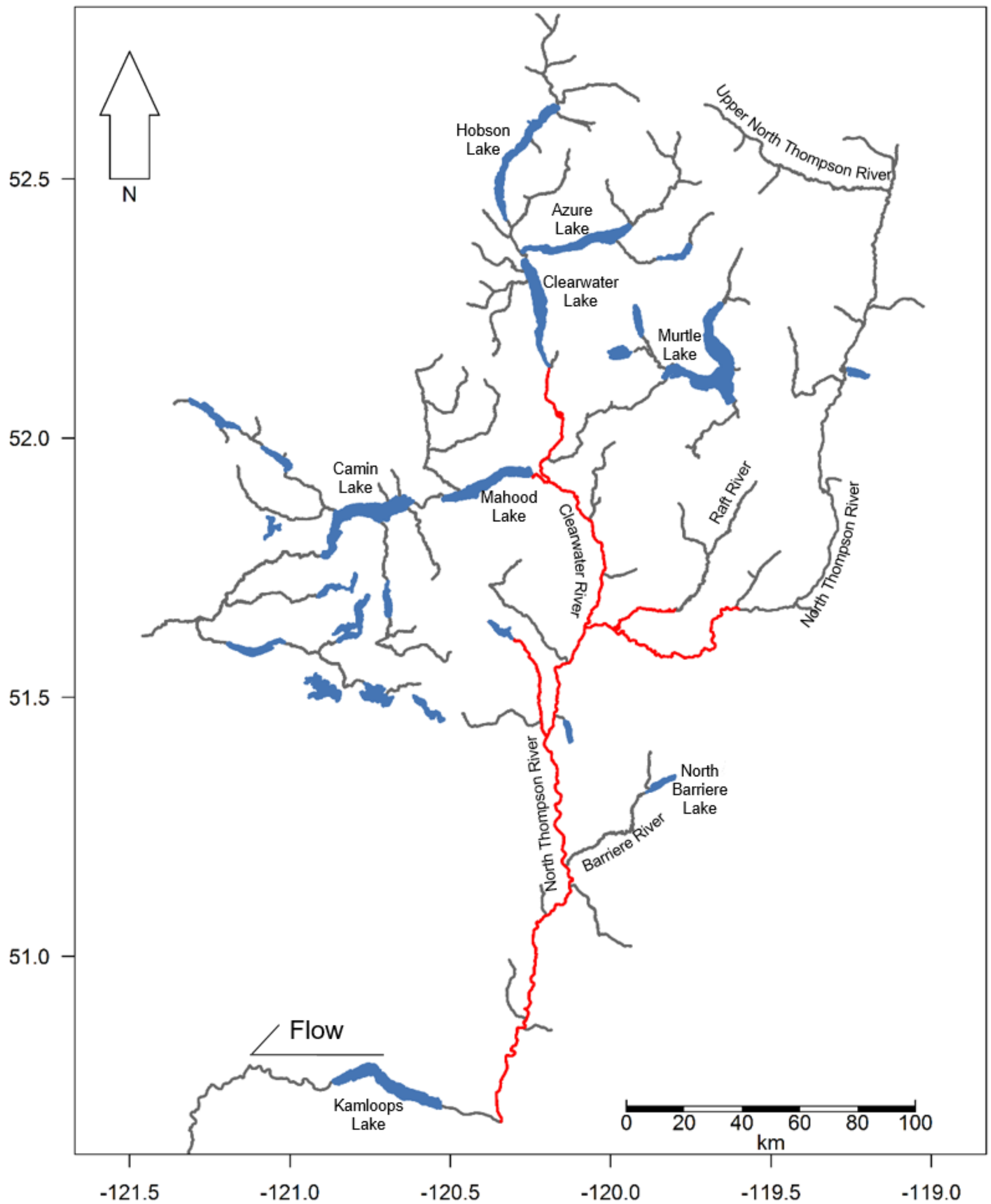

Figure 23. Map of DU17 – North Thompson Stream Summer. The river length in red denotes the distribution of potential spawning area.

3.2.2. Marine Distribution

As discussed in Element 4, the marine distribution of Chinook Salmon differs between ocean- and stream-type life histories. Ocean-type Chinook Salmon tend to spend most of their time in the marine environment on the coastal shelf from BC to Alaska, typically spending their first summer in the Salish Sea before migrating out the Strait of Juan de Fuca and dispersing along the continental shelf (Healey 1991). Stream-type Chinook Salmon appear to spend their first summer in the marine environment in the Salish Sea but then migrate off the coastal shelf to the North Pacific to feed and grow before migrating back to freshwater. They differ from ocean-type Chinook Salmon in their early distribution in that they exit the Salish Sea through both the Strait of Juan de Fuca and Johnstone Strait. While the full extent of FRC marine distribution is unknown at the DU level due to insufficient sampling to adequately characterize all their rearing locations in the North Pacific, there is some historical evidence available from CWT high seas fisheries recoveries that can be used for inference. High seas fisheries CWT recovery data are available for 7 of 11 FRC DUs, the exceptions being DU5 (LFR-Summer), DU7 (MFR-Nahatlatch), DU8 (MFR-Portage), and DU14 (STh-Bessette).

Figures 24, 25, and 26 illustrate high seas recovery coordinate data for spring, summer, and fall-returning FRC populations respectively. All CWT recoveries for spring-return DUs 9 (MFR-Spring), 11 (UFR-Spring), and 16 (NTh-Spring) were recorded in the Gulf of Alaska and Bering Sea, suggesting a far-north distribution (Figure 24). While not considered in this RPA, recoveries from spring-return FRC in the lower Fraser River (DU3 LFR-Birkenhead) also exhibit similar distribution patterns. CWT recoveries for summer-return FRC from DU4 (LFR-Upper Pitt), DU10 (MFR-Summer), and DU17 (NTh-Summer) were also primarily recorded in the Gulf of Alaska and Bering Sea, suggesting similar far-north distribution patterns to spring-return FRC (Figure 25). CWT recoveries from summer-return FRC produced in the Chilliwack hatchery were plotted for comparison as there have been numerous stock transfers into the Chilliwack River hatchery from other summer-return FRC DUs, which include the Upper Pitt River (DU4) and Chilko and Quesnel rivers (DU10 MFR-Summer). These fish exhibit similar distribution patterns to other summer-return FRC DUs.

The majority of CWTs recovered from DU2 (LFR-Harrison), the only fall-returning ocean-type population covered in this RPA, were from high seas fisheries within the Salish Sea or in coastal waters near Washington and Oregon, and within 1,000 km from the mouth of the Fraser River. This supports a relatively local and coastal shelf distribution (Figure 26). CWT recoveries from fall-return ocean-type FRC produced at the Chilliwack hatchery, which has seen multiple stock transfers from the Harrison and Chehalis (tributary to Harrison) rivers, exhibit similar distribution patterns as seen in Figure 26.

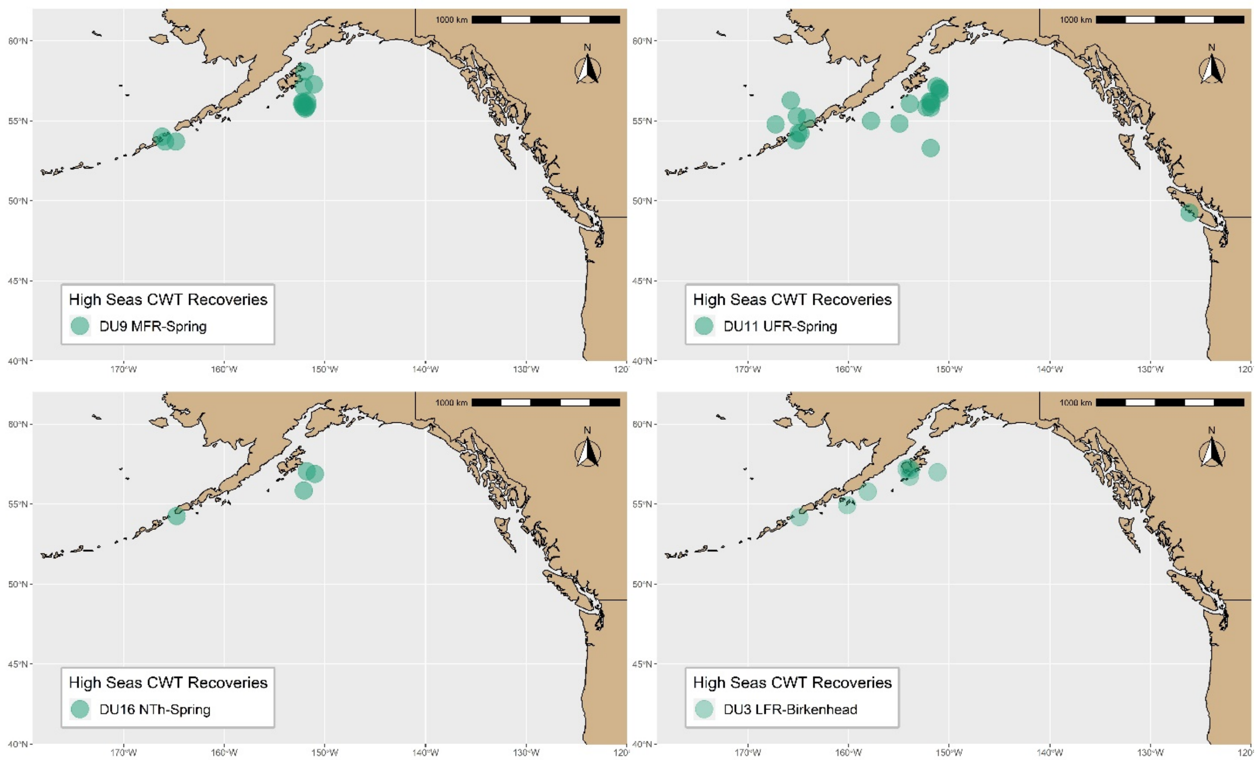

Figure 24. High seas fisheries CWT recoveries for spring-return stream-type FRC: DU9 (MFR-Spring), DU11 (UFR-Spring), and DU16 (NTh-Spring), in addition to DU3 (LFR-Birkenhead, not covered in this RPA) for comparison.

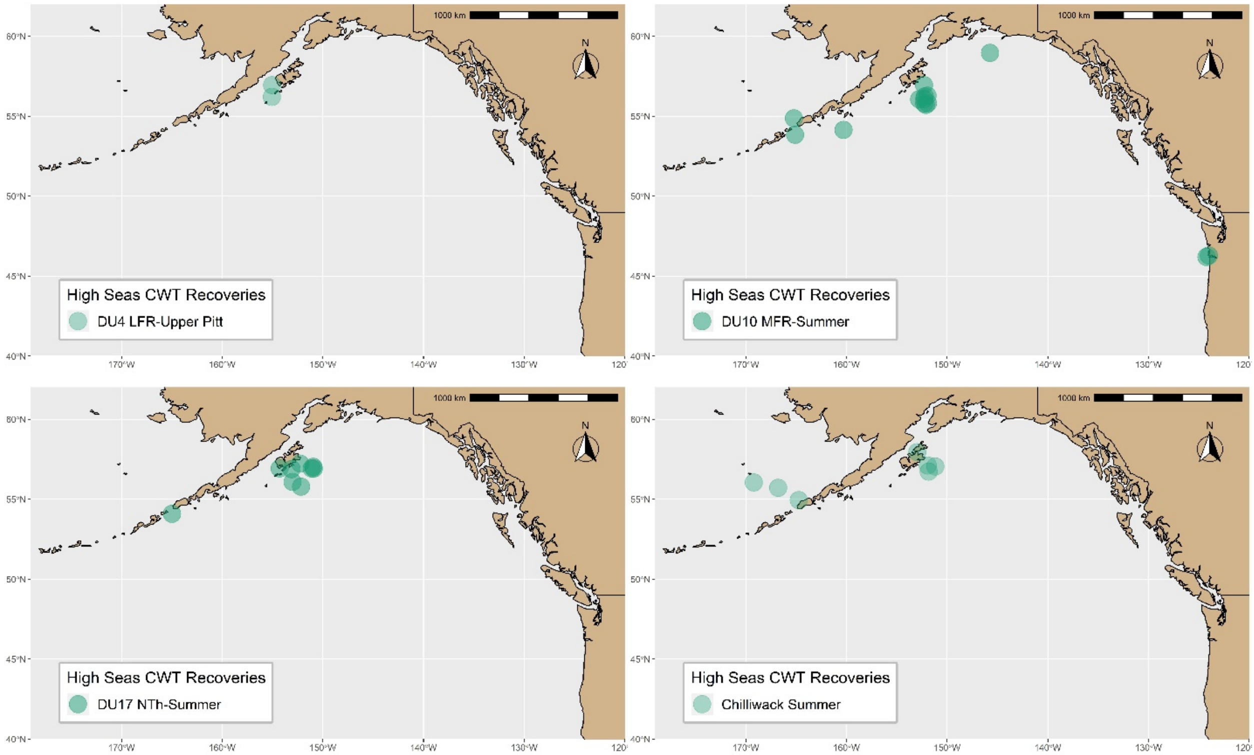

Figure 25. High seas fisheries CWT recoveries for summer-return stream-type FRC: DU4 (LFR-Upper Pitt), DU10 (MFR-Summer), DU17 (NTh-Summer), in addition to summer-return stream-type FRC produced at the Chilliwack hatchery (not covered in this RPA).

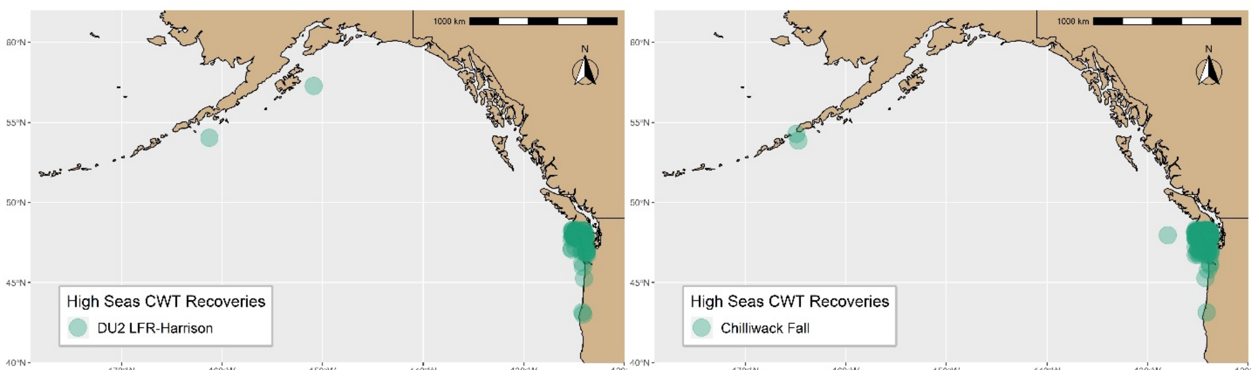

Figure 26. High seas fisheries recoveries for fall-return ocean-type DU2 (LFR-Harrison), in addition to fall-return ocean-type FRC produced at the Chilliwack hatchery for comparison (not covered in this RPA).

3.3. ELEMENT 6: PRESENCE AND EXTENT OF SPATIAL CONFIGURATION CONSTRAINTS

3.3.1. Hydroelectric Dams

Interior Fraser Chinook Salmon have not been heavily affected by hydroelectric development. The Nechako River (DU10 MFR-Summer) is the only major system in the Fraser River basin that is regulated by hydroelectric dams, following construction of the Kenney Dam in the early 1950s to power the Alcan aluminium smelter in Kitimat, BC. Impounded water upstream of Kenney Dam is diverted from Nechako Reservoir to the coastal Kemano River watershed outside of the Fraser River basin (Déry et al. 2012). The impacts on local ecosystems in the Nechako River basin were significant post-construction of Kenney dam, with large areas of land either flooded or drained leading to the displacement or impoundment of a number of fish (and other animal) species. On a Fraser basin-wide scale, however, the overall impacts from Kenney Dam on FRC are minimal, and impacts to DU10 specifically are also likely minimal due to the extensive geographic range of this DU.

Populations in the Bridge-Seton hydroelectric complex have been impacted by the construction of dams on the Seton and Bridge Rivers. The Terzaghi dam on the Bridge River cut off a large section of the river that had historically been the important spawning and rearing locations for Bridge River population of Chinook Salmon (DU9 MFR-Spring). Downstream of the dam, changes to the natural hydrograph led to impacts on juvenile rearing habitat (Bradford et al. 2011). The construction footprint of Seton Dam on the Seton River likely destroyed high quality spawning habitat for FRC which is common at the outlets of lakes. The Seton Dam has also been a concern for Chinook Salmon passage from Seton River into Seton Lake on their way to their spawning grounds at Portage Creek, which connects Seton and Anderson Lakes. Initially there were concerns about Chinook passage through small tubes used as sensors to a resistivity counter at the top of Seton Dam fishway (Pon et al. 2006) but low abundances of the Portage Creek population (DU8 MFR-Portage) have prevented tagging studies that could evaluate that hypothesis. The tubes have been replaced and the new larger tubes are unlikely to cause passage issues, although passage success through the resistivity counter has not been evaluated. Smolt outmigration may also be impacted as there are an unknown number of smolts that are entrained through the turbines at the Seton generating station.

3.3.2. Landslides

Landslides or other impacts have produced blockages of Chinook migration routes such as at Hells Gate in the Fraser River Canyon and Little Hells Gate in the North Thompson River. Hells Gate and Little Hells Gate continue to act as barriers to upstream migrating Chinook Salmon at certain flows, although fishways installed at Hells Gate alleviate most passage issues. These potential barriers are likely to have a greater affect on smaller individuals. Natural or human alterations of channel morphology at these or other critical locations represent future threats to Fraser Chinook DUs.

Landslides in the Seton-Anderson watershed have impacted FRC from DU8 (MFR-Portage). The most recent and significant events have occurred on Whitecap Creek, where ongoing sedimentation issues from landslide events threaten FRC from this DU. In September 2015, a debris flood and channel avulsion occurred on Whitecap Creek that deposited large amounts of sediment into Portage River, and the following year another channel avulsion occurred that resulted in an approximate 75% blockage of Portage River (BGC 2018). These events occurred in high quality spawning habitat and there are no alternate spawning grounds in the DU. The details of these events are discussed in detail in section Avalanches & Landslides.

In 2019, the Big Bar landslide impacted the upstream migration for many Chinook populations and the distribution of spawners above the slide. It also may have led to fish falling back and dispersing into other systems downstream of the slide. The Big Bar slide is discussed further in section Geological Events.

3.3.3. Floodplain Connectivity

Flood control and agricultural development, particularly in the lower Fraser River have led to a loss of off-channel and stream habitat. The loss of floodplain connectivity has likely reduced the freshwater carrying capacity for Fraser River Chinook DUs with life histories that rely on these non-natal areas for rearing (Murray and Rosenau 1989). Large-scale development within the floodplain of the lower Fraser River for agricultural and residential development, as well as dike construction, has caused wetlands to be drained, riparian zones to be degraded, and the aquatic systems to be polluted. Most streams in the lower Fraser River valley are classified as threatened or endangered (FRAP 1998; Langer, Hietkamp, and Farrell 2000; Brown 2002; Rosenau and Angelo 2005). Diking for flood control has led to the majority of wetland habitats being disconnected from the lower Fraser River floodplain (Birtwell et al. 1988). Impacts associated with the development in the lower Fraser are discussed further in section 4 of this report.

3.4. ELEMENT 7: EVALUATION OF THE CONCEPT OF RESIDENCE AND DESCRIPTION FOR CHINOOK SALMON

SARA defines "residence" as "a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating" (DFO 2015[7]). Redds, i.e. spawning nests constructed by Pacific salmon and other fish species, are considered residences because they meet the following criteria:

1. individuals (not a population) make an investment (e.g., energy, time, defense) in the redd and/or invest in the protection of it;
2. the location and features of the redd contribute to the success of a life history function (i.e., breeding and rearing);
3. the redd is a central location within an individual's larger home range, with repeated returns by the species to complete a specific life function; and

there is an aspect of uniqueness associated with the redd, such that if it were "damaged" the individuals would usually not be able to immediately move the completion of the life history function(s) to another place without resulting in a loss in fitness (DFO 2015[7]). Chinook Salmon are semelparous and are therefore unable to replace a damaged redd following their death. The fertilized eggs are functionally immobile until the egg develops into an alevin. The eggs must remain buried deep in the gravel otherwise other predatory fishes, such as cottids, will eat them (Steen and Quinn 1999; Foote and Brown 1998).

4. THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF FRC SALMON

4.1. ELEMENT 8: THREATS TO SURVIVAL AND RECOVERY

This report follows the definition of threats found in the "Guidance on Assessing Threats" Science Advisory Report (DFO 2014). A threat in the context of this RPA may be defined as any human activity or process that has caused, is causing, or may cause harm, death, or behavioural changes to FRC, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur. Limiting Factors are defined as natural (abiotic or biotic) factors that negatively affect the productivity of FRC populations. A human activity may exacerbate a natural process and be deemed a threat, which is important to consider in the context of Element 10, Limiting Factors.

[7] DFO. 2015. Directive on the Application of Species at Risk Act Section 33 (Residence) to Aquatic Species at Risk. (Accessed July 21, 2020)

The threat categories are based on the IUCN-CMP (World Conservation Union–Conservation Measures Partnership) unified threats classification system (Salafsky et al. 2008), which COSEWIC uses to assess the status of wildlife species. The threat classification system was originally developed to define broad categories of threats. The assessment of the threat categories follows DFO's (DFO 2014) Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk, to the extent possible in the context of limited data and information on threats to FRC within Canadian waters (DFO 2014). For FRC, a working group assessed threats to FRC DUs using the IUCN-CMP threat assessment method used by COSEWIC during a three day workshop (Appendix F). Each DU was treated individually by the group, and all threat categories were discussed with the assistance of a COSEWIC moderator to ensure threats were scored according to IUCN-CMP guidelines. For each individual threat category the room was surveyed for expert opinion, and following a group discussion a vote was made for threat rankings. No threats were scored without group consensus. The threat assessments determined during the workshop were subsequently converted to the DFO standardized assessment method (DFO 2014).

The following sections represent the rationale used to estimate Likelihoods of Occurrence, Levels of Impact, Causal Certainties, and Threat Occurrences, Frequencies, and Extents for the threats tables below. Detailed definitions of the levels of the aforementioned aspects can be found in DFO (DFO 2014). The threat occurrence and frequency assigned to each threat in the tables below are not discussed explicitly in the following sections to avoid excessive repetition. For all threats, the threat occurrence is historical/current and anticipatory, as every threat assessed has occurred, is occurring, and is expected to occur in the future. Threat frequency is either recurrent, for threats that are not expected to occur regularly, or continuous, for threats that are expected to occur frequently or have ongoing continuous impacts. Categories in the text are organized by the order in which they appear in the COSEWIC threats list and not by threat risk. The results of the workshop assessment for each threat category are summarized in tables below including the threat risk per DU, and are organized by threat risk. Complete threat tables for each individual DU that were assessed during the workshop are available in Appendix F. In some cases, a threat risk category was omitted if it was not deemed to be a threat to FRC. Any category omitted was identified at the top of the section.

Table 23. Definitions for the Levels of Impact, Likelihood of Occurrence, and Causal Certainty that may be assigned to each threat category. Definitions were modified from DFO (2014) to include the clarification that the level of impact was evaluated based on the expected population level decline over the next three generations if the threats are not successfully moderated.

Level of Impact	Definition
Extreme	Severe population decline (e.g. 71-100%) over the next 3 generations with the potential for extirpation
High	Substantial loss of population (31-70%) over the next 3 generations or threat would jeopardize the survival or recovery of the population.
Medium	Moderate loss of population (11-30%) over the next 3 generations or threat is likely to jeopardize the survival or recovery of the population.
Low	Little change in population (1-10%) over the next 3 generations or threat is unlikely to jeopardize the survival or recovery of the population.
Unknown	No prior knowledge, literature or data to guide the assessment of threat severity on population.

Level of Impact	Definition
Negligible	Negligible change in population (<1%) over the next 3 generations or threat Is likely to negligibly jeopardize the survival or recovery of the population.

Likelihood of Occurrence	Definition
Known or very likely to occur	This threat has been recorded to occur 91-100%
Likely to occur	There is 51-90% chance that this threat is or will be occurring
Unlikely	There is 11-50% chance that this threat is or will be occurring
Remote	There is 1-10% or less chance that this threat is or will be occurring.
Unknown	There are no data or prior knowledge of this threat occurring

Causal Certainty	Definition
Very High	Very strong evidence that threat is occurring and the magnitude of the impact to the population can be quantified
High	Substantial evidence of a causal link between threat and population decline or jeopardy to survival or recovery
Medium	There is some evidence linking the threat to population decline or jeopardy to survival or recovery
Low	There is a theoretical link with limited evidence that threat is leading to a population decline or jeopardy to survival or recovery
Very Low	There is a plausible link with no evidence that the threat is leading to a population decline or jeopardy to survival or recovery

4.1.1. Residential and Commercial Development

4.1.1.1. Housing & Urban Areas

The threat from housing and urban areas includes new footprints of human cities, towns, and settlements including non-housing development typically integrated with housing (IUCN-CMP threat category 1.1). Pollution from domestic and urban wastewater is discussed in section Pollution & Contaminates *(IUCN-CMP threat category 9.1)*

The lower Fraser Valley is highly urbanized and expansion is expected to continue at a low rate; however, increasing human populations will lead to increased densification of these areas and ultimately new development that may encroach on FRC habitat. There will also be continued development upstream of the lower mainland through time, yet given the reduced density in these areas it is not thought that there will be significant in-river impacts in the near future beyond those in the lower Fraser River.

The footprint from house boats has been considered in this category, as they sit directly in aquatic habitat. There are currently about 300 floating homes in the lower Fraser River below

Maple Ridge[8]. As the price of land in the lower mainland continues to increase, it is possible that the number of houseboats in the area will increase. The impact of houseboats is unknown, but is not expected to be positive.

The scope of this threat is pervasive for all FRC DUs, as a significant portion of juvenile and adult salmon migrating through or rearing in the lower Fraser River will likely encounter any new development or house boats. DU2 (LFR-Harrison) is least threatened by new urban development as they immediately migrate to estuarine habitat following emergence and it is unlikely future development will occur on spawning grounds in the Harrison River. However, they would be the most sensitive to encroachment into the estuarine areas by houseboats. Stream-type Chinook are at the greatest risk of new urban development between Hope and Mission, as some juveniles from up-river DUs would overwinter in these areas, and removal of this habitat could lead to increased competition and overcrowding of other areas. Future urban development likely poses some threat to all FRC DUs, yet the level of impact is currently unknown.

4.1.1.2. Commercial & Industrial Areas

The threat from commercial and industrial areas include new footprints of industrial activities and other commercial centers, including manufacturing plants, shopping centers, office parks, military bases, power plants, train and ship yards, and airports (IUCN-CMP threat category 1.2).

The lower Fraser River is highly developed and the remaining habitat is currently more prone to industrial development than housing. There are a number of industrial developments on the banks of the Fraser River, some of which are encroaching on critical foreshore habitat for FRC. One such development is Roberts Banks, an 8000 ha bank environment located in the southern portion of the Fraser River delta, which has been the site of two major port developments since 1960: the Tsawwassen Ferry Terminal and the Roberts Bank Coal Port (Tarbotton and Harrison 1996; Sutherland et al. 2013). This area provides important juvenile rearing habitat for all species of Pacific salmon before their seaward migration including FRC, and developments on Roberts Bank have led to changes in tidal flow patterns, water depths, sediment transport and wave climate, in addition to significant changes in abundance and composition of eelgrass communities (Tarbotton and Harrison 1996) (pollution generated from these developments is discussed in section *4.1.9 Pollution & Contaminates).* The proposed development of a new marine container terminal on Roberts Bank has raised concerns surrounding future impacts on an already highly degraded habitat (see Raincoast Conservation Foundation (2016[9]) for a detailed review of the proposed development and potential resulting impacts). While it is currently unknown whether the proposed expansion on Roberts Bank will proceed, it is anticipated this development will lead to net losses in critical estuarine habitat and have an overall negative impact on all FRC DUs.

All migrating salmon pass through the lower Fraser River on their way to the ocean and will be similarly impacted by the encroachment of new industrial areas, therefore this threat is pervasive in scope. Though the impacts from industrial development on FRC has not been quantified, based on expert opinion from the Threats Calculator Workshop, participant consensus was that there is likely a low level of impact for DUs in the lower Fraser River (DU2 LFR-Harrison, DU4 LFR-Upper Pitt, DU5 LFR-Summer) because their habitat is concentrated

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[8] Floating Home Association of BC. "You can find out what it's like to live on the Fraser River". (Accessed July 22, 2020)

[9] Raincoast Conservation Foundation. 2016. Roberts Bank Terminal 2 Assessment - Sufficiency and Technical Merit Review. (Accessed July 22, 2020)

within areas with ongoing pressure for development. For the upstream DUs, participant consensus was that this impact was negligible because these juveniles would not be rearing in these areas, but migrating through them. It is important to note that this is only the impact from new activities; the impact that has occurred from the encroachment of development into FRC habitat in the past was not considered in the assessment of this threat's risk level.

4.1.1.3. Tourism & Recreation

The threat from tourism and recreation includes new tourism and recreational sites with a substantial footprint (IUCN-CMP threat category 1.3).

There is a high concentration of marinas, boat launches, and private docks in the lower Fraser River and increasing urban densification in metro Vancouver may lead to increased pressure for development in an already highly degraded habitat. There is not currently enough information to predict the amount of development that will occur in any of the DUs or the lower Fraser, but there will likely be marina upgrades and expansions. Overwater structures such as marinas, reduce the light levels below and next to them, causing reduced growth and density of aquatic plants, and in some cases can eliminate seagrasses completely (Burdick and Short 1999; Shafer 1999). One study found that even some mitigation efforts, such as installing grating on the platforms, does not fully mitigate impacts from shading (Fresh et al. 2006). These structures, while small on their own tend to be aggregated in seagrass areas and could have cumulative impacts.

The impacts from tourism development, specifically marinas, on Chinook Salmon are not known with certainty. The scope of this threat is pervasive for all FRC DUs, as a large proportion of juvenile and adult salmon migrating through or rearing in the lower Fraser River are likely to encounter any new developments. In addition, ocean-type Chinook from DU2 will likely encounter any new developments along the coast of the Salish Sea or in coastal Washington and Oregon where fish from this DU are known to rear.

Table 24. DFO threats assessment calculator results for impacts from Housing & Urban Areas for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Housing & Urban Areas	DU2	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 25. DFO threats assessment calculator results for impacts from Commercial & Industrial Areas for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Commercial & Industrial Areas	DU2	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 26. DFO threats assessment calculator results for impacts from Tourism & Recreation for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Tourism & Recreation	DU2	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive

4.1.2. Agriculture & Aquaculture

IUCN-CMP threat category 2.2 was not included in this section because to our knowledge, there are no new wood or pulp developments that will encroach on any of the FRC DUs discussed in this report.

4.1.2.1. Annual & Perennial Non-Timber Crops

The threat from annual and perennial non-timber crops includes new footprints of farms, plantations, orchards, vineyards, mixed agroforestry systems (IUCN-CMP threat category 2.1).

Threats resulting from the use of agrochemicals, rather than the direct conversion of land to agricultural use, are included under section Agricultural & Forestry Effluents (IUCN-CMP threat category 9.3).

Utilization of land adjacent to the lower Fraser River is high and much of the existing development is behind dikes. However, in recent years, islands in the Fraser River near Chilliwack (such as Herrling Island) have been subject to clearing to allow for agricultural intensification. The BC Ministry of Agriculture (2016) reported 67% (37,669 ha) of the Fraser Valley Regional District (Abbotsford, Chilliwack, Hope, Kent, Mission, Harrison Hot Springs) is actively farmed or supporting farming, with only 18% of land available for potential future development. Most of the remaining 18% (9,943 ha) is comprised of relatively small areas and provides limited opportunity for further agricultural development. This includes construction of greenhouses on existing fields, and these conversions can reduce stream areas through reductions in riparian areas and changes to banks. From 2006 to 2016, the amount of land used for greenhouses in the Fraser Valley grew by 400,000 m^2 (Fraser Valley Regional District 2017[10]). Intensification or conversion of existing agricultural land in the lower Fraser River will therefore be the likely threat to FRC in future years.

The conversion of forest to agricultural land may also result in a significant loss of overwintering habitat, particularly at high water levels. There is limited riparian area left in the lower Fraser River to contribute to overwintering habitat for yearling FRC, and further agricultural development encroaching into already limited side channel and back water habitat could have impacts on FRC. Up-river stream-type Chinook Salmon may be more severely impacted than Chinook Salmon from the lower Fraser River DUs because a portion of the upriver-origin juveniles would overwinter in such areas. This may be particularly true for DU7 (MFR-Nahatlatch), as there is limited rearing habitat in the lower Nahatlatch River and it is likely that a large portion of the juveniles move down into the lower Fraser River to rear and overwinter. Predicting the magnitude of impacts from future development is difficult, but it is anticipated that there will be some impacts. DU4 (LFR-Upper Pitt) was the only DU deemed to be not threatened by agricultural development because the Fraser River below the confluence to the Pitt River is highly developed behind existing dikes and inaccessible, and there is currently no agriculture in the Upper Pitt River drainage.

[10] Fraser Valley Regional District. 2017. Regional Snapshot Series: Agricultural Economy in the Fraser Valley Regional District. (Accessed July 21, 2020)

4.1.2.2. Livestock farming and ranching

The threat from livestock, farming and ranching is defined as the direct impact from domestic terrestrial animals raised in one location on farmed or non-local resources, as well as domestic or semi-domesticated animals allowed to roam in the wild and supported by natural habitats (IUCN-CMP threat category 2.3).

Direct impacts of livestock primarily affect the egg life-stage of FRC through disturbance, alteration, damage, or destruction of redds when crossing or standing within streams. Although it is possible for livestock (primarily cattle) to enter FRC habitat for all DUs, the impacts from this threat are thought to be negligible or non-existent for most DUs due to the location of cattle ranching operations. Livestock typically only enter low gradient sections or rivers and most may be deterred from entering or crossing streams by riparian buffers and fencing, which will limit the extent of their impacts. It should be noted, however, that despite regulations surrounding the use of fences to prevent cattle from entering streams, enforcement is difficult and often lacking within the middle and upper Fraser River DUs (DUs 9, 10, and 11) where cattle are often observed in streams, particularly in DU9 (S. Curtis pers. comm. 2019). Of these DUs, DU10 (MFR-Summer) is threatened to a lesser extent from livestock as many of the streams are large lake-fed systems with little to no possibility of crossing by foot, yet cattle have still been observed in some shallow headwater areas (S. Curtis pers. comm. 2019). DU9 (MFR-Spring) and DU11 (UFR-Spring) were assessed to have a low level of impact with a high level of uncertainty, whereas the impacts on DU10 were considered to be negligible. This is supported by a study in Oregon that found that when cattle were near active spring Chinook Salmon redds, the cattle contacted the redds less than 0.01% of the time (Ballard and Krueger 2005). DU14 (STh-Bessette) is most threatened from the trampling of redds as livestock farming and ranching is most pervasive in the area surrounding this DU. Additionally, streams within this DU are smaller than those of other DUs, with livestock having multiple entry points to the river near the spawning habitats. Cattle are often seen in the stream in this DU when conducting aerial surveys (particularly Duteau and Harris, R. Bailey pers. comm. 2019). The overall impact to DU14, however, was considered to be low-medium with a moderate level of uncertainty due to the low probability of cattle directly trampling FRC redds within spawning gravels.

In addition to direct trampling of redds, cattle can have significant impacts through bank destabilization and increased sedimentation in streams. These impacts are assessed under section Agricultural & Forestry Effluents.

4.1.2.3. Marine & Freshwater Aquaculture

The threats from marine and freshwater aquaculture include footprints of shrimp or fin fish aquaculture, fish ponds, hatchery salmon, and artificial algal beds (IUCN-CMP threats category 2.4). This threat category also includes interactions between wild fish and hatchery fish allowed to roam in the wild. Threats from mixed stock fisheries are discussed in section Fishing & Harvesting Aquatic Resources, and threats from disease transmission and introduced genetics are discussed in section Invasive & Other Problematic Species & Genes.

Fish aquaculture is pervasive in the Fraser River basin and nearshore rearing habitats, and it is probable that all FRC will encounter aquaculture in the form of open net pens or hatchery fish at some point in their life cycle. There are likely negligible impacts resulting from footprint of open net pens and were not considered to be a threat to FRC. There are, however, concerns surrounding competitive interaction between FRC and hatchery-origin fish, which can impact wild populations through competition for food, and for spatial resources by occupying preferred feeding areas and displacing wild fish to less productive feeding areas. Inter-specific competition with other Pacific salmon species is considered to be low because the species occupy somewhat different ecological niches both spatially and/or temporally (Hearn 1987;

Quinn 2005; Tatara and Berejikian 2012). Thus, the major threat from aquaculture comes from competitive interactions between wild FRC and hatchery-origin Chinook Salmon.

Wild and hatchery-origin salmon compete for resources at all life stages and in all associated habitats, and these competitive interactions can negatively affect wild populations when resources are limited (Tatara and Berejikian 2012). The lower Fraser River and estuary are highly developed, with the vast majority of intertidal marsh habitats and riparian areas altered with rip rap or vertical steel sheeting to create shoreline suitable for shipping and other industries (Levings et al. 1991). These modifications may have yielded a limited carrying capacity for juvenile FRC, and with the high degree of hatchery supplementation in the Fraser River drainage the number of fish may exceed this capacity. The ability for Chinook to forage and grow in nearshore and offshore estuarine habitats may have a large influence on their early marine survival and cohort abundance, called the critical size and period hypothesis (Beamish and Mahnken 2001). While not FRC-specific, the marine survival of CWT Chinook in Puget Sound was most strongly related to their average body size in July, and mortality after this period was strongly size-dependent (Duffy and Beauchamp 2011). In short, there can be substantial early natural mortality in the marine environment resulting mostly from predation (e.g. river lampreys, Beamish and Neville 1995), when the juvenile Chinook do not grow large enough to reach a critical minimum size by July (Duffy and Beauchamp 2011) or the end of their first marine summer (Beamish et al. 2011). The abundance of aquatic food resources in nearshore and offshore areas can be influenced by variations in ocean productivity (e.g. nutrients regulating food production) and competition for food (Beamish and Mahnken 2001), and competitive effects may be exacerbated during years of low ocean productivity. For Spring Chinook in the Snake River, a tributary of the Columbia River, a negative relationship was reported between smolt-adult survival and the number of hatchery fish released, particularly in years with poor ocean conditions, which suggested that hatchery programs that produce increasingly higher numbers of fish may hinder the recovery of threatened wild populations (Levin et al. 2001). Based on these negative effects, paired with limited available habitat in the lower Fraser River and estuary, releasing high numbers of hatchery-origin juveniles into these ecosystems could decrease wild productivity and reduce overall survival of juveniles. For a more complete review of potential competitive interactions between hatchery-origin and wild salmon refer to Appendix G.

DU2 (LFR-Harrison) was deemed to be at greatest risk from competition with hatchery fish, as these fish directly compete with fall-return Chinook Salmon releases from the Chilliwack River and other lower Fraser River hatcheries. There is a pattern of declining smolt-to-age 2 survival with increasing lower Fraser Fall Chinook hatchery production based on CWT recoveries of hatchery Chinook (refer to Appendix G for data treatment and analysis). A similar pattern is observed with the Harrison wild smolt production index, suggesting density-dependent competition for resources among smolts can adversely affect survival, and thus abundance and productivity. Lower Fraser Fall Chinook production has averaged 1.6 million smolts over the last 10 years, and the recent announcement of an increase in hatchery production by 1,000,000 fall Chinook Salmon smolts at the Chilliwack hatchery could reduce DU2 smolt-to-age 2 survival by estimates as high as 26% (Appendix G). This was considered to be a Medium level of impact to the DU by participants at the threats workshop. It should be noted there is considerable uncertainty in this analysis, and it is difficult to say with certainty that this density-dependent pattern has a causal effect on survival.

In addition to increases hatchery production in the Fraser system, in 2018, the State of Washington created the Southern Resident Orca Task Force in response to declines in the endangered population with the mandate to identify, prioritize, and support the implementation of a long-term action plan for the recovery of Southern Resident Orcas (SRO; SROTF 2018).

Part of the overall recommendations from the Task Force was the increase of hatchery production of certain stocks of Chinook Salmon in Puget Sound, on the Washington Coast, and in the Columbia River basin by approximately 50 million smolts beyond 2018 levels to provide increased numbers of Chinook to augment the diet of SRO based on their preference for these stocks (Washington Department of Fish and Wildlife 2019)[11]. Thirty million of those releases are proposed for Puget Sound (Washington Department of Fish and Wildlife 2019)[11] where FRC from DU2 (LFR-Harrison) are known to transit and rear (Figure 26). The additional smolt production by the US could very likely further increase competition for Chinook from DU2, and as such, the level of impact was increased from Medium to Medium-High.

The remaining 10 DUs covered in this report are stream-type Chinook Salmon that rear in freshwater for extended periods of time before migrating seaward. Wild salmonids with prolonged freshwater life histories may be at greater risk for competition with hatchery fish because multiple cohorts of wild fish can be present when hatchery fish are released (Tatara and Berejikian 2012). There is, however, considerably less hatchery supplementation for stream-type FRC DUs, as ocean-type variants make up the majority of overall numbers in the Fraser River drainage (Figure 27). Due to their ocean distributions, stream-type DUs are more likely to experience competition from hatcheries that produce Chinook Salmon that feed in the Gulf of Alaska and Bering Sea (e.g. far north migrating stocks from Oregon and Washington, in addition to hatchery production from northern BC and Alaska). These 10 DUs are likely to experience a low level of competition, yet the uncertainty surrounding these scores is high. There is insufficient information to quantify the threat at this time for the remaining 10 DUs, but it was suspected to be low by the working group.

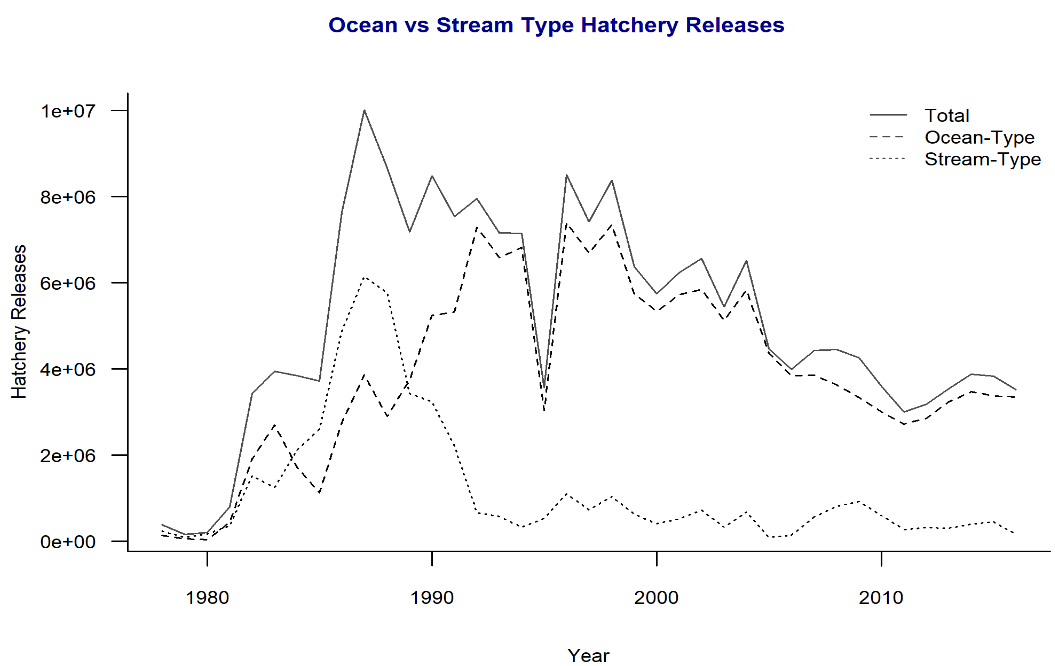

Figure 27. Ocean and stream-type hatchery releases in the Fraser River Basin from 1978 to 2016.

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[11] Washington Department of Fish and Wildlife. 2019. [Proposal to increase Hatchery Production to Benefit Southern Resident Killer Whales](). (Accessed July 21, 2020)

Table 27. DFO threats assessment calculator results for impacts from Annual & Perennial Non-Timber Crops for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Annual & Perennial Non-Timber Crops	DU2	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU5	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU7	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU8	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU9	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU10	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU11	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU14	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU16	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU17	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	For DU4 this not anticipated to be a threat.							

Table 28. DFO threats assessment calculator results for impacts from Livestock Farming & Ranching for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Livestock Farming & Ranching	DU9	Likely	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU10	Likely	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU11	Likely	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU14	Likely	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	For DU2, DU4, DU5, DU7, DU8, DU16 and DU17 this is not anticipated to be a threat.							

Table 29. DFO threats assessment calculator results for impacts from Marine & Freshwater Aquaculture for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Marine & Freshwater Aquaculture	DU2	Known	Medium-High	Medium	Medium-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive

4.1.3. Energy Production & Mining

IUCN-CMP threat category 3.1 Oil & Gas Drilling and 3.3 Renewable Energy are not included in this section, as to our knowledge, these activities are not occurring directly within FRC habitat. Hydroelectric facilities are considered under section Dams & Water Management.

4.1.3.1. Mining & Quarrying

The threats from mining and quarrying include impacts due to the production of non-biological resources, specifically the exploration, developing, and producing of minerals and rocks (IUCN-CMP threat category 3.2). Impacts from chemical runoff from these activities is discussed in section Industrial & Military Effluents (IUCN-CMP threat category 9.2).

Mining and quarry activities occur in many areas of the Fraser River Basin, and pose some level of threat to most DUs discussed in this RPA (the possible exception being DU4 (LFR-Upper Pitt)). These activities consist of placer mining (primarily for gold), hard-rock or open-pit mining (copper, molybdenum, and gold etc.), and gravel/sand extraction.

Gravel extraction from the lower Fraser River is a common occurrence and any out-migrating Chinook from upstream DUs will encounter these areas. The extraction occurs on dry gravel bars and hence the act of extracting the gravel is not anticipated to have direct impacts. However, there is concern that these activities could reduce the amount of available shallow water habitats in the lower Fraser River for juvenile FRC. There is some evidence that overwintering FRC from upstream use the gravel bars and are impacted by gravel extraction (B. Rublee, pers. comm. 2019). It is considered unlikely that extractions would have large impacts as there are other habitats that FRC could utilize (but it adds to cumulative habitat impacts). Alterations through gravel extraction have immediate impacts on FRC habitat; however, due to the dynamic nature of the system, any physical alterations may re-stabilize with time and may have minimal impacts. The current gravel bed load is likely an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excessive removal of gravel from these sections of the Fraser River. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set backs. Impacts from future gravel removal was thought to be likely for DU2 (LFR-Harrison) because a reduction in gravel in the Fraser River at the confluence with Harrison River could influence bed-load movement in the Harrison River. Additionally, out-migrating Harrison fry would be the most susceptible to a loss in shallow water habitat.

Placer mining has the most significant direct impacts on salmon habitat resulting from the mechanical dredging, sifting, washing, and re-deposition of fluvial substrates and stream side deposits, primarily in search of gold (Smith 1940). Historical mining practices resulted in significant long-term negative effects on fish habitat, with hydraulic mining, stream channel diversion, suction dredging, and discharge of mine tailings into streams causing much of this damage. Loss of riparian vegetation, development on adjacent floodplains (used seasonally by juvenile fish when flooded), increased sediment loads, and destabilization of stream channels continue to affect the productive capacity of numerous streams that have been exposed to placer mining. Placer mining operations have improved over time from an environmental standpoint, but the productivity of fish habitat for the middle Fraser River (DUs 9 and 10) and some systems in the upper Fraser (DU11) remain affected by present-day placer operations, and there are continued impacts from historical mining. Historically, placer mining was pervasive in the Fraser River and there are lasting sediment effects in the lower Fraser River (Nelson and Church 2012). DU9 (MFR-Spring) was deemed to be at the greatest risk from this threat, as placer mining activities are ongoing in many of the streams, with daily activity in some streams during the summer months (S. Curtis pers. comm. 2019). There are fewer opportunities for placer mining within DU10 (MFR-Summer) because many of the streams are large lake-fed systems, and access to substrates is limited. In-depth summaries of the legacy effects of placer mining sediments on the Fraser River drainage were described by Nelson and Church (2012) and Ferguson et al. (2015).

Both placer and open-pit mining activities have the potential to increase in the future, especially in the Quesnel and Cariboo River watersheds due to speculated mineral and metal deposits. It has been hypothesized that declines in the forestry industry could lead to regional increases in mining activities in certain areas of BC (Picketts et al. 2017; Owens et al. 2019). Mining operations are regulated under provincial jurisdiction as well as the *Fisheries Act*. Continued routine monitoring and participation of habitat staff from both the province and DFO's Fish and Fish Habitat Protection Program during mine development and operational stages are required to ensure local habitat impacts are minimized or avoided.

Table 30. DFO threats assessment calculator results for impacts from Mining & Quarrying for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Mining & Quarrying	DU2	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	For DU4 this is not anticipated to be a threat.							

4.1.4. Transportation & Service Corridors

IUCN-CMP threat category 4.4 Flight Paths was not included in this section as to our knowledge, there are no airplane, helicopter, or drone flight paths that interfere with any FRC DUs.

4.1.4.1. Roads & Railroads

This threat category focuses specifically on the threat of road transportation and road construction (IUCN CMP threat category 4.1). Impacts from runoff are dealt with in section 4.1.9.1, Household sewage & urban waste (IUCN CMP threat category 9.1).

The threat to FRC from roads and railroads is limited to new footprints of stream crossings. The density of these infrastructures and their maintenance frequencies are expected to increase with human population density. Culvert and bridge construction on smaller tributaries often requires that the stream be blocked or diverted during construction, which can temporarily affect fish behaviour. Any given tributary consists of a small proportion of the total DU, and the low frequency of construction and maintenance should limit any chronic behavioural impacts associated with construction.

The construction of bridges for road and railroad river crossings over smaller streams is often avoided due to economic costs. Culverts are often used on smaller stream crossings and can affect fish movement. When culverts are not sized properly, they can become impassible and cut-off large sections of upstream habitat (Mount et al. 2011). Culverts are unlikely to impact the majority of FRC spawning habitat, given the size of spawning streams, but juvenile access to rearing habitat can be impeded. There is ongoing work to replace old culverts with replacements built to higher standards. Currently, the impact to FRC is unknown because the impacts have not been quantified in many sites, so it is possible there could be a positive effect when replacing bridges and culverts. The extent to which Chinook are potentially impacted by roads and railroads will vary by DU and with local geomorphology. The proportion of any DU exposed to roads and railroads will be greater in DUs located in narrow valleys or ones that have been heavily logged near Chinook streams.

As indicated in threats Table 31, several DUs (DU2 LFR-Harrison, DU7 MFR-Nahatlatch, DU8 MFR-Portage, DU17 NTh-Summer) are not expected to be significantly impacted by roads and railroads. This is mostly due to the low density of the roads and road crossings near the spawning and rearing habitat in those DUs. For DU2, there is significant road density near the Harrison and Fraser Rivers, but impacts will most likely be low since most of the crossings would be bridges and would not cause direct impact on juvenile salmon.

This threat ranking does not include impacts associated with general modifications to catchment surfaces caused by roads and railroads, see Natural Systems Modifications.

4.1.4.2. Utility & Service Lines

This threat focuses specifically on the transport of energy and resources(IUCN CMP threat category 4.2). Impacts from oil spills from pipelines and groundwater contamination are dealt with in section *Industrial & Military Effluents* (IUCN *CMP threat category 9.2)*

Currently there are two major pipelines adjacent to FRC habitat. The TransMountain Pipeline is the most extensive utility route near freshwater habitat used by FRC and it crosses about 1000 fish bearing streams between Edmonton and Burnaby (TransMountain 2018[12]). This pipeline

[12] TransMountain. 2018. Watercourse Crossings in Burnaby. (Accessed July 22, 2020)

runs through the top of DU11 (upper Fraser), along the length of North Thompson DUs (DU16, DU17), along part of the Lower Thompson (i.e. the Coldwater River), and along the lower Fraser River. The natural gas Westcoast Transmission System Pipeline parallels the upper Fraser River beginning at Prince George, is diverted away from the river near William's Lake, and then follows the TransMountain Pipeline route along the Coldwater and lower Fraser rivers.

The TransMountain Pipeline may be twinned in the next 10 years. Efforts will be made to minimize impacts for stream crossings including the North Thompson River, Blue River, Raft River, Clearwater River, and Mann Creek through horizontal directional drilling; however, the expansion will impact some streams, and existing lines may displace sediment during construction or removal that could destroy redds or change stream morphology. The Westcoast Transmission line will also require construction in the future as the polyethylene tape, previously used for patching, is now considered to be a hazard and has to be replaced. The impacts from construction and repairs to both of these pipelines should be minimal if appropriate mitigation measures are followed.

4.1.4.3. Shipping Lanes

This threat category includes impacts associated with transport on and in freshwater and ocean waterways (IUCN-CMP threat category 4.3). This includes dredging activities; the physical footprint from log booms and barges; and wake displacement.

Direct impacts of ship traffic on salmon are unknown, but the maintenance of shipping lanes via dredging could have effects on salmon populations. Dredging for shipping lane traffic is common in the lower Fraser River, a migratory corridor for all FRC, but dredging activities should not occur during critical times nor in the littoral zone of the river. Changes in turbidity alter the foraging and predator avoidance abilities of juveniles FRC, which can affect survival (Gregory 1993; Gregory and Northcote 1993). An unknown proportion of FRC juveniles rear and overwinter in the lower Fraser River so there will likely be some impact to an unknown proportion of each of the DUs. Since all the DUs migrate past possible dredging and shipping activities, the threat extent is considered extensive.

The lower Fraser River is a highly active channel for log boom shipping, and contains a high concentration of log booms and barges. Storage of logs in the lower Fraser River is common because brackish waters protect logs from wood borers and storage areas are located in proximity to many processing mills (Sedell et al. 1991). The transport, storage and dumping of logs in aquatic habitats can lead to a variety of adverse physical, chemical, and biological effects to the surrounding environment (Power and Northcote 1991). Log booms can compact, scour, and shade nearshore habitats which in turn can reduce plant cover and food availability for juvenile salmon (Nelitz et al. 2012). There is a large proportion of tide-marsh habitat that has been used as moorage for log booms and barges, where some booms become grounded and impact important habitat. Additionally, wood and bark debris can also accumulate beneath storage areas and alter the composition of food sources, smother emergent vegetation, increase biological oxygen demand, and increase concentrations of potentially toxic log leachates (Nelitz et al. 2012). Log booms can also provide cover and attract inbound migrating Chinook Salmon seeking refuge; however, they can also attract predators such as Killer Whales and Harbour Seals, the latter of which use log booms as haul-out sites and for pupping (Baird 2001; Brown et al. 2019).

Wake displacement from vessels is also considered as a threat in this category. Both commercial and recreational boat activity is high in the lower Fraser River, and as such, the potential threat for wake displacement and stranding is pervasive and is known to occur at times. Propeller or jet wash from commercial vessels can also play a significant role in re-suspending bottom sediments, which can lead to erosion, internal nutrient loading, or elevated levels of turbidity and heavy metals in the water column (Hill 2002). The DU level impacts, however, are currently unknown; therefore, this threat was not scored.

Table 31. DFO threats assessment calculator results for impacts from Roads & Railroads for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Roads & Railroads	DU4	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU5	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU9	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU10	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU11	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU14	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU16	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	For DU2, DU7, DU8 and DU17 it is not anticipated to be a threat.							

Table 32. DFO threats assessment calculator results for impacts from Utility & Service Lines for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Utility & Service Lines	DU9	Likely	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU10	Likely	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU11	Known	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU16	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	For DU2, DU4, DU5, DU7, DU8 and DU14 this is not anticipated to be a threat.							

Table 33. DFO threats assessment calculator results for impacts from Shipping Lanes for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Shipping Lanes	DU2	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive

4.1.5. Biological Resource Use

IUCN-CMP threat categories 5.1 Hunting & Collecting Terrestrial Animals, and 5.2 Gathering Terrestrial Plants was not included in this section as these activities likely have no impact on FRC.

4.1.5.1. Logging & Wood Harvest

This threat category includes impacts associated with the direct physical activities of harvesting trees and other woody vegetation for timber, fibre, or fuel (IUCN-CMP threat category 5.3). Pollution as a result of these activities is scored in section *Pollution & Contaminates*. Impacts from the reduction of forest cover is discussed in section *Natural Systems Modifications*.

Extensive logging and timber harvest has occurred throughout the Fraser River Basin. When regulations are followed, direct physical impacts in the stream from logging activities should be minimized by riparian buffer requirements. However, in the BC Forest Planning and Practices Regulations (BC Reg 14/04), there is an exemption under section 51(1)(g) for the felling of trees in the riparian area if they have been damaged by fire, insects, or disease. Therefore, logging may occur right to the water's edge when salvaging burnt or damaged timber. A massive mountain pine beetle outbreak and numerous catastrophic wildfires have prompted aggressive salvage logging operations to recover as much economic potential as possible (BC Ministry of Forests 2004; BC Ministry of Forests and Range 2005; Schnorbus, Bennett, and Werner 2010). With salvage logging occurring right next to streams, there is likely to be some intrusion into FRC habitat, either by machines or by felled trees. Forest disturbances in the form of pests and diseases are likely to increase in BC with climate change (Woods et al. 2010; Haughian et al. 2012), and hence unless forest regulations and practices change, future salvage logging is probable. Future salvage logging may be particularly likely in DU11 (UFR-Spring), where the Spruce Beetle may become a large problem (S. Curtis pers. comm. 2019).

In addition to salvage logging, the physical activity of dumping logs into rivers or lakes for storage and/or transport scours the area and removes vegetation which would impact the habitat and make it less usable. This has occurred at the mouth of the Pitt River and the top end of Pitt Lake in DU4 (LFR-Upper Pitt), and at the mouth of the Tipella Creek in DU5 (LFR-Summer). Log storage in lakes can reduce dissolved oxygen and cause decreased juvenile salmon presence in affected areas (Levy et al. 1990). While the threat from these activities will not impact the entire DU and the level of impact is likely low, there is a relatively high certainty there will be some resultant effects at the DU level through loss of habitat.

4.1.5.2. Fishing & Harvesting Aquatic Resources

This threat is defined as harvesting aquatic wild animals or plants for commercial, recreation, subsistence, research, or cultural purposes; and includes accidental mortality/bycatch (IUCN-CMP threat category 5.4).

Fisheries operating in both Canada and the US intercept FRC along a large portion of their migration corridor. In Canada, this includes: First Nations Food, Social, and Ceremonial (FSC) fisheries; recreational fisheries; commercial fisheries (including First Nations Economic Opportunity); and test fisheries. Appendix H provides details about when and where these fisheries occur. The specific US fisheries that intercept FRC are not discussed in this RPA because mitigation scenarios can currently only be implemented in Canada. Broad scale US impacts are considered in the determination of whether sustainable exploitation rates are met.

Commercial fisheries that impact FRC stocks include the Chinook-targeted troll fisheries on the west coast of Vancouver Island (WCVI) and northern BC (NBC). There are also a seine and gill net demonstration fisheries (considered a commercial fishery) in Kamloops Lake. The demonstration fisheries target Thompson Summer 4_1 Chinook and attempt to avoid Chinook from DU16 (NTh-Spring) and DU17 (NTh-Summer), but they can be caught as bycatch. FRC stocks are impacted by Chinook-targeted recreational hook and line fisheries in NBC, WCVI, Johnstone Strait, Strait of Georgia, Strait of Juan de Fuca, and the Fraser River. DU2 (LFR-Harrison), DU4 (LFR-Upper Pitt), and DU5 (LFR-Summer) are impacted in recreational fisheries in Freshwater Region 2, but they are not impacted by recreational fisheries in Freshwater Regions 3, 5, 7, and 8, which occur upstream of the spawning areas of these DUs.

FSC fisheries in the South Coast marine waters are expected to primarily impact South Coast stocks, though there are also likely to be impacts to other co-migrating stocks, including Fraser stocks, and especially those that reside within the Salish Sea. Chinook-targeted FSC fisheries in the Lower Fraser River from the mouth of the river to the confluence with Harrison River impact all FRC stocks except DU4, which is impacted by the FSC fisheries but only those occurring downstream of the confluence of the Pitt River. Further upstream, Chinook-targeted FSC fisheries occurring between the confluence with the Harrison River and the confluence with the Thompson River impact all Fraser stocks assessed in this RPA except DU2, DU4, and DU5. DU8 (MFR-Portage) is the latest returning group of Fall Chinook and overlaps with the return of more-abundant Chinook stocks and other salmon species, potentially leading to higher bycatch rates compared to the other DUs. Upstream of the confluence with the Thompson River, Chinook-targeted FSC fisheries only impact DU9 (MFR- Spring), DU10 (MFR-Summer), and DU11 (UFR- Spring).

Several Canadian test fisheries operate along the migration corridor of FRC. The only test fisheries that currently target Chinook are the Brooks Peninsula troll test fishery and the Albion gill net test fishery that operates in the Fraser River. It is unlikely that many FRC are intercepted in the Brooks Peninsula test fishery, as the number of samples are capped at 1,000 Chinook; in 2017, of 943 Chinook caught, 115 (12%) of the samples were identified as Fraser-origin (Luedke et al. 2019). The Albion test fishery impacts all FRC DUs assessed in this RPA except DU4, which spawns in the Pitt River downstream of the test fishery. Catch at Albion is proportional to abundance in-river, and over the last 10 years (2009 to 2018) has averaged 1,712 Chinook. This typically accounts for 0.5% to 1.2% of the total FRC abundance. Several other test fisheries intercept Chinook Salmon as bycatch, including: the Pacific Salmon Commission’s Sockeye Salmon test fisheries in the lower Fraser River, Strait of Juan de Fuca, and Johnstone Strait; and Fisheries and Oceans Canada’s Chum test fisheries in Johnstone Strait and Juan de Fuca.

FRC may also be caught incidentally in fisheries of all sectors that are targeting other fish, including salmon (Chum, Sockeye, and Pink salmon seine and gill net, Sockeye Salmon troll), groundfish trawl and longline, lingcod gang-troll, tuna troll, sardine seine, herring seine, and shrimp trawl. Retention of Chinook Salmon is typically not permitted in these fisheries, except for some salmon-directed fisheries in years when harvestable surplus is expected at the time of the fishery. Impacts are generally only estimated for salmon fisheries; there are not enough data available to evaluate the impact of non-salmon fisheries on FRC.

The impact of all fisheries on the individual Fraser Chinook DUs being assessed in this RPA is not well known at the DU level, especially where Chinook are impacted mainly as bycatch. At the MU level, impacts have been estimated with different tools, depending on data availability. One method developed by the PST Chinook Technical Committee (CTC) estimates calendar year exploitation rate (CYER) on 20 indicator stocks in British Columbia, including the indicator stocks for three of the five FRC MUs, based on coded-wire tag (CWT), catch, and escapement data. Nicola River is the indicator stock for the Spring 4_2 MU (DU14), Harrison River is the indicator stock for the Fall MU (DU2), and Lower Shuswap is the indicator stock for the Summer 4_1 MU (not assessed in this RPA). There are currently no indicator stocks for the Spring 5_2 and the Summer 5_2 MUs (all DUs in this RPA except DU14 (STh-Bessette) and DU2). There was an indicator stock for Spring 5_2 MU at Dome Creek, but the CWT program there was discontinued after brood year 2002 due to failure of hatchery water system and financial constraints for repair work. Work is underway to develop the Chilko River to become an indicator stock for the Summer 5_2 MU.

A second method for estimating impacts is with the Fraser River run reconstruction model. This model produces annual stock-specific estimates of the total number of Chinook Salmon returning to the mouth of the Fraser River and estimates of in-river harvest rates by fishery sector (English et al. 2007). Harvest rate estimates are produced for all five FRC MUs; however, these estimates do not currently account for incidental fishing mortality, harvest of FRC in marine areas, or natural mortality.

Estimates generated from both of these methods have uncertainty associated with them, which results in uncertainty when determining the threat risk from fishing activities. These uncertainties are described in extensive detail in DFO (2019) and are largely related to limited or deficient data. The authors outline that uncertainties with the CWT-based method are associated with low CWT recoveries and sampling rates for several reasons; for example, some fisheries are not directly sampled (potential bias), have low sampling rates (imprecision), and do not represent he impact of mark-selective fisheries with high confidence due to several assumptions. Similarly, mass-marking of hatchery-origin fish has contributed to a decrease in CWT submission rates for recreational fisheries. Estimates of smolt-age-2 survival rate are also uncertain because they are CWT-based. There are also several uncertainties with the run reconstruction method. There are often instances of incorrect or missing input data (escapement, kept and released catch, GSI), which sometimes require infilling to complete an analysis or lead to bias. There are non-representative sampling issues with the GSI sampling program for fishery encounter categories that pertain to fishing regulations, and there are no bias corrections for GSI errors. Finally, model estimates may be less reliable if critical model assumptions are violated, such as the vulnerability to fisheries, variable fishing effort among years and areas, release mortality rates, peak of run timing, and stock composition. Given the high uncertainty in the estimates from both methods, lack of measurement of all fishery impacts, and the inability to quantitatively measure the estimates to the DU level, neither of these data sets were used when determining threat scores for any DUs except for DU2 (LFR-Harrison). Instead, for the other DUs, the threat score was initially based off the assessment for DU2 and adjusted given known similarities/differences in life history and habitat to DU2. General comments about the likely differences in impacts compared to DU2 are detailed below, but none of these differences resulted in a different overall threat score from DU2.

A consistent time series of escapement and CYER estimates exists for DU2 (Table 34). Since 1985, the lower bound of the escapement goal range (75,100) for DU2 has not been met in 14 of 34 years, with most of the low escapements occurring within the last 15 years. However, management actions in response to low escapements were not implemented until very recently (within the last 5 years) when escapements and pre-season forecasts began consistently being estimated below target. An updated sustainable ER for this DU was recently estimated at 16% (Catarina Wor and Antonio Velez-Espino, see Appendix I), which is substantially more conservative than the previously published optimum ER of 57% (Brown et al. 2001; CTC 2018). Both ER estimates suggest what would be sustainable given both Canadian and US exploitation. Based on the CTC's ER analysis, the average total ER in the years when the escapement goal was not met was 43% (31% Canadian, 12% US), which is nearly triple the sustainable exploitation rate. The US ER has averaged around 10% in the last 3 generations and is expected to continue at this rate going forward. In 2019, the Department implemented a precautionary reduction in Canadian ERs by at least 25% from the recent years' (2013-2016) average ER of 17.4%. However, to meet the sustainable ER for this DU, the Canadian ER would need to be reduced to approximately 6% (a reduction of approximately 65% from recent years). The analysis that generated the sustainable ER was based on productivity estimates from brood year 2013 (return year 2018), so it is possible that this value may decrease if productivities continue to decline. This may result in greater population decline if ERs remain at current levels, suggesting that fishing activity has the potential to present a High threat risk to this DU. In addition, as described in Appendix I the confidence intervals around the median estimate are quite wide and the output is sensitive to the prior distribution selected; while this is unlikely to greatly change the declining trend shown, it could affect the magnitude of the estimate. Given the uncertainties in the exploitation rate estimates and management implementation error, a threat risk of Low to High with Very High causal certainty was assigned to this DU.

Harvest rates for the remaining DUs are thought to have declined in recent years given management actions to restrict impacts on the earliest-timed Chinook returning to the Fraser River, but like DU2 there is uncertainty about the future impact of fishing activity on these DUs. Actions to reduce impacts to one of the earliest returning groups, Spring 4_2 Chinook, have been in place since the early 2000s. A short time series of escapement and CYER estimates exists for DU11 (UFR-Spring) based on the Dome Creek indicator stock for Spring 5_2 Chinook (Table 35). The Dome Creek data were provided for context on historical ERs, but they were not directly used in the threat risk assessment. In 2012 the Department set a goal of reducing overall harvest rate on Spring 5_2 and Summer 5_2 Chinook by at least 50%, from a base period harvest rate ranging from 50% to 60% to less than 30%. A 3-zone management approach was adopted to work toward this goal (DFO 2018b[13]). A recent review of the management actions on these three MUs (Spring 4_2, Spring 5_2, Summer 5_2) estimated the overall reduction in the ER index was 39.6% for the Spring 4_2 MU, 24.0% for the Spring 5_2 MU, and 11.4% for the Summer 5_2 MU (DFO 2019). The analysis indicated it was possible that the total ER on the Spring and Summer 5_2 Chinook averaged less than 30% in Zone 1 (low abundance) years, suggesting the overall reduction targets for Spring and Summer 5_2 Chinook may have been met, but considerable uncertainties rendered the analysis inconclusive. Additional measures were put in place in 2018 to implement a precautionary 25% to 35% reduction from the average ER between 2013 and 2016 for FRC stocks to support conservation and promote rebuilding. In 2019, the management objective was further refined to reduce overall Canadian fishery mortalities on these early-timed populations to near 5%; an analysis of the effectiveness of the management actions is still in progress.

Fishing dynamics in mixed-stock areas may change in the future with recent increases in hatchery production, such as the doubling of production of Chilliwack Chinook which co-migrate with DU2 LFR-Harrison. The effects of salmon hatchery production and mixed stock fisheries was identified as a serious risk as early as the 1970s (see Gardner et al. 2004 for an in-depth review of hatchery impacts). To summarize, high levels of hatchery supplementation relative to wild juvenile production can contribute to harvest rates that are too high for wild fish to sustain, and the presence of large numbers of hatchery fish can mask declines in wild salmon stocks. In areas that have hatchery fish mixed with wild stocks, enhanced production can lead to unsustainable fishing mortality rates for wild salmon, when harvest rates are set at levels related to total abundance of fish in an area which is increased due to the presence of hatchery fish (i.e.

[13] DFO. 2018b. Pacific Region Integrated Fisheries Management Plan, Salmon, Southern B.C, June 1, 2018 to May 31, 2019. (Accessed July 21, 2020)

abundance-based management strategies). The enhanced stocks may withstand the harvesting pressure or even be under-harvested, while less productive, co-migrating wild stocks are overharvested. For example, Barnett-Johnson (2007) reported 90% of fall-run California Central Valley Chinook caught in the ocean fishery were of hatchery-origin, and acknowledge an additional unknown but potentially large contribution of juveniles from hatchery-origin adults spawning in the rivers. These findings were particularly alarming as previous estimates considered approximately 30% hatchery contribution to the fishery (Carlson and Satterthwaite 2011). While not FRC-specific, the overharvest of weaker or smaller stocks in mixed-stock fisheries has led to complete elimination of some Pacific salmon populations such as wild Coho Salmon in the lower Columbia River (Policansky and Magnuson 1998), and declines of many other populations including Fraser River Sockeye Salmon (Collie et al. 1990) and various Chum Salmon populations in BC (Beacham et al. 1987). In the case for DU2, the doubling of production at Chilliwack hatchery will likely lead to increased fisheries encounters in the Salish Sea, which can in turn lead to increased fishing effort in those areas. As fishing pressure increases on these fish in the Salish Sea, the impacts on Harrison fish thereby also increase. Objectives and appropriate protocols can be developed to ensure enhancement activities are aligned with the recovery of these DUs.

It is also known that some illegal fishing activity occurs in marine areas and in the Fraser River, but the extent of the impact to these DUs is not known. The low abundance of some DUs (e.g. DU14 STh-Bessette) may elevate the low end of the threat risk above 10% (into the Medium category). A threat risk of Low to High was assigned to these DUs with Medium causal certainty due to the high uncertainty in ER estimates, unknown optimal ER, and the expectation of management implementation error.

The threat risk from fishing activities to all FRC DUs was estimated as Low to High (1% to 70% population decline), with the expectation that the maximum threat risk is likely closer to the lower end of the High (30% to 70% population decline) category. The threat of population decline occurring from fishing activity was evaluated as being greater than zero when ERs were expected to exceed sustainable levels, which are uncertain because sustainable levels vary annually with productivity. Though precise estimates of ERs for most DUs are not available, there have been notable changes in recent fishing activity in all sectors that have likely led to overall reductions in ER over the last 10-20 years. It is anticipated that the current ERs are higher than what these populations can sustain at current productivity levels. Experts participating in the threat evaluation suggested the population decline due to fishing activity is expected to be less than 30% (the breakpoint between the Medium and High threat risk categories) over the next three generations, but agreed the population decline could rise above 30% at current ERs if productivity continues to decline, as anticipated. Fishing activity is not likely the main factor driving recent declines in these DUs, though it is a contributing factor when ERs sustainable levels. Fishing activity is expected to continue, but the magnitude of the threat is highly uncertain. A forward projection of select DU abundances at a variety of ER and productivity scenarios will be explored in the second part of the RPA.

Table 34. Escapement and exploitation rate (ER) summary for DU2 (LFR-Harrison), 1985 – 2018. Data provided by the Pacific Salmon Treaty Chinook Technical Committee. Years marked with an asterisk are those in which the minimum escapement goal of 75,100 was not met.

Year	Escapement	Canadian ER	US ER	Total ER
1985	174,776	63.7%	7.8%	71.5%
1986	162,594	72.3%	6.6%	78.8%
1987	79,036	49.8%	13.1%	62.8%
1988*	35,114	55.7%	17.3%	73.0%
1989*	74,683	60.2%	15.7%	75.9%
1990	177,373	40.9%	15.0%	55.9%
1991	90,636	54.6%	18.1%	72.7%
1992	130,409	45.7%	19.2%	64.9%
1993	118,997	36.6%	13.7%	50.3%
1994	98,342	47.2%	8.5%	55.7%
1995*	28,616	43.1%	15.7%	58.8%
1996*	37,392	26.2%	12.1%	38.2%
1997*	70,514	39.5%	20.9%	60.4%
1998	200,258	4.3%	6.5%	10.8%
1999	104,415	13.9%	17.0%	30.9%
2000	77,754	30.1%	18.3%	48.5%
2001	108,502	14.7%	12.7%	27.5%
2002	83,011	24.9%	17.1%	42.0%
2003	246,986	23.4%	14.5%	37.9%
2004	139,126	28.2%	21.2%	49.4%
2005	88,589	31.1%	10.2%	41.3%
2006*	60,421	29.6%	18.3%	48.0%
2007	76,483	12.9%	2.8%	15.7%
2008*	41,603	43.1%	10.8%	53.9%
2009*	70,142	12.8%	2.8%	15.6%
2010	103,558	15.0%	8.4%	23.5%
2011	123,647	16.5%	6.6%	23.1%
2012*	44,467	13.0%	9.6%	22.5%
2013*	42,953	13.6%	11.1%	24.7%
2014*	44,686	23.8%	10.1%	34.0%
2015	101,516	16.3%	6.8%	23.1%
2016*	41,327	15.8%	3.1%	18.8%
2017*	29,799	38.6%	10.1%	48.7%
2018*	46,094	21.2%	9.4%	30.6%
3-generation average	63,856	20.2%	7.6%	27.9%

Table 35. Escapement and exploitation rate (ER) summary for DU 11 – Upper Fraser Spring Chinook, 1991 – 2006. The Dome Creek indicator stock program was discontinued after the 2002 brood year. Data provided by the Pacific Salmon Treaty Chinook Technical Committee. Escapements marked with an asterisk are not included because they were developed using different methodology than the rest of the time series and are thus not directly comparable.

Year	Escapement	Canadian ER	US ER	Total ER
1991	*	17.4%	19.4%	36.8%
1992	*	61.3%	7.5%	68.8%
1993	*	64.4%	1.7%	66.1%
1994	*	32.0%	0.7%	32.7%
1995	30,001	31.8%	1.9%	33.7%
1996	20,847	48.9%	2.2%	51.1%
1997	23,244	46.2%	2.5%	48.7%
1998	23,525	55.7%	0.0%	55.7%
1999[A]	13,918	54.9%	0.0%	54.9%
2000[A]	16,198	57.6%	3.0%	60.6%
2001	21,136	78.5%	0.3%	78.8%
2002	31,464	55.8%	3.6%	59.4%
2003	37,675	85.1%	0.0%	85.1%
2004	25,398	NA	NA	NA
2005	15,693	74.5%	0.0%	74.5%
2006[A]	16,524	49.5%	1.1%	50.5%

[A] Calendar year exploitation rates were based on fewer than 100 estimated CWT recoveries.

Table 36. DFO threats assessment calculator results for impacts from Logging & Wood Harvest for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Logging & Wood Harvest	DU4	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU5	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU9	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Recurrent	Narrow
	DU10	Known	Negligible	High	Low (2)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU11	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU16	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU17	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Recurrent	Narrow
	For DU2, DU7, DU8 and DU14 this is not anticipated to be a threat.							

Table 37. DFO threats assessment calculator results for impacts from Fishing & Harvesting Aquatic Resources for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Fishing & Harvesting Aquatic Resources	DU2	Known	Low-High	Very High	Low-High (1)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low-High	Medium	Low-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive

4.1.6. Human Intrusions & Disturbance

4.1.6.1. Recreational Activities

This threat category includes human activities that alter, destroy, or disturb habitats and species with non-consumptive uses of biological resources (IUCN-CMP threat category 6.1).

Recreational activities that can disturb or destroy FRC habitat, or directly cause FRC mortality are considered in this section. Recreational activities include any off-road vehicle (i.e. ATVs/UTVs, dirt bikes) or other mode of transportation (e.g. horse) that enter streams and destroy habitat or redds, and boat activity occurring in FRC habitat when occupied by juvenile fish or eggs. Jet boats in particular have the potential to suck up fish or eggs causing direct mortality if the boats are driven through gravel beds or littoral habitat during critical periods. Additionally, boat wakes may strand juveniles along shorelines or from shallow habitats. The pressure fluctuations created under a passing jet in shallow water is also capable of killing salmon eggs incubating in the stream-bed, with mortalities of up to 40% in controlled laboratory studies (Sutherland and Ogle 1975). Recreational propeller or jet wash can also play a significant role in re-suspending bottom sediments, which can lead to erosion, internal nutrient loading, or elevated levels of turbidity and heavy metals in the water column (Hill 2002). A study conducted by Dorava and Moore (1997) demonstrated streambank erosion in a popular boating area of the Kenai River, Alaska, was 75% greater when compared to areas where boating restrictions are in place. Reduced water clarity may also interfere with the use of shallow water habitat by fish, in addition to wildlife habitat along the water's edge (Laderoute and Bauer 2013).

There has been an increase in recreational jet boat activity in the Pitt River (DU4) in recent years, with reports of juvenile fish washed ashore, and physical damage to redds and fish from boats running through gravel bars (Luymes 2017[14]). There is also considerable recreational activity in and near the mouth of the Harrison River (DU2) above the Kilby boat launch. Owing to the habitat within the Harrison River, however, the proportion of fish from this DU that come into contact with jet boats is likely negligible. The proportion of these DUs exposed to this threat is small, yet when they are exposed there is a serious impact. DUs 16 (NTh-Spring) and 17 (NTh-Summer) also have jet boats in the spawning streams that can encounter the spawning grounds, but the effects are expected to be minimal.

Although jet boating also occurs in the middle and upper Fraser River (DUs 9, 10, and 11), the threat from recreational activities in these DUs is primarily from off-road vehicles (particularly ATVs/UTVs) entering streams. Many streams in DU9 (MFR-Spring) and DU11 (UFR-Spring) are small with numerous opportunities for crossing with off-road vehicles, and some of these crossings are within FRC spawning grounds (S. Curtis, pers. comm. 2019). These vehicles can degrade FRC habitat or crush redds when entering streams, yet the proportion of DUs exposed to this threat is low. DU10 (MFR-Summer) consists of larger streams with little opportunity for off-road vehicles entering streams, therefore it was not scored.

DU7 (MFR-Nahatlatch) has some jet boat traffic from DFO scientific activities, and rafting in the Nahatlach River below the lakes, but precautions are taken to minimize impacts. DU5 (LFR-Summer) and DU8 (MFR-Portage) are not thought to have any significant recreational activities, and hence it is not considered a threat to those DUs.

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[14] Luymes 2017 – News article for the *Vancouver Sun: "Joy-riding jet boaters destroying Pitt River salmon: fisherman".* (Accessed Jully 22, 2020)

4.1.6.2. War, Civil Unrest and Military Exercises

This threat includes actions by formal or paramilitary forces without a permanent footprint, such as armed conflict, mine fields, tanks and other military vehicles, training exercises and ranges, defoliation, and munitions testing (IUCN-CMP threat category 6.2)

War, Civil Unrest and Military Exercises are currently not expected to be a threat to any FRC DUs. There are some military activities in test ranges in the vicinity of Nanoose Bay and perhaps in other areas, but the impacts are unknown. Twinning of the Transmountain pipeline could attract large protests. Protests could result in damage to equipment or the pipeline itself leading to accidental spills. While these issues were raised and discussed at the threats workshop, due to the high amount of uncertainty of these events occurring, this threat was not scored for any DU.

4.1.6.3. Work & Other Activities

This category includes threats from people spending time in or traveling in natural environments for reasons other than recreation or military activities (IUCN-CMP threat category 6.3). This includes scientific research, and activities associated with law enforcement, drug smugglers, and illegal immigration.

The threat to FRC within this category is limited to scientific research. There is ongoing stock assessment and scientific research within many streams in FRC DUs, yet there is likely minimal to no population effect as the survey methods are designed to minimize any negative influences on the spawning populations. In addition, DFO field staff attempt to mitigate the negative effects of stress when conducting escapement survey programs. For Chinook Salmon indicator studies, capture and marking are carried out earlier in the day before daytime heating results in temperatures above 20°C. Capture is not done in areas where there are no opportunities to work at suitable temperatures. Hatchery broodstock capture activities do proceed at temperatures up to 23°C, but only when tanks of 7-10°C, highly oxygenated water are available to hold the fish immediately after capture. In addition to DFO, there are various other research groups and programs that are operating in other DUs and may be encountering or studying Chinook Salmon. Among the DUs assessed in this RPA, the only location where brood stock have been collected is the Chilko River (DU10), where cooler water temperatures (<16°C) likely limit any temperature-related impacts.

This threat was deemed to be extensive only for DU8 (MFR-Portage) due to ongoing research in Seton River that is investigating salmon passage and entrainment. In the past, activities in the Seton River have involved blocking passage through construction of a weir and could be of particular concern for Chinook Salmon as they can be unwilling to pass weirs on a descending hydrograph. The level of impact, however, is anticipated to be negligible at the population level.

Table 38. DFO threats assessment calculator results for impacts from Recreational Activities for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Recreational Activities	DU2	Remote	High	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU4	Likely	Medium-High	Low	Medium-High (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU7	Remote	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU9	Likely	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU11	Likely	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Narrow
	DU14	Remote	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU16	Remote	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU17	Remote	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Continuous	Restricted
	For DU5, DU8 and DU10 this is not anticipated to be a threat.							

Table 39. DFO threats assessment calculator results for impacts from Work & Other Activities for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Work & Other Activities	DU2	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU4	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU5	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU7	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU8	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU10	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU14	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU11	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU16	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU17	Known	Negligible	Very Low	Low (5)	Historical/ Current/ Anticipatory	Continuous	Negligible

4.1.7. Natural Systems Modifications

4.1.7.1. Fire & Fire Suppression

This threat is defined as suppression or increase in fire frequency and/or intensity outside of its natural range of variation (IUCN-CMP threat category 7.1).

Forest fires are becoming more frequent as a result of climate change, historic forestry practices, pest infestations, pathogens, and incidences of human initiated fires (Mote et al. 2003; Wang et al. 2015), which can impact fish in multiple ways. The immediate and direct heating from flames, and the lasting effect (removal of riparian stream cover) of a forest fire is increased stream temperatures that can affect the behaviour and physiology of juvenile salmon (Beakes et al. 2014). Fire suppression tactics such as aerial bucketing can directly capture juvenile Salmon, depending on the location and depth they are occupying in the water column during the daylight hours when such scooping would occur. The threat from aerial bucketing is likely most prevalent in systems with shallow streams (i.e. DU9 MFR-Spring, DU11 UFR-Spring) because areas may be excavated with machinery to create pools deep enough to deploy aerial buckets. In the summer, adult Chinook may enter these artificial pools, leading to the potential for fish to be removed from the streams by an aerial bucket. In addition, equipment conducting this work may inadvertently destroy habitat or release suspended sediments into the water column, indirectly impacting fish downstream. North Thompson Chinook (DU16 NTh-Spring and DU17 NTh-Summer) may also be affected to some extent by this threat, but it would be similar or less than that acting upon DU9 (MFR-Spring) and DU11 (UFR-Spring). In the case of DU2 (LFR-Harrison), DU4 (LFR-Upper Pitt), DU5 (LFR-Summer), DU8 (MFR-Portage) and DU10 (MFR-Summer), there are unlikely to be any direct effects from fire suppression, as any water would be collected from the large lakes in those systems where it would be unlikely to encounter FRC.

The proportion of any DUs covered in this report that would encounter or be impacted from this threat is either restricted or negligible, and is therefore not considered to be a significant threat to FRC.

4.1.7.2. Dams & Water Management

This threat is defined as dams and water management/use activities which change water flow patterns from their natural range of variation either deliberately or as a result of other activities (IUCN-CMP threat category 7.2). This includes changes to water flow patterns and volumes (hydrology), sediment transport, and the in-river footprints of structures.

The threat to FRC through water management and utilization (for a variety of sectors) in the Fraser River Basin is pervasive for all DUs discussed in this RPA. This includes threats from structures related to flood control (i.e. dikes, flood boxes, tide gates), dams and hydroelectric development, and water extraction.

Flood Control

There has been significant removal of historical off-channel rearing habitat in the lower Fraser River due to dikes and other structures for flood control (i.e. flood boxes, tide gates, etc.). There are approximately 600 km of dikes, 400 flood boxes and 100 pump stations in the Fraser River Basin (Fraser Basin Council 2019[15]). Some of these structures have cut off access to backchannels and sloughs that were historically inhabited by FRC and there is currently very limited floodplain habitat left for overwintering juveniles in the lower Fraser River. Flood boxes

[15] Fraser Basin Council 2019. Flood and the Fraser. (Accessed July 22, 2020)

and tide gates can have ongoing impacts by preventing access to ephemeral habitat and creating undesirable habitat for juvenile Chinook (Gordon et al. 2015; Collins et al. 2016).

In general, salmonids are known to actively move into seasonal floodplain wetlands to avoid high main-channel flood flows, but reductions in connectivity to and degradation of side-channels and tributaries has the potential to reduce survival and create long-term selection pressures that affect migration patterns (Trombulak and Frissell 2000). Junk et al. (1989) proposed the flood pulse concept, which predicts that annual inundation is the driving force for productivity and biotic interactions in river–floodplain systems. Floodplain habitats have higher biological diversity and increased production invertebrates when compared to adjacent river channels (Junk et al. 1989; Gladden and Smock 1990), and provide a seasonal source of food for juvenile Chinook Salmon during and following the freshet. While not FRC-specific, Jeffres et al. (2008) report off-channel floodplain habitats in the Cosumnes River provide significantly better rearing habitat than the intertidal river channel, supporting higher growth rates. When juvenile Chinook salmon leave fresh water at a larger size, as seen in fish reared on floodplains, overall survivorship to adulthood is increased (Unwin 1997; Galat and Zweimüller 2001; Jeffres et al. 2008). As such, it has been proposed that floodplain restoration an important tool for enhancing salmon production (Sommer et al. 2005). Additional flood control impacts are from pump stations, which evacuate water from flood plains, potentially stranding fish that may have entered during high water, or directly causing mortality to FRC juveniles if fish are sucked into the pump.

Dams & Hydroelectric Power

Hydroelectric dams alter the natural hydrograph, act as migration barriers, cause direct smolt mortality during downstream migration, scour redds immediately downstream, reduce natural gravel recruitment, and reduce overall productivity and abundance of upstream salmon populations and other aquatic prey resources (Levin and Tolimieri 2001; Welch et al. 2008). Despite a rush to develop hydropower sites in British Columbia during the middle 20th century, no dams were constructed on the Fraser River mainstem (Ferguson et al. 2011). DUs 8 (MFR-Portage), 9 (MFR-Spring) and 10 (MFR-Summer) are impacted by large hydroelectric facilities.

The Bridge-Seton hydroelectric complex has impacted both DUs 8 and 9. The Bridge River was originally impounded in 1948 through the construction of the Mission Dam (renamed to Terzaghi Dam in 1965), where water is diverted from the Bridge River to Seton lake to generate hydropower (Melville et al. 2015). Construction of Terzaghi Dam cut off a large section of the river that had historically been important spawning and rearing locations for Bridge River Chinook Salmon. Prior to construction of Terzaghi Dam the Bridge River contained an estimated accessible watershed area of 2,057 km^2, which was reduced to 416 km^2 post-construction decreasing the productive capacity of the watershed (Parken 2013)[16]. Downstream of the dam, changes to the natural hydrograph have led to impacts on juvenile FRC through significant reductions in flows and rearing habitat (Bradford et al. 2011). Furthermore, the flow release drawn from the bottom of Carpenter Reservoir above Terzaghi Dam has directly influenced the thermal regime of the lower Bridge River affecting the incubation and emergence timing of Chinook salmon recruits. Recently flows have been increased in the Bridge River to draw down the Downton Lake reservoir for dam repairs. This release of additional warm water has significantly decreased egg incubation time, and has lead to fry emergence as early as December (R. Bailey pers. comm. 2019). A recent attempt to collect broodstock from Bridge River spawners failed, due to low returns. It is possible that the portion of DU9 that returns to

[16] Parken, C.K. 2013. Department of Fisheries and Oceans, Canada. Kamloops B.C. Bridge Seton Escapement Goals. chuck.parken@dfo-mpo.gc.ca

spawn in the Bridge River will become extirpated due to these impacts. However, this area makes up a small proportion of the total area of the DU and thus overall impact on the DU is likely low.

The Bridge-Seton facility also impacts all Chinook from DU8 (MFR-Portage). Prior to construction of Seton Dam, it was estimated the historic accessible area of the Seton watershed was 792 km^2, which was reduced to 550 km^2 post-construction decreasing the productive capacity of the system (Parken 2013[17]). The construction footprint of Seton Dam also likely destroyed high quality spawning habitat for FRC which is common at the outlets of lakes. All returning spawners must migrate over the fishway at Seton Dam to reach their spawning grounds in Portage Creek. A study on Sockeye Salmon passage at Seton dam found that passage efficiency was 80%, and provided evidence to suggest reduced survival due to dam passage (Rosecoe et al. 2011). While these results are not directly applicable to FRC, they indicate there are possible impacts from the fishway. Mortality of out-migrating smolts can also occur if fish pass through an operational powerhouse, where they are subject to strong velocity shear, pressure gradients, turbulence, cavitation, and direct impact of turbine blades (BC Hydro 2006)[18]. The impacts on fish are variable due to physical factors such as turbine type/size, intake arrangement, and discharge, or biological factors such as fish size, swimming style, body orientation entering turbines, and buoyancy (Coutant and Whitney 2000). It is currently unknown what proportion of out-migrating smolts are entrained at Seton Dam, but it has been identified as a source of mortality and/or injury for FRC from DU8.

The Nechako River is regulated by the Kenney Dam, which has been operating since 1954. Impounded water upstream of Kenney Dam is diverted from Nechako Reservoir to the coastal Kemano River watershed outside of the Fraser River basin (Déry et al. 2012) to power the Alcan aluminium smelter located in Kitimat, BC. Flow regulation downstream of the dam involves release of water from the Nechako reservoir into the Cheslatta River system approximately 9 km downstream of Kenney Dam, which is the upstream limit of FRC distribution in the system as the Kenney Dam releases no water into the dewatered Nechako Canyon (Sykes et al. 2009). The impacts on local ecosystems in the Nechako River basin were significant following construction of Kenney dam, with large areas of land either flooded or drained leading to the displacement or impoundment of a number of fish (and other animal) species; however, the impacts from the flow diversion differ between the upper and lower reaches of Nechako due to the mitigating impacts of tributary flows in the lower reaches (Bradford 1994). Brood survival is low in the upper portion of the Nechako River, potentially caused by early emergence due to warmer fall and winter temperatures, and a lack of spring freshet (Bradford 1994). Currently releases from Kenney dam are above the required minimum flow release and it is uncertain if this will continue (S. Curtis pers. comm. 2019). On a Fraser basin-wide scale, however, the overall impacts from Kenney Dam on FRC are minimal, and impacts to DU10 (MFR-Summer) specifically are also likely minimal due to the extensive geographic range of this DU.

There are numerous Independent power projects, often built as run-of-river hydroelectric facilities within tributaries of the Fraser River that may impact FRC. These facilities have smaller in-river impacts than large hydro projects (Anderson et al. 2014) but may have larger cumulative impacts by modifying catchment surfaces through construction of roads and other infrastructure (see *Modifications to Catchment Surfaces*). The in-river impacts from run-of-river facilities are expected to be limited, as many of the facilities are above fish bearing waters and are less

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[17] Parken, C.K. 2013. Department of Fisheries and Oceans, Canada. Kamloops B.C. Bridge Seton Escapement Goals. chuck.parken@dfo-mpo.gc.ca

[18] BC Hydro 2006. Fish Entrainment Risk Screening and Evaluation Methodology. Report No. E478. 100 p.

impactful to the hydrology and geomorphology of streams than large hydroelectric dams. Recent operational monitoring results from run-of-river hydroelectric facilities in the Harrison and have not detected any large changes in resident salmonid abundances (DFO 2016). Likely the largest in-river threat from run-of-river facilities are ramping rates, the rate at which the facility changes water levels in the river. Ramping rates are set conservatively to prevent fish stranding, but ramping exceedances do occur and can strand fish. Mortality from these exceedances would depend on the magnitude and timing of the event, as well as the presence of FRC. There is not an anticipated population level impact from run-of-river facilities.

It should be noted that while unlikely, failure of fishways can have serious negative implications for FRC that require passage above these structures. While not considered in this RPA, the failure of the Bonaparte River fishway (2017) had serious negative impacts on DU15 (LTh-Spring) and serves as the most recent example of the importance of fishway maintenance in the Fraser basin. In the event of fishway structures failing, such as those at Hells Gate or Seton Dam, the migration of some or all fish from DUs 8 (MFR-Portage), 9 (MFR-Spring), 10 (MFR-Summer), and 11 (UFR-Spring) would be inhibited from reaching spawning grounds.

Future hydroelectric development in BC is a complex issue that involves Federal, Provincial, and First Nations governments; however, no major hydroelectric development is expected in the near future within systems inhabited by FRC. There is a framework to facilitate the development of independent power projects; however, with the development of Site C, it is unlikely that another request for power will be issued in the immediate future. Only DUs 8, 9 and 10 were scored based on dams and hydroelectric development.

Water Extraction

Water extraction can impact FRC through reduced flows in streams, limiting the wetted area of streams, and altering natural water temperatures. Groundwater extraction is of particular concern to yearling Chinook Salmon that reside in streams with snow-dominated hydrographs, as these populations are highly dependent on ground water for much of their freshwater residence (Brown et al. 2019). Groundwater upwelling protects redds from anchor-ice formation, maintains suitable temperatures for late-summer rearing habitats, and moderates temperatures and water levels for returning adults (Brown 2002). Despite the critical dependence of stream-resident salmonids on groundwater, allocation and quantity control are still only passively managed (Douglas 2006). Surface water resources are also fully subscribed in many rivers, particularly in the arid southern interior, yet new wells continue to be drilled without consideration of the impact on the groundwater supply to nearby rivers (Brown et al. 2019) or the impact to the overall water availability.

DU14 (STh-Bessette) occurs in a drought-sensitive system and lies within an oversubscribed area. Extreme levels of agricultural water use creates low summer flows and high stream temperatures to the point where fish kills have been recorded (M. Walsh pers. comm. 2019). The town of Lumby is a large contributor to groundwater extraction for the surrounding area, and water demands are expected to increase in the future (R. Bailey pers. comm. 2019). Due to the extreme deficit of water caused by anthropogenic activities, water extraction and management was deemed to have a high to extreme level of impact on this population, with a medium level of causal certainty surrounding these impacts.

DU9 (MFR-Spring) and DU11 (UFR-Spring) exhibit spring return-timing and tend to utilize streams fed by groundwater and runoff. Therefore, the impacts from groundwater extraction are likely to be higher in DUs 9 (MFR-Spring) and 11 (UFR-Spring) than in DU10 (MFR-Summer), which benefits from stable flows from large lakes. DUs 16 (NTh-Spring) and 17 (NTh-Summer) also experience water extraction for farming and agriculture, though portions of DU17 are also moderated by larger lake outflows.

Ranking

All the DUs upstream of Hope were scored as at levels of low or above because of impacts from flood control in the lower mainland, which would influence the amount and quality of overwintering habitat available for juveniles from those DUs. DU14 (STh-Bessette) was ranked high to extreme due to the amount of water use in this DU, while DU8 (MFR-Portage) was scored medium for the impacts from Seton Dam. DUs 9 (MFR-Spring), 11 (UFR-Spring), 16 (NTh-Spring) and 17 (NTh-Summer) were all scored low to medium because, in addition to the flood control impacts, portions of those DUs are at risk for reduced flows from water extraction. DUs 10 (MFR-Summer) and 7 (MFR-Nahatlatch) are ranked low, as large portions of these DUs are in areas where water extraction is not expected to be a significant threat. The threat scores for DUs 9 (MFR-Spring) and 10 (MFR-Summer), may be interpreted at the upper end of their ranges due to the impacts from hydroelectric facilities on a portion of each DU.

DUs 4 (LFR-Upper Pitt) and 5 (LFR-Summer) are scored low because these DUs are located in areas that have less development for water use and rearing mostly occurs away from the flood controlled lower mainland area. Chinook from DU2 (LFR-Harrison) principally rear in the marshy areas of the Fraser River estuary for approximately six weeks and it is unknown what the impacts from flood control in the lower Fraser has on the estuary and this DU.

Other Ecosystem Modifications

This threat includes other actions that convert or degrade habitat in service of "managing" natural systems to improve human welfare. This includes land reclamation projects, abandonment of managed lands, riprap along shoreline, mowing grass, tree thinning in parks, beach construction, removal of snags from streams, effects on the hydrological regime from forestry and mountain pine beetle, changes in food web composition (IUCN-CMP threat category 7.3)

Modifications to Catchment Surfaces

Modifications to catchment surfaces through forestry, wildfires, agriculture and development are known to impact stream temperature and flow regimes because of vegetation clearing and/or increases in impervious surfaces. Activities that result in modified catchments include: forestry and pine beetle- or other pest-induced forestry, forest fires (also linked with pine beetle impacts and historic forestry practices), agriculture, and urban and rural/industrial development. Altered sediment transport as resulting from forestry and agricultural activities is assessed in Agricultural & Forestry Effluents.

Forestry

Forestry development (e.g. harvesting and replanting) on crown land, as well as private land logging, is a major resource activity throughout many FRC DUs and can impact flow and temperature regimes in a variety of ways. Forestry activities have been prevalent in the central Interior, the Cariboo – Chilcotin and the Omineca regions, impacting all the DUs treated in this RPA to some extent. Extensive logging (e.g. clear-cut logging) within a watershed may lead to reductions in Chinook Salmon carrying capacity through degradation of the stream channel stability, riparian habitat, increased summer stream temperatures, and altered seasonal hydrographs by altering run-off dynamics (Meehan 1991).

Historically, forestry and agriculture practices were associated with extensive removal of riparian vegetation. The effects of riparian vegetation removal on stream temperature and morphology are well documented (Quigley and Hinch 2006; Richter and Kolmes 2005). Changes in flow regime, sediment and large woody debris input can reduce habitat complexity by widening the channel and decreasing undercut bank habitat (Gregory et al. 2008; Hogan and Luzi 2010). Riparian vegetation removal is also known to increase stream temperature (Beschta et al. 1987;

Poole and Berman 2001; Tschaplinski and Pike 2017), impacting Chinook salmon habitat and their benthic invertebrate prey (Quigley and Hinch 2006; Richter and Kolmes 2005; Brett, Clarke, and Shelbourn 1982; Keefer et al. 2018; Shrimpton, Zydlewski, and Heath 2007). Modern forest management practices of healthy timber stands have effectively reduced the impact of forestry on stream temperatures by leaving strips of riparian vegetation (buffers) intact (Beschta et al. 1987; Cole and Newton 2013; Bladon et al. 2018).

Increased peak flows can directly and indirectly impact Chinook Salmon freshwater survival through juvenile displacement, increased competition, removal or crushing of the eggs and increased sediment input downstream (Greene et al. 2005; Lewis and Ganshorn 2007; Alila and Beckers 2001). Seasonal hydrographs may be more variable or peak flows may shift because of the reduction in vegetation that typically moderates run-off and infiltration rates (Meehan 1991; Winkler et al. 2017). Increases in peak flow can also decrease Chinook habitat complexity by removing functioning large woody debris (Tschaplinski and Pike 2017).

In some cases, logging can lead to a decrease in base flow. Lower flows can result from a decrease in fog drip or from a change in tree species composition, usually from coniferous to deciduous species, increasing transpiration (Pike et al. 2010; Lewis and Ganshorn 2007). Replanting after forestry, for example with monocrops of Douglas Fir (*Pseudotsuga menziesii*), may also increase evapotranspiration rates and reduce stream flow relative to the original older, mixed conifer forest that could have been present pre-logging (Perry and Jones 2017). Reduced base flow can negatively affect all life stages by restricting Chinook Salmon habitat extent and conductivity, increasing competition and predation, and degrading water and habitat quality (Beschta et al. 1987; Connor et al. 2002; Lewis and Ganshorn 2007; Zeug et al. 2014).

Fires and outbreaks of insects and forest diseases in the province often trigger large scale salvaging logging operations. Salvage logging typically covers a larger area than conventional cutblocks and can occur right to the stream edge, further impacting hydrological processes. As discussed in section 4.1.5.1 Logging and Wood Harvesting, it is probable that salvage logging will occur in the future, and hence future impacts to catchment surfaces from forest removal are expected.

Wildfires

As noted in section Fire *& Fire Suppression*, forest fires are becoming more frequent as a result of climate change, historic forestry practices, pest infestations, and incidences of human initiated fires (Mote et al. 2003; Wang et al. 2015). Historic wildfires in 2017 and 2018 have led to the loss of over 3 million hectares of forest cover across the Province of BC, notably in the Cariboo-Chilcotin and the Central Interior regions.

The impacts of forest fires are similar to forestry in how they alter flow and temperature regimes, but there can be additional impacts. Wildfires do not follow forestry management rules and can remove all vegetation, including riparian vegetation. As noted in Fire *& Fire Suppression,* removal of forest by fire can increase irradiation levels from the sun that increase stream temperatures until vegetation regrows (Beakes et al. 2014). The loss of vegetation also causes changes to the natural hydrological cycle by increasing runoff and modifying evapotranspiration dynamics (Springer et al. 2015). As well, severe fires have the potential to create hydrophobic soils by burning all organic content (Letey 2001). A greater prevalence of hydrophobic soils may increase the frequency and magnitude of bank erosion from high volume run-off events. Recolonization rates by plants may also be reduced relative to forestry impacted areas from severe burns, which prolongs the impacts of the modified catchment. Widespread, intense fire activity in 2017 and 2018 resulted in the creation of areas of hydrophobic soils that are totally denuded of vegetation and prone to severe erosion, which will likely continue to impact hydrology in DU9 (MFR-Spring) in particular and DU10 (MFR-Summer) to some extent.

Urban and Industrial Development

Urban and industrial development increases the amount of impervious surfaces which can have a number of impacts on salmon. Impervious or semi-pervious surfaces include (but are not limited to) roads, structures with roofs, drainage and sewer systems, and turf and gravel recreational fields. Impervious surfaces alter stream dynamics by increasing the magnitude of peak and low flows due to the reduction of gradual penetration of water into the ground (Booth et al. 2002), which can result in bedload movements that destroy redds, strand fish, and change migration and foraging behaviours. Roads, particularly highways and forest service roads, may also intercept shallow groundwater flow paths and amplify run-off effects at stream crossings (Trombulak and Frissell 2000). These effects are particularly evident in smaller stream systems at forest service road crossings. Bradford and Irvine (2000) found a negative correlation between annual change in recruitment of Coho Salmon and both road density and the proportion of land used in the Thompson River watershed. Urban and rural development, particularly centered around Shuswap Lake, Kamloops, and Merritt, is also increasing.

Although there are many government agencies involved in planning urban and industrial development, this type of activity is not directly under the control of any single government body. An apparent lack of integrated planning for urban, rural, and industrial developments can lead to cumulative alterations in stream hydrology with greater peaks or decreased low flows and produce degraded water quality from urban storm-water runoff. The increase in impervious surfaces can also influence the amount of pollution entering streams, whish is discussed in section Household Sewage & Urban Waste Water.

Linear Development

Linear development involves the straightening and channelization of streams, generally through the construction of structures involved in flood protection, and covers mainly riprapping, dikes, levees, culverts, bridges, and floodgates. These structures lead to reductions in the complexity and diversity of fish habitat, and can isolate critical rearing habitats such as side channels, ponds, and wetlands historically used to a greater extent by FRC. In general, salmonids are known to actively move into seasonal floodplain wetlands to avoid high main-channel flood flows, but reductions in connectivity to and degradation of side-channels and tributaries has the potential to reduce survival and create long-term selection pressures that affect migration patterns (Trombulak and Frissell 2000). Channelization of streams can also reduce the overall amount of habitat due to a reduction in stream length originally produced by bends and forks (Chapman and Knudsen 1980).

Land surrounding the lower Fraser River and its tributaries is highly utilized with urban, industrial, and agricultural developments, much of which (57%) is reinforced with riprap for a variety of functions (Ham and Church 2012). The large, angular stones along the stream bank can lead to changes in stream hydrology and reductions in critical streambank habitat. The placement of riprap prevents lateral streambank erosion, a natural process leading to the development of undercut banks and overhead cover which provides important summer habitat for stream salmonids (Brusven 1986; Beamer and Henderson 1998). Fine-grained stream reaches that are prevented from moving laterally can begin to incise (adjusting downward rather than laterally), which may cause a series of morphological changes: floodplain abandonment, bank steepening and erosion, lowering of the water table, changes in stream bank vegetation, and changes in stream substrate (Schmetterling, Clancy, and Brandt 2011). Preventing lateral stream adjustments also leads to the elimination of large woody debris (LWD) recruitment, the importance of which is well documented for salmonids including Chinook Salmon (Meehan

1991; Mossop and Bradford 2004). Riprap can also reduce shading from the riparian zone and contribute to warmer stream temperatures (Massey 2017), and provide hiding places for predators such as sculpins, that can prey on small juveniles. All DUs are affected by linear development to some degree, either from within their own area where rip-rap is used to stabilize local banks around agriculture and development, or because juvenile and adult FRC use the corridors in the lower Fraser River that are heavily linearized. The exact impacts of linearization and rip-rapping would require intensive research.

Invasive Plants Modifying Habitat

Globally, the abundance of invasive aquatic plants (non-native and competitively dominant species) is highly correlated with decreases in native fish abundance (Gallardo et al. 2016). In British Columbia, invasive aquatic plants are one of the most widespread and numerous groups of invasive species (MOE 2015[19]), though their population level impacts on FRC are unknown. In the lower Fraser River, Reed Canary Grass (*Phalaris arundinacea*) is becoming established along riverbanks and has the potential to modify flows and overgrow sections of streams (Barnes 1999). Relative to other threats, invasive plants are likely having a low impact on FRC, but their extent and effects should be monitored in the future.

Ranking

The threat from the aforementioned ecosystem modifications is pervasive for all FRC DUs. Modifications to catchment surfaces and linear developments are most concentrated in the areas surrounding the lower Fraser River, the migratory corridor in that all DUs must transit through twice in their life and where some FRC reside over winter. A causal certainty of medium was assigned to all FRC DUs for this category, as while there is some evidence linking these ecosystem modifications with declines in productivity, there is little research investigating the direct effects on FRC.

All FRC DUs will be impacted by the loss off off-channel habitat and a shifting hydrological regime due to modifications to catchment surfaces. The degree to which ecosystem modifications will impact FRC Chinook is uncertain, but at the very least a low impact is anticipated. Therefore, a low to medium level of impact was assigned for all DUs, with the exception of DU14 (STh-Bessette) and DU9 (MFR-Spring).

DU14 (STh-Bessette) was deemed to be most threatened from this category due to the high degree of modification along stream banks and impervious surfaces within the DU area relative to historical conditions. DU14 (STh-Bessette) is the most temperature and flow-sensitive stream discussed in this RPA, and as such, ecosystem modifications that alter these characteristics may have severe impacts on FRC within the DU area. This threat is assigned a high to extreme range for level of impact, as while we cannot assuredly predict the impacts to be extreme, the expert panel anticipated the impacts could be in the upper bounds of this range.

DU9 (MFR-Spring) was assigned a medium to high level of impact from this threat to capture both the uncertainty and the possible cumulative impact of all of the aforementioned activities. There have been significant impacts within this DU as a result of the changing hydrological regime due to forest cover removal through logging, fires, and pine beetle infestations; some of these changes have already occurred, and more are anticipated to occur in the near future. Future changes to aquifers and groundwater will lead to an overall destabilization of many systems within this DU, in addition to an overall decrease in habitat complexity. While the

[19] BC Ministry of Environment (MOE). 2015. Status of Invasive Species in BC. BC Ministry of Environment.

threats workshop participants do not predict a decline as high as 70% as a result of this threat, it was determined that the medium level impact did not address this potential for risk sufficiently.

Table 40. DFO threats assessment calculator results for impacts from Fire and Fire Suppression for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Fire & Fire Suppression	DU7	Likely	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Recurrent	Negligible
	DU9	Likely	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU10	Likely	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Recurrent	Negligible
	DU11	Likely	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU14	Likely	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU16	Likely	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU17	Likely	Negligible	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	For DU2, DU4, DU5, and DU8 this is not anticipated to be a threat.							

Table 41. DFO threats assessment calculator results for impacts from Dams and Water Management for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Dams & Water Management	DU2	Known	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	High-Extreme	Medium	High-Extreme (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 42. DFO threats assessment calculator results for impacts from Other Ecosystems Modifications for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Other Ecosystems Modifications	DU2	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Medium- High	Medium	Medium-High (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	High-Extreme	Medium	High-Extreme (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive

4.1.8. Invasive & Other Problematic Species & Genes

4.1.8.1. Invasive Non-Native/Alien Species

This threat is defined as harmful plants, animals, pathogens and other microbes not originally found within the ecosystem(s) in question and directly or indirectly introduced and spread into it by human activities (IUCN-CMP threat category 8.1).

Aquatic invasive species (AIS) have been described as one of the most prevalent threats for Canadian at-risk freshwater fish species (Dextrase and Mandrak 2006), having the potential to reduce the abundance and diversity of native fish species through competition, predation, or introduction of new pathogens (Cambary 2003). The following sections discuss both freshwater and estuarine/marine AIS that pose some level of threat to FRC, in addition to our current knowledge of threats from non-native pathogens.

Freshwater AIS

Thirteen non-native freshwater species have established populations within the Fraser River Basin, yet the majority of these species appear to pose little to no risk to migrating salmonids (Brown et al. 2019). Region-specific assessments of distribution (Runciman and Leaf 2009) and biological risk (Bradford et al. 2008a, 2008b; Tovey et al. 2009) have been completed in the past for several AIS in British Columbia including Yellow Perch (*Perca flavescens*), Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), Northern Pike (*Esox lucius*), Pumpkinseed (*Lepomis gibbosus*), and Walleye (*Sander vitreus*). These species became established in British Columbia as a result of natural dispersal in transboundary watersheds via introductions to Washington and Idaho, deliberate introductions by government agencies in Canada since the 1980s, and unauthorized introductions in recent years (Arbeider et al. 2019). Of greatest concern to FRC are three spiny-rayed fish: Largemouth Bass, Smallmouth Bass, and Yellow Perch.

The following three sections on the potential interactions between FRC and Largemouth Bass, Smallmouth Bass, and Yellow Perch borrow heavily from Part I of the Pre-COSEWIC review of FRC Conservation Units (Brown et al. 2019).

Largemouth Bass is a voracious piscivore that will consume salmonid juveniles (Brown et al. 2009b). They have not become established in the interior Fraser River Basin, but now inhabit the mouths of tributary streams, backwaters, and sloughs throughout the lower Fraser River. A fish-wheel operating in the main-stem Fraser River above Mission BC in 2009-2010 caught 32 Largemouth Bass (Brown et al. 2019). Although the number of bass residing within the lower Fraser River is unknown, the species is well-established and thriving. Largemouth Bass can consume large numbers of juvenile Chinook as they migrate to sea, thus there is the potential for impacts on FRC in many DUs.

Smallmouth Bass reside in the littoral zone of lakes and slower moving rivers (Brown et al. 2009c). They can also have a significant impact on native communities through predation on small-bodied fish. There is considerable literature that shows Smallmouth Bass prey on juvenile Chinook, although the ultimate effect on salmonid abundance varies (Brown et al. 2009c; Counihan et al. 2012). In 2006, Smallmouth Bass were found in Beaver Creek, a tributary of the Quesnel River, leading to the intervention by the Province of BC in 2007 (L.M. Herborg, Province of British Columbia, Victoria, BC, pers. comm. 2019); despite these mitigation efforts, it is likely Smallmouth Bass will eventually move downstream into the Quesnel River, potentially reducing Chinook productivity in the Quesnel drainage (Tovey et al. 2009; DFO 2011).

Yellow Perch is a highly adaptable species that utilizes a wide range of habitats (Brown et al. 2009a). They utilize the lacustrine-limnetic habitat, although in larger lakes, they utilize the littoral zone. Perch juveniles tend to bottom-feed, and larger perch will consume fish eggs and fish (Brown et al. 2009a). When introduced into small lakes, Yellow Perch can have severe impacts on native fish species, largely as a result of competition for food (Bradford et al. 2008a; Brown et al. 2009a). Nine small interior lakes were rotenone treated during 2008-2010 to eradicate the populations of Yellow Perch (L.M. Herborg, Province of British Columbia, Victoria, BC, pers. comm. 2019). There is much concern for the range expansion of Yellow Perch that would cause greater impacts on native fish populations, including interior Chinook Salmon within the Thompson River system (DFO 2010). Once these invasive species redistribute and enter into larger water bodies such as Shuswap Lake, they put all fish species at risk and are very difficult to eliminate. Although they may not cause extinction, they can alter natural patterns of species diversity and reduce native fish productivity.

While not a current threat to FRC, Northern Pike (subsequently referred to as Pike) may pose significant future threats if further expansion into BC occurs. Pike are voracious opportunistic predators, and invasive populations can impose significant top-down pressure on native fish community structure through predation and competition for resources. Pike have been shown to preferentially prey on juvenile salmonid species (Rutz 1999), and invasive populations in Southcentral Alaska have been linked to significant declines in once abundant salmon populations (Haught and von Hippel 2011). Juvenile Chinook and Coho Salmon were shown to dominate the diets of invasive Pike in some of these streams (Sepulveda et al. 2013), suggesting serious impacts on FRC if establishment were to occur in the Fraser River Basin. Pike have recently colonized the Columbia River and are currently distributed between the Hugh L. Keenleyside Dam near Castlegar, BC, and the Grand Coulee Dam at the lower reach of Lake Roosevelt in WA. A Pike was recently (Nov 2018) captured within 10 miles of the Grand Coulee Dam indicating there is a real threat of Pike continuing to spread downstream in the Columbia (Francovich 2018[20]). If Pike move beyond the Grand Coulee Dam they could spread into systems such as the Okanagan River and further into BC. See Doutaz (2019) for a detailed synthesis of Pike biology and distribution in the Columbia River.

While not yet present in BC, the establishment of Zebra (*Dreissena polymorpha*) and Quagga (*Dreissena rostriformisbugensis*) mussels pose a serious threat to aquatic ecosystems and infrastructures in the province. Dressenids are known as ecosystem engineers and couplers of benthic and pelagic habitats (Crooks 2002; Karatayev et al. 2002), and can restructure energy and nutrient fluxes throughout ecosystems producing fundamental changes in food web structure (Higgins and Vander Zanden 2010). Dressenids have a short maturation time (1-2 years) and high fecundity (>1 million eggs/female in each spawning event), with tremendous dispersal abilities at all life stages (Ludyanskiy et al. 1993), compounding the threat to not only the Fraser River basin, but the entire province of BC. The threat of Dressenid mussels was not scored for this category, but it should be noted as a potential future threat due to the severity of risk these mussels pose if established.

Estuarine/Marine AIS

The European Green Crab (*Carcinus maenas*) has been introduced to coastal ecosystems around the globe, including the Pacific Coast of North America, where they are known to have negative impacts on eelgrass habitats (Howard 2019). Eelgrass meadows provide critically important habitat for juvenile Chinook Salmon, with habitat features that provide both cover and foraging opportunities in the nearshore environment (Kennedy et al. 2018). Green Crabs can both shred blades and dislodge whole plants through bioturbation while foraging for prey,

[20] Francovich 2018 – News article for *The Spokesman Review: “Invasive northern pike found 10 miles from Grand Coulee Dam, Spokane Tribe catches 45-inch fish”.* (Accessed July 22, 2020)

causing rapid degradation of eelgrass meadows with high crab densities (Howard 2019). There have been significant losses of eelgrass meadows along the Atlantic coast linked to Green Crab abundance. A study conducted in Placentia and Bonavista bays, Newfoundland, reported reductions of eelgrass cover of 50% between 1998 and 2012, and up to 100% in areas with the longer-established and higher-density Green Crab populations. Green Crab is currently found along the entire West Coast of Vancouver Island from Barkley Sound to Winter Harbour with isolated, potentially ephemeral, populations in the Central Coast (DFO 2019[21]). A controlled enclosure study conducted in Barkley Sound demonstrated 73-81% more rapid reductions of eelgrass cover in the presence of high densities of Green Crabs when compared to low density or control treatments (Howard 2019). There have also been reports of Green Crab in the Salish Sea, with detections in Sooke Basin, Beecher Bay, Esquimalt Lagoon, Witty's Lagoon, Salt Spring Island (2 locations), and Boundary Bay (P. Menning, pers. comm. 2019). DNA analysis is currently underway to determine the source population for these early invaders, the results of which will potentially help inform what future distribution expansions of Green Crab may look like in BC.

Eelgrass meadows in the Fraser estuary have already been highly impacted from historical activities, and further loss of these habitats through invasion of Green Crabs could exacerbate impacts on juvenile FRC rearing in these habitats (i.e. Chinook from DU2 LFR-Harrison). The timing of invasive species establishment and subsequent impact on FRC has been identified as a significant knowledge gap for all DUs and should be considered for future mitigation planning.

Introduced Pathogens & Viruses

This category does not include naturally occurring pathogens and viruses but activities associated with the introduction of non-native diseases may increase the prevalence of naturally occurring disease in FRC.

This threat mainly pertains to new pathogens and diseases whose introduction has been linked to salmon farming. Piscine Orthoreovirus (PRV) is a ubiquitous and highly prevalent virus of net-pen farmed salmon, and is transmissible to wild fish of all five species of Pacific salmon (and Steelhead Trout) (Polinski and Garver 2019). PRV was likely introduced to the Pacific Ocean in the 2000s (DFO 2018b[22]), possibly from and likely spread via the presence of farmed Atlantic salmon (*Salmo salar*) in open-net pens. There are three distinct genotypic groups of PRV, but only PRV-1 has been observed in BC. This strain has been associated with Heart and Skeletal Muscle Inflammation (HSMI) in Atlantic salmon (*Salmo salar*) and Jaundice Syndrome in farmed Chinook salmon (Di Cicco et al. 2017; Miller et al. 2017); however, both conditions appear rare, likely have complex etiologies, and have not yet been reported in wild Pacific salmon (Polinski and Garver 2019). Across multiple independent surveys of wild Pacific salmon and trout, PRV-1 was consistently detected in Chinook Salmon (6%) and Coho Salmon (9%) as compared to Pink (4%), Sockeye (1.4%), and Chum salmons (<1%), and Steelhead Trout (<1%) (Polinski and Garver 2019). While PRV-1 has been shown to be transmissible to Chinook Salmon, experiments attempting to transmit Jaundice Syndrome in association with PRV were unsuccessful despite passage of PRV (Garver et al. 2016). Therefore, PRV is likely to pose a negligible threat to wild populations of FRC.

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[21] DFO. 2019. European Green Crab. (Accessed July 22, 2020)

[22] DFO. 2018. Piscine Orthoreovirus (PRV) and Heart and Skeletal Muscle Inflammation (HSMI). (Accessed March 23, 2020)

Contained populations (i.e. in net-pens) affected by disease present a potential risk to wild fish residing in the system receiving water from an infected site because it may amplify a normally present pathogen (Brannon et al. 1999; Brown et al. 2019). The risk of disease transmission is also increased when individuals are exposed to physical, chemical or biological pressures that may compromise their resistance (Brown et al. 2019). However, there is currently little evidence to support the risk of transmissions from fish farms to wild populations.

Ranking

Due to the different life history strategies employed by ocean-type and stream-type Chinook Salmon, the threat to DU2 (LFR-Harrison, ocean-type) is largely from AIS within estuarine and marine habitat. There are many invasive species in the lower Fraser River that can have impacts on DU2 (LFR-Harrison) if out-migrating smolts are encountered during their migration to the Fraser River estuary, yet it is currently unknown what these impacts are. Of particular concern for DU2 (LFR-Harrison) is the potential future colonization of Green Crab in the Fraser River estuary. The threat of Green Crab invasion to FRC is high, but one cannot predict when or if it will occur, or what the level and timing of impacts will be.

The remaining DUs are more threatened by region-specific freshwater AIS in habitats where juvenile fish are rearing prior to, or residing during ocean migration. The threat of freshwater AIS was deemed to be pervasive for both DUs 4 (LFR-Upper Pitt) and 5 (LFR-Summer), as all habitat within these DUs lies within the lower Fraser River. All fish from these DUs will likely encounter some of the invasive species within the lower Fraser River. The threat extent of AIS for the remaining stream-type DUs was considered to be restricted, as while some upstream fish will disperse into the lower Fraser River, the proportion exposed will likely be small. There are Eastern Brook Trout (*Salvelinus fontinalis*) within DUs 16 (NTh-Spring) and 17 (NTh-Summer) in the North Thompson River, although there is currently very limited known habitat overlap with FRC. The impacts of AIS were therefore deemed to be either low or negligible with some uncertainty.

There are likely some impacts on FRC from disease transmission between contained salmon and wild Chinook Salmon, yet a definitive cause and effect relationship has not been shown. This threat was therefore not scored in this report.

4.1.8.2. Problematic Native Species

This threat category includes harmful plants, animals, pathogens, and other microbes that are originally found within the ecosystem(s) in question, but have become "out-of-balance" or "released" directly or indirectly due to human activities (IUCN-CMP threat category 8.2).

Pinniped Predation

Predation by pinnipeds has been identified as a potentially major source of mortality for Chinook Salmon, particularly for populations with small run sizes (Brown et al. 2019). The following sections on pinniped predation lean heavily on Brown et al. (2019), the *Pre-COSEWIC review of southern British Columbia Chinook Salmon conservation units, Part 1: Background*.

Harbour seal abundance along the Pacific coast has increased dramatically since harvests ended in the late 1960s (Brown et al. 2013). Consistent with trends south of the border, harbor seal abundance increased in the Strait of Georgia at a rate of 11.5% per year after the mid-1970s before stabilizing in the mid-1990s at about 40,000 animals (Brown et al. 2019). This trend is typical of the BC coast generally, with current total abundance estimated at 105,000 animals (Olesiuk 2010). Juvenile salmon, including Chinook Salmon, are preyed upon by Harbour Seals (Thomas et al. 2016), and can occur in marine areas as well as in rivers (Brown et al. 2019). The constrained morphology of a river can increase vulnerability to highly mobile and agile predators such as seals (Brown et al. 2019). Predation rates of downstream migrating juveniles can be significant in areas that are artificially illuminated at night such as bridge crossings (e.g. Puntledge River, Olesiuk et al. 1996).

Steller Sea Lion abundance in BC has also increased approximately three-fold in BC since harvesting ended in the late 1960s (Brown et al. 2013). Current abundance in BC (based on pup production) and adjacent waters of Southeast Alaska is approximately 60,000 animals, which is considerably greater than the estimated abundance for the early 1900s (Brown et al. 2019). Steller Sea Lions range widely in coastal waters, but during summer the majority congregate at traditional breeding rookeries, the largest of which are found in the Scott Islands off the north end of Vancouver Island, and at Forrester Island, Alaska just north of Haida Gwaii (Queen Charlotte Islands) (Brown et al. 2019). Diet studies using prey remains found in scats collected at these rookeries and other haul-out sites indicate that Steller Sea Lions feed on a variety of fish and cephalopods, and that salmon constitutes a significant portion of their diet particularly in summer and fall. Salmonids have been estimated to represent about 10% of their overall diet (Olesiuk et al. 2010). Preliminary studies on the salmonid species composition of Steller Sea Lion diets indicates that Chinook Salmon may represent a significant component of salmonids consumed (Olesiuk et al. 2010).

The annual biomass of Puget Sound Chinook Salmon consumed by pinnipeds was estimated to increase from 68 to 625 metric tons between 1970 and 2015 (Chasco et al. 2017). By 2015, pinnipeds were estimated to have consumed double that of resident killer whales (RKWs) (RKWs discussed in section 4.3, Natural Limiting Factors), and six times the combined commercial and recreational catches (Brown et al. 2019). Recent research by Nelson et al. (2018) evaluated the relationship between two covariates, seal density and hatchery abundance, and Chinook Salmon productivity for 20 ocean-type type (fall return timing) Chinook populations originating from watersheds in the Salish Sea and Washington coastal areas. The study found significant negative relationships between Chinook production and harbour seal density in 14 of the 20 populations (DU2 included in this analysis). While not FRC specific, these studies highlight the threat of pinniped predation, particularly on DUs whose abundances are already significantly depressed.

Parasites & Disease

Parasitism and disease are natural components of ecosystems and are capable of shaping population dynamics through regulation of host population sizes, trophic interactions, competition and biodiversity (Price 1980; Minchella and Scott 1991; Bass et al. 2017). Parasites and disease may be associated with chronic infections that can impact behavior, condition, and performance, that can cause fish to be less capable of continued migration and/or more vulnerable to predation or starvation (Miller et al. 2014) Many of these parasites are opportunistic and do not impact survival unless fish are also stressed by other factors impacting immune system function, such as poor water quality or toxins (Barton et al. 1985; Miller et al. 2014). Pacific salmon are semelparous, and mature, senesce, and starve while migrating back to freshwater, which reduces their condition and ability to fight infection, and makes them especially vulnerable to additional environmental stressors and disease (Miller et al. 2014). Immunosuppression induced by maturation hormones (Pickering and Christie 1980) may also contribute to enhanced susceptibility by even opportunistic parasites or those previously at a carrier state (Miller et al. 2014).

It is difficult to study the prevalence and impact of pathogens and disease in wild salmon populations as salmon inhabit geographically large environments, and mortalities often go unnoticed due to predation and disappearance (Bakke and Harris 1998). Much of our current knowledge of disease in wild salmon populations comes from aquaculture, where stressful conditions and high densities of fish promote infections and increase disease transmission (Bakke and Harris 1998; Bass et al. 2017). While our current understanding of these dynamics is limited, disease has been identified as a potential driver of declines in sockeye salmon in the Fraser River (Cohen 2012), suggesting similar potential impacts on FRC.

Salmonid fish are host to many infectious agents including viruses, bacteria, fungi, protozoans, helminths, and arthropods (Thakur et al. 2018). Recent research conducted by Bass et al. (2017) surveyed 82 adult Chinook Salmon returning to the Fraser River (6 of which were of Harrison origin) for prevalence and load of microparasite taxa. This study identified 20 different microparasites across six sampling events, four of which had not been previously described in Chinook Salmon and four of which had not been detected in any salmonid in the Fraser River. The authors identified *Cryptobia salmositica, Flavobacterium psychrophilum,* and *Ceratonova shasta* as having some positive associations with physiological indices suggestive of morbidity. The authors also identify that the Chinook Salmon sampled were migratory survivors, and therefore their results did not reveal which microparasites may cause mortality during migration or at other life stages. While this study did not directly determine linkages between microparasites and disease, it identified infectious agents with the potential for impact using correlations between parasite load and blood parameters indicative of stress, osmoregulation, maturation and senescence. Bass et al. (2017) provide detailed descriptions of key findings within each microparasite taxon detected in abundance.

The previous study by Bass et al. (2017) focused on mature salmon close to spawning, and all populations were from sub-yearling stocks. Tucker et al. (2018) surveyed pathogenic agents in juvenile FRC within their first year of ocean residence, contrasting the presence and load of infectious agents in yearling and sub-yearling populations. Yearling and sub-yearling fish were found to carry different agent profiles in terms of diversity, abundance, and origin of individual agents, possibly reflected by variations in residency patterns in near-shore and offshore environments, and the resulting differences in exposure to infectious agents. The authors identified 11 potential pathogens that could be associated with FRC mortality, and 5 of these pathogens were associated with yearling stocks exclusively. While this study also did not find direct linkages between pathogens and disease, it highlights the complexity of disease dynamics in FRC due to their variable life-histories and the need for future research.

Ranking

The threat from pinniped predation is pervasive for all FRC DUs, as all Chinook from these populations transit habitat occupied by pinnipeds. DUs within the lower Fraser River (DU2 (LFR-Harrison), DU4 (LFR-Upper Pitt), and DU5 (LFR-Summer)) may be the most threatened by pinniped predation since they occupy and transit considerable habitat that overlaps with these species, particularly harbour seals. Year-round seal colonies have been identified in the lower Fraser River and Harrison River/Lake which could pose a significant threat to Chinook present in these areas. There are numerous log storage facilities and sort-yards in these areas that likely attract seals, as they provide haul-out habitat and increase prey abundance through the attraction of inbound migrating Chinook Salmon seeking refuge. While it is currently unknown what the extent of seal predation is on FRC, it is expected to pose a low to medium risk for DUs 2, 4, and 5 in the lower Fraser River.

While not mentioned previously in this section, DU14 is at additional risk of predation from native salmonid species, including large rainbow and bull trout present in Shuswap and Mable lakes. This predation may be exacerbated by their earlier return when compared to other Shuswap DUs (not discussed in this RPA), which may focus attention on these individuals during their initial period of residence (see threats calculator in Appendix G). During the threats workshop concern was raised about the potential impact of river otters in some populations, especially in smaller watersheds where returning adult fish are confined to pools. The impacts associated with River Otters are uncertain, but may be an issue in DU14, DU16 and DU17, meaning the risk may be at the higher end of the assigned risk category for those DUs.

Microparasites are ubiquitous in the environment, and as such, all FRC encounter and are host to a variety of agents that can lead to infection and disease. Infections and disease affect all FRC DUs to some degree, yet there is currently a large amount of uncertainty surrounding the direct impacts on productivity and survival of FRC.

4.1.8.3. Introduced Genetic Material

The threat from introduced genetic material includes human altered or transported organisms or genes, which encompasses the genetic effects from hatchery salmonids (IUCN-CMP threat category 8.3).

The threat to FRC from introduced genetic material involves enhancement and hatchery activities. Enhancement and hatchery programs can change genetic diversity (typically through reduction) in hatchery-origin fish by producing cohorts from smaller gene pools and exposing them to different selective (and unnatural) pressures found in hatchery environments (Gardner et al. 2004; Grant 2012). Hatchery-origin fish can then interbreed with wild stocks, leading to a decrease in fitness, and limiting population adaptability in future generations due to the reduction of genetic diversity (Waples 1991; Gardner et al. 2004). There is growing empirical evidence suggesting there are progressive, intergenerational declines in fitness in wild populations when hatchery-origin fish are present (Fleming 2002; Berejikian and Ford 2003; Gardner et al. 2004; Grant 2012). Waples (1999) outlines how risks posed by hatcheries can never be fully avoided, even with best management practices. Since approximately 40% of the total biomass of immature and adult salmon in the North Pacific (between 1990-2015) is comprised of hatchery fish (Ruggerone and Irvine 2018), it is likely there is some level of negative interaction as a result of introduced genetic material.

The introduction of genetic material is either unknown or not considered to be a threat for the majority of FRC DUs, particularly for stream-type populations where levels of hatchery supplementation are relatively low, therefore these populations were not assigned a score. DU2 (LFR-Harrison) is likely at the greatest level of risk from the introduction of genetic material due to the high degree of hatchery supplementation for the more abundant ocean-type Chinook stocks in BC and along the Pacific coast. Hatchery-origin Chinook Salmon from the Cowichan River and Robertson Creek have been observed on spawning grounds in the Harrison River, indicating that the straying of hatchery Chinook from outside the DU may be a noteworthy source of introgression. It has been noted that Chinook from DU2 (LFR-Harrison), which were historically comprised of all white-fleshed individuals, now exhibit red-colored flesh in approximately 5-10% of individuals (R. Bailey, pers. comm. 2019) suggesting the introduction of foreign genes or genetic drift/mutation. Recent unpublished information supports the latter, as red-fleshed Chinook sampled from DU2 were found to be genotypically identical to white-fleshed variants, suggesting no introduction of foreign genes has occurred (R. Withler pers. comm. 2019). While there is considerable uncertainty surrounding the introduction of genetic material from other hatchery stocks, DU2 was assigned a Low level of impact due to the observations of straying hatchery Chinook from outside the DU.

There is also some concern for DU9 due to hatchery activities conducted by Spruce City Wildlife in Prince George, where 20 year old cryo-preserved milt from Endako River Chinook were crossed with current brood stock (R. Bailey, pers. comm. 2019). While the level of impact from these activities is unknown, there is high causal certainty that there maybe some effect through the re-introduction of genes that were selected out over that period of time.

While not considered in the threat ranking, straying of FRC from DUs that spawn above the Big Bar slide may lead to future introductions of genetic material into other DUs. Observations in 2019 indicate fish unable to migrate upstream of the slide dispersed into other downstream locations such as the Bridge, Nahatlatch, and Stein, where adult fish in poor health condition were observed by the DFO resource management program (C. Parken 2019 pers. comm.). If the Big Bar blockage is not resolved, the straying of fish from upstream DUs into other systems may be a future source of genetic introgression that could lead to reduced fitness or survival.

Table 43. DFO threats assessment calculator results for impacts from Invasive Non-Native & Alien Species for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Invasive Non-Native & Alien Species	DU2	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU4	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU8	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU9	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU10	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU11	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU14	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU16	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU17	Known	Negligible	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Restricted

Table 44. DFO threats assessment calculator results for impacts from Problematic Native Species for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Problematic Native Species	DU2	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 45. DFO threats assessment calculator results for impacts from Introduced Genetic Material for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Introduced Genetic Material	DU2	Known	Low	Low	Low (2)	Historical/ Current/ Anticipatory	Continuous	Negligible
	DU9	Known	Unknown	Low	Unknown (2)	Historical/ Current/ Anticipatory	Continuous	Negligible
	For DU4, DU5, DU7, DU8, DU10, DU11, DU14, DU16, and DU17 this is not anticipated to be a threat.							

4.1.9. Pollution & Contaminates

IUCN-CMP threat category 9.6, Excess Energy, was not included in this section as there is likely no impact on FRC.

Much of the information in the following sections on pollution were summarized in Arbeider et al. (2019) for Interior Fraser coho salmon. The information provided in their report is highly relevant to FRC due to the considerable habitat overlap within the Fraser River drainage.

Threats from pollution include introduction of exotic and/or excess materials or energy from point and nonpoint sources, including nutrients, toxic chemicals, and/or sediments. Many sources exist for the Fraser River drainage, therefore pollution is broken into multiple categories which include: Household Sewage & Urban Waste Water; Industrial & Military Effluents; Agriculture & Forestry Effluents; Garbage & Solid Waste; and Air-Borne Pollutants. Contaminants from within these categories include suspended solids, road salts and sand, ammonia and other nitrogen-based chemicals, phosphorus-based chemicals, heavy metals (e.g. copper, zinc, arsenic, etc.), phenols, poly-aromatic hydrocarbons (PAHs) and other hydrocarbons, endocrine-disrupting chemicals (e.g. hormones like estrogen, plasticizers like phthalates and phenolic compounds, some heavy metals like cadmium), pesticides, herbicides, and organohalogens (e.g. polychlorinated biphenyls (PCBs)). Many of these contaminants are generated from multiple sources and accumulate as mixtures in the environment, therefore the effects from each threat category on FRC are extremely difficult to ascertain from one another. In this section the potential effects of contaminant exposure on FRC are first discussed, followed by known sources of pollution from individual categories and their predicted threat to FRC.

Many contaminants are persistent in the environment, may travel long distances, and have a tendency to accumulate in sediments and food chains from multiple sources. For example, persistent organic pollutants (POPs) such as PCBs, PAHs, and other organohalogens (e.g. DDT and dioxin) from industrial and agricultural discharge from before the 1980s are still present in Fraser River sediments (higher concentrations in lower Fraser River), and were even found in burbot (*Lota lota*) in Chilko, Nicola, and Kamloops lakes (Garette 1980; Gray and Tuominen 1999). In the Nechako River POPs have been detected in sediments of the mainstem and most of its tributaries (Owens et al. 2019), and historical use of other POPs (e.g. dieldrin, HCHs, chlordanes, endosulfans and toxaphene) in the basin has been shown through detection in fish muscle tissues (Raymond and Shaw 1997). PCB concentrations may be highest in estuaries due to sediment deposition by rivers, but persistent organic pollutants (POPs) have also been found in the headwaters of the Fraser River (Gray and Tuominen 1999). The likely source of these POPs at higher elevations, is long range atmospheric transport and deposition coupled with the release of historic deposits of contaminants from melting glaciers and permanent snowfields. These contaminants are not only from local sources; transport time of atmospheric contaminants from Asia to North America is estimated to be as little as 5-10 days (Ross et al. 2013). In a warming global climate, the release of contaminants from glacial deposits into headwaters may increase and expose younger more vulnerable stages of FRC to POPs. Additionally, PCBs and other POPs are still present in consumer products, and even though they are produced at much lower rates, their persistent nature allows them to accumulate in environments.

FRC are particularly susceptible to the effects of contamination. Extensive migrations, physiological transformations, and rapid growth rates lead to high rates of exposure and accumulation from many sources (Ross et al. 2013). FRC spend the majority of their life in the pelagic marine environment where they undergo the majority of their growth (95%), and where bioaccumulation of contaminants may be greatest (Healey 1991; Ross et al. 2013; COSEWIC

2017). Cullon et al. (2009) estimate that 97-99% of organic pollutants accumulated in Chinook Salmon tissue samples were acquired while at sea. Adult salmon then migrate back to freshwater spawning grounds where fish may undergo up to 95% reductions in total lipid reserves, exposing them to potentially high levels of sequestered contaminants in fat tissues (Hendry and Berg 1999; Debruyn et al. 2004; Kelly et al. 2011). This exposure can lead to impairment of salmonid olfactory function, migratory behaviour, and immune system function, which may reduce individual survival (Casillas et al. 1997), but can also reduce reproductive success and productivity of a population (Kelly et al. 2011). The effects of pollutants on marine fish populations are difficult to distinguish unless fish kills occur directly, yet sublethal effects of toxic exposures have been implicated as important factors in population decline (Spromberg and Meador 2006).

A variety of pharmaceuticals, personal care products, metals, and other contaminants have been shown to affect fish at low concentrations (Fairchild et al. 1999; Daughton and Brooks 2011; Schultz et al. 2012; Saaristo et al. 2017). The toxic responses of fish to these chemicals is poorly understood, because many contaminants accumulate as mixtures and may have synergistic effects (Meador et al. 2018)). There is evidence that common urban contaminants such as PAHs and PCBs are immunotoxicants in juvenile salmon at environmentally low concentrations (Arkoosh et al. 1991, 1998, 2010; Bravo et al. 2011), making them more susceptible to fatal infections from common pathogens found in the environment (Meador 2014). Heavy metal contaminants are known to affect adult fish by increasing pre-spawn mortality rates (Feist et al. 2011; Scholz et al. 2011) and juvenile salmon through chemosensory deprivation at low concentrations, potentially leading to mortality at higher concentrations (Sandahl et al. 2007).

Few studies have examined the effects of pollutants in FRC; however, considerable work has been conducted in the US on ocean-type Chinook Salmon in Puget Sound. Meador et al. (2014) reported juvenile ocean-type Chinook Salmon migrating through contaminated estuarine habitat in Puget Sound had a 45% lower rate of survival when compared to juvenile Chinook transiting through uncontaminated estuaries. The lowest survival rates mostly occurred in estuaries with wastewater inputs into the estuary itself, or into near-shore areas occupied by juvenile Chinook Salmon before migration to open water. A more recent study by Meador et al. (2018) reported exposure of juvenile Chinook Salmon to urban effluents in estuarine habitat resulted in metabolic dysfunction that appeared to mimic starvation. While the authors conclude it is unknown what combination of contaminants cause these responses, blood chemistry, condition factor, and total lipid content, measurements suggest this metabolic response was indeed contaminant-induced. While not FRC specific, the results of these studies suggest that similar effects may occur for FRC as the lower Fraser River is a migratory bottleneck for all DUs, and FRC migrate through this area twice in their lifetime. These effects may be particularly pronounced for DU2 as they immediately migrate to and rear in the Fraser River estuary following emergence where they are exposed to the sum of contamination from the entire drainage for the longest duration of time. Further to this, many of the Chinook from DU2 disperse into and rear in habitat in Puget Sound where they encounter additional high levels of contamination through their diet, such as from pacific herring and other oceanic fishes, which are highly contaminated in Puget sound (West et al. 2008). Puget Sound herring were found to be 3-9 times more contaminated with PCBs when compared to Strait of Georgia herring, and 1.5 to 2.5 times more contaminated with DDTs (West et al. 2008). Harrison Chinook collected in Puget Sound contained higher concentrations of POPs than other FRC DUs because of their time spent foraging in the Salish Sea and the Puget Sound (O'Neill and West 2009; Arostegui et al. 2017). Future research on the many sources of pollution in the Fraser River drainage is needed to better mitigate the effects of contaminates and to reduce their introduction into the environment, and has been identified as a major knowledge gap that needs to be addressed for future recovery planning.

One lesser explored aspect of pollution with respects to FRC is light pollution. In general, migration of Pacific salmon can be slowed or stopped by the presence of artificial lights making them more vulnerable to capture by predators (Tabor et al. 2004; Nightingale et al. 2006). While not FRC-specific, Chinook salmon exposed to constant light have been shown to decrease smoltification and increase the deterioration in body condition associated with smoltification (Hoffnagle and Fivizzani 1998). This may occur due to the synchronization of downstream migration with the new moon, although it is possible that the lunar timing of downstream migration is stock dependent (Perkin et al. 2011). Light pollution may also affect FRC indirectly. Light is an important cue for both predator avoidance and feeding in freshwater systems, and light pollution may result in altered food webs in lentic systems leading to increased algal biomass as zooplankton spend less time in the upper euphotic water column feeding on algae (Moore et al. 2000, 2006; Perkin et al. 2011). Artificial lights near streams have also been shown to change the behavior of adult aquatic insects as they disperse through the terrestrial environment (Perkin et al. 2011), and riparian vegetation exposed to streetlamps, particularly incandescent or high pressure sodium luminaires, may have longer growing periods leading to earlier leaf-out and later leaf fall times than those in darker environments (Cathey and Campbell 1975). The effects of light pollution on FRC, particularly at the DU level, are currently unknown for FRC therefore it was not considered in any of the following pollution categories.

4.1.9.1. Household Sewage & Urban Waste Water

This section includes threats from water-borne sewage and non-point runoff from housing and urban areas that include nutrients, toxic chemicals and/or sediments (IUCN-CMP threat category 9.1).

The area surrounding the lower Fraser River is highly concentrated with urban development, and as such, the surrounding area generates considerable sewage and wastewater that enters the Fraser River and its tributaries. The highly impermeable urban landscape of Metro Vancouver and its extensive network of plumbing outflows divert effluents directly through sewer systems or combined sewer outfalls (CSOs), or through wastewater treatment plants (WWTPs) including those at Annacis Island (Delta), Lulu Island (Richmond), Iona Island (Richmond), Lions Gate (West Vancouver), and NW Langley (Langley) in the lower Fraser River. Some of these facilities have been upgraded to reduce the amount of contaminants in discharge and to increase capacity to accommodate the human population in Metro Vancouver, yet when wastewater volume exceeds working capacity, these effluents will bypass treatment plants through CSOs directly entering the Fraser River. In 2016, Metro Vancouver released over 30,000,000 cubic meters of untreated sewage in the Fraser River, making BC the province that consistently has the highest outflow volume in Canada (Cruickshank 2018[23]; Li and Cruickshank 2018[24]). Other sources of urban contaminants include street-side sewer systems are not diverted through wastewater treatment plants, which can have adverse effects on smaller systems and result in die-offs of juvenile Chinook (D. Hussey, pers. comm. 2019). Heavy metals, such as copper from vehicles, can accumulate on roads and then enter CSOs. Dust from roads and highly trafficked areas can also act as a vector of fine sediments and contaminants (e.g. PAHs and heavy metals) to aquatic systems (Gjessing et al. 1984). Although

[23] Cruickshank 2018 – News article for The Star Vancouver: *"Untreated sewage pollutes water across the country"*. (Accessed July 22, 2020)

[24] Li and Cruickshank 2018 - News article for StarMetro: *"Sewage problems must be fixed if Vancouver wants to be a global role model, say advocates"*. (Accessed Jan 15 2020)

traffic may be highest in urban areas, highways along streams that are closer to spawning areas may have relatively larger impacts because embryos are a more sensitive life stage. In the North Thompson River, the road runs along the valley bottom near the river which could increase the potential impacts of runoff for DUs 16 and 17.

As noted, Metro Vancouver has the largest population and amount of effluent, but contaminants can travel great distances and accumulate from a variety of sources. The threat from urban contaminants depends on every cities' sewage systems and waste water treatment in both the Fraser River watershed and any city that has outflow into the Georgia Basin. For example, the WWTP in Kamloops includes tertiary treatment (lagoons with biological nutrient removal), whereas Victoria has no treatment facilities. A more thorough assessment of this threat will require collaboration with municipalities and Environment and Climate Change Canada.

The scope of this threat was deemed to be pervasive for all FRC DUs, as all Chinook must all migrate through the lower Fraser River twice and sometimes reside as juveniles. There is, however, considerable uncertainty surrounding the level of impact from urban effluents on FRC. While there is some evidence suggesting adverse effects of contaminant exposure from contaminants such as pharmaceuticals, home and personal care products, yet it is difficult to separate these effects from other cofactors that may be acting on FRC. As such, it is predicted there is a low-medium range of impact on all FRC DUs with a medium level of causal certainty.

4.1.9.2. Industrial & Military Effluents

This section includes water-borne pollutants from industrial and military sources including mining, energy production, and other resource extraction industries that include nutrients, toxic chemicals and/or sediments (IUCN-CMP threat category 9.2).

Many industrial effluent outflows connect to municipal sewage systems, WWTP, and CSOs, but some facilities may also have their own treatment systems on site. Numerous treatment systems were upgraded between 1980-2000 to reduce the amount of contaminants in discharge. Paper and pulp mill effluents make up the largest proportion of industrial discharges in the Fraser River watershed (Gray and Tuominen 1999) and often have on-site treatment facilities. Federal and provincial legislation enacted in the late 1980s and 1990s increased required effluent monitoring programs and treatment of discharge to reduce the levels of dioxins, furans, and other total suspended solids, sometimes reducing contaminants by up to 99 %. Wood preservative facilities contributed to a large proportion of non-pulp mill industrial discharge, using antisapstain fungicides such as dodecyl dimethyl ammonium chloride (which is also used as a pesticide in BC). Again, legislation and operational changes have decreased the quantity of antisapstains in discharge by around 99 % relative to the mid-1980s (Gray and Tuominen 1999). Treated lumber, railway ties, pilings, and utility pole construction uses chemicals such as creosote, pentachlorophenol, chromated copper arsenate, and ammoniacal copper arsenate; many direct discharges were reduced by around 90 % since the mid-1980s (Gray and Tuominen 1999). Unfortunately, historical seepage of creosote into soil at historic operations resulted in significant underground reservoirs of contaminants that are slowly infiltrating systems through groundwater.

Mining activities (particularly metal mining) have the potential to adversely affect environmental conditions if proper mitigation is not in place. There are 7 metal mines in the Fraser River watershed. Six of these mines conduct open pit mining: Endako (Prince George area); Huckleberry (Houston area); Gibraltar (between Williams Lake and Quesnel); Mount Polley (near Williams Lake); Quesnel River (near Quesnel); and Highland Valley (near Kamloops). One mine, Bralorne (Bridge River area), is an underground gold mine. The Endako mine discharges wastewater into a creek that drains into Francois Lake (sockeye-rearing) and then into the Endako River, which drains into Fraser Lake. The Huckleberry mine discharges into the Tahtsa

Reach on the Nechako Reservoir, which has two discharge points (it is unclear how much discharge enters the Fraser River). Intentional and unintentional release from mines include contaminants such as: conventional variables; microbiological variables; major ions; nutrients; metals; cyanides; petroleum hydrocarbons; monoaromatic hydrocarbons; and polycyclic aromatic hydrocarbons. There are also closed/abandoned mines in the Fraser River watershed. Accidental spills from mine tailings and transportation of resources may have impacts on FRC in the Fraser River. The recent Mt. Polley mine embankment breach may have had several negative impacts on FRC that use Quesnel Lake, its tributaries, or migrate through it. The breach released approximately 24 million cubic meters of copper/gold mine tailings effluent into Polley Lake, Hazeltine Creek and Quesnel Lake (Petticrew et al. 2015). The acute changes in turbidity and other suspended pollutants can cause physiological trauma (such as gill abrasions), increased incidence of disease, and behavioural changes (Bisson and Bilby 1982; Nikl et al. 2016). If copper sediments remain suspended or become suspended, there may also be impacts to juvenile salmonids chemosensory systems that may have lasting and detrimental behavioural effects (Sandahl et al. 2007). Short-term effects were likely limited to the few demes in DU10 that rear in the immediate system in the year of the breach; however, long-term effects are unknown.

Coal is the most polluting of the fossil fuels at all stages of production, containing abundant particulate matter, heavy metals, and organic pollutants such as PAHs (Mamurekli 2010). Coal dust can enter the environment through storm water discharge, coal pile drainage run-off, air-borne transfer of coal dust during processing/transport (storage piles, converyor belts, rail cars), and train derailments. While not FRC-specific, controlled enclosure studies conducted by Campbell and Devlin (1997) demonstrated that juvenile Chinook Salmon exposed to coal dust exhibit dysfunction in gene expression of proteins critical for cellular metabolism. Further to this, exposure to coal dust extracts can trigger oxidative imbalance in biological systems leading to cellular damage and the development of a wide range of anomalies (Indo et al. 2015; Pizzino et al. 2017). The Roberts Bank Coal Terminal is the largest coal export facility on the Pacific coast of North America, shipping more coal than all other Canadian terminals combined (Westshore 2019)[25]. The coal terminal has had numerous effects on the local ecology of the surrounding area, and the release of coal dust from the terminal has had detrimental impacts on the region (Johnson and Bustin 2006). Local residents as far away as Pt. Roberts (5-10 km) have reported coal dust escaping the terminal from the incoming loaded rail cars, conveyor belts, and returning empty trains during the loading processes (DFO 1978[26]; Johnson and Bustin 2006) indicating significant air-borne transfer into the surrounding environment. It is currently unclear as to how coal dust currently threatens and/or impacts FRC at the DU level, but it is anticipated the overall effect is negative.

The transport of diluted bitumen (dilbit) through pipelines may have impacts if leaks or spills occurr within FRC habitat. The short-term impacts of a dilbit spill could potentially kill all eggs in a stream depending on the amount of weathering and mixture, thus removing a whole cohort from a deme. Dilbit products vary in the proportions and types of PAHs, polycyclic aromatic compounds (PACs), and in their molecular weights, resulting in varying embryo toxicities (Alsaadi et al. 2018). This variability therefore increases the uncertainty of the impacts of a dilbit spill. Two studies that examined the toxicity of dilbit on salmon were conducted for Sockeye Salmon parr (Alderman et al. 2017a, 2017b). They found that parr suffered reductions in

[25] Westshore 2019. Premier Mover of Coal. (Accessed July 22, 2020)

[26] DFO. 1978. Roberts Bank Port Expansion: A Compendium of Written Submissions to the Environmental Assessment Panel. (Accessed July 21, 2020)

swimming performance and increased rates of cell damage, which would likely result in increased mortality in subsequent stages. A study on Pink Salmon eggs that were exposed to sub-lethal concentrations of PAHs (not in the form of dilbit) showed a 40% reduction in survival of fry that emerged compared to non-impacted years, with an overall reduction in productivity greater than 50 % (Heintz et al. 2000). The TransMountain pipeline runs through the top of DU11 (upper Fraser), the length of North Thompson DUs (DUs 16 and 17), part of the Lower Thompson (i.e. the Coldwater River), and along the lower Fraser River. Spills over land may also pose an unknown threat if dilbit or its constituents seep into groundwater and are transported into streams and the hyporrheic incubation environment in low concentrations but over a long period of time. Dilbit is also transported by rail, where trains pose a derailing risk along several routes that run along the middle Fraser, North Thompson, South Thompson, Lower Thompson, and lower Fraser River. Other chemicals are also transported by rail, such as creosote and caustic substances that have the potential to kill hundreds of thousands of fish (Ross et al. 2013). Spills from industrial activities directly into streams would likely create acute but catastrophic impacts where they occurred, but chronic long-term effects are also a possibility if contaminants enter groundwater or accumulate in sediments.

The scope of this threat was deemed to be pervasive for all FRC DUs, as all Chinook must all migrate through the lower Fraser River twice and sometimes reside there as juveniles. As with the threat from urban effluents, there is a growing body of evidence suggesting there are negative impacts on fish from exposure to a variety of industrial-derived contaminants (PCBs, PCBEs, PAHs, etc.), but to our knowledge, there is no research directly linking these effects to declines in FRC. Research conducted on Chinook Salmon in Puget Sound has showed high enough levels of accumulated industrial pollutants (e.g. PCBs, PCBEs, and PAHs) to cause negative impacts including reductions in growth, disease resistance, and altered blood/tissue profiles (Carey et al. 2017). It should be noted that DU2 may be at the highest level of risk compared to other DUs due to the increased amount of time spent in the Fraser River estuary, in addition to their inhabitancy of Puget Sound. Given the above, it is predicted there is a low to medium range of impact on all FRC DUs with a medium level of causal certainty.

4.1.9.3. Agricultural & Forestry Effluents

This threat includes water-borne pollutants from agricultural, silvicultural, and aquatic systems that include nutrients, toxic chemicals, and/or sediments including the effects of those pollutants on the site where they are applied (IUCN-CMP threat category 9.3).

Contamination from agriculture and forestry include sediments, large woody debris (LWD), nutrients, and a variety of toxic chemicals such as pesticides and herbicides. Also included in this category is forest fires, which can exacerbate the impacts of effluents from the agricultural and forestry sectors, and the threat of introducing toxic chemicals into aquatic ecosystems through forest fire management.

The frequency and magnitude of sedimentation that may occur from the removal of vegetation through forestry is related to variables such as slope, soil composition (including bacterial communities), wind, the extent and method of vegetation removal, precipitation, riparian buffer areas, and the presence of roads (Meehan 1991). It is well established that logging practices may destabilize sediments and increase sedimentation in adjacent and downstream fish habitat with the additional increased risk of landslides that can affect connectivity (Wise et al. 2004). Additionally, fire affected forests and soils can also increase rates of sedimentation and exacerbate effects from logging. Cattle grazing is another significant source of sediment inputs to streams through bank destabilization and increased surface erosion (Rhodes et al. 1994). Sediments and their effects can be broadly separated into fine and coarse sediments. Fine sediments have more direct impacts than coarse, primarily by reducing egg survival through decreasing oxygen circulation, intrusion of fine sediments and preventing fry from emerging from redds (Chapman 1988; Meehan 1991). Fine sediments also lead to changes in primary and secondary productivity, hyporheic exchange, and flocculation rates, which all interact in complex ways and their impacts are often variable across systems (Meehan 1991; Moore and Wondzell 2005). Within some coastal systems, beneficial effects from logging were initially observed, but long-term bank erosion, streambed scour, changes in LWD, and sediment movement downstream generally outweighed the short-term benefits (Tschaplinski and Pike 2017). Changes in coarse sedimentation can result in stream habitats shifting from pools to riffles (Meehan 1991), reducing habitat quality.

One complicated aspect of forestry effluents is LWD, which can provide complex and beneficial habitat for juvenile salmon through creating lower-velocity zones in which fish can rest and forage for prey. Drift-feeding fish such as FRC grow at faster rates when they can hold position in slow water (i.e minimizing energy expenditures) and feed adjacent to higher-velocity zones (to maximize available invertebrate drift supply) (Fausch 1984; Hafs et al. 2014). One of the chronic impacts of logging is that there is usually less LWD in effluent, which decreases habitat complexity (Meehan 1991). However, when stumps and LWD are left in piles at harvest locations, landslides may move large amounts of LWD into streams and modify habitats, create sediment traps, or impact connectivity (e.g. Tschaplinski and Pike 2017). Wood management has been identified as an important tool in river health and restoration, yet it is currently unknown what impacts forestry practices have on the LWD inventory in the Fraser River basin or the biological influences on FRC.

Nutrient loading from fertilization of agricultural lands and forestry replanting, or feces from livestock that enriches effluent may also impact juvenile salmon and their habitat. Increases in nutrients and/or organic loading of an aquatic ecosystem can lead to increased biological productivity, sedimentation of unutilized organic matter, and changes in community composition (Likens 1972). Above natural nutrient levels can cause eutrophication and create hypoxic zones in stagnated water that likely prevent juvenile salmon from using those habitats (Gordon et al. 2015). There is little evidence that this is occurring in the Interior Fraser (though data exists for analysis through Environment and Climate Change Canada); however, tributaries of the lower Fraser are known to become eutrophic (Gordon et al. 2015). For example, the biological oxygen demand (BOD) from agricultural fecal waste has decreased O_2 levels to the point where it has caused fish kills of adult Chum Salmon in Chilqua Creek multiple times (C. Parken pers. comm.). Nutrients may also affect primary and secondary productivity in beneficial ways. Nutrient additions have been used to enhance stocks in lakes and streams before, but there are sometimes unintended consequences of increased predation rates that mask benefits (Hyatt et al. 2004; Collins et al. 2016). There are currently no nutrient enhancements in the Fraser River watershed.

A variety of pesticides and herbicides are used in the agricultural and forestry sectors to control insects, weeds, and fungi, which can have a range of negative effects when introduced into aquatic environments. These chemicals mainly fall in the general categories organochlorines (e.g. DDT, endosulfan, cyclodienes), organophosphates (e.g. glyphosate aka RoundUp), chlorophenoxies (e.g. 2, 4-D), and triazenes (e.g. atrazine). As noted in the industrial effluent section, organochlorine chemicals are slow to biodegrade and persist in environments. Organochlorine pesticides used before the 1980s (i.e. DDT) are still present in Fraser River sediments (highest concentrations in lower Fraser River) and were also found in burbot (*L. lota*) in Chilko, Nicola, and Kamloops lakes (Garette 1980; Gray and Tuominen 1999). Other organochlorines (i.e. non-DDT) have also been observed in agricultural ditch water connected to lower Fraser River tributaries that salmon use (Wan et al. 2005). Glyphosate is used in both agriculture and forestry. There are laws that prevent its use near aquatic systems but it can be transported in rain eroded soils and enter streams, though it also degrades quicker when it becomes dissolved in water (Van Bruggen et al. 2018). Therefore, even if glyphosate enters streams, it may not reach concentrations that are lethal to juvenile FRC (Mitchell et al. 1987). Chlorophenoxy herbicides and triazenes are also transported into streams by rain water but may persist for longer periods than organophosphates and may accumulate in sediments (Hill et al. 1990; Solomon et al. 2008). There may be some effects of atrazine on Chinook Salmon immune systems, but generally there is little evidence of lethal or sublethal effects at concentrations found in environments (Solomon et al. 2008). The above contaminants (and more) have been observed in the interior and lower Fraser River watersheds (Gray and Tuominen 1999), but more consistent and intensive surveys are required to understand their impacts on FRC.

Wildfires are expected to occur with increasing frequency with climate change, resulting in a concurrent increase in fire management. The application of fertilizer-based fire retardants is an important tool in aerial firefighting, yet these chemicals can enter aquatic ecosystems via surface runoff, misapplication from an aerial drop, or during exceptions to the application restrictions during extreme fires (Buhl and Hamilton 1998). Fire retardants contain inorganic salts such as diammonium phosphate and ammonium polyphosphate, and are the primary toxicants that lead to the formation of un-ionized ammonia in the water column (Buhl and Hamilton 1998; Dietrich et al. 2014). Ammonia exists in both ionized (NH_4^+) and unionized (NH_3^0) forms when dissolved in surface water, the former of which does not easily cross fish gills and is less bioavailable than the unionized form (Francis-Floyd et al. 2009). Ammonia can be acutely toxic to fish mainly due to its effect on the central nervous system, also known as "acute ammonia intoxication", which can lead to loss of equilibrium, hyperexcitability, increased breathing, cardiac output, and oxygen uptake, and in extreme cases, convulsions, coma, and death (USEPA 1989; Randall and Tsui 2002). Lower concentrations of ammonia can lead to reductions in hatching success, growth rate, and morphological development, in addition to causing pathologic changes in tissues of fish gills, livers, and kidneys (USEPA 1989). Ammonia is also more toxic to aquatic life at higher temperatures (Levit 2010), suggesting smaller streams in areas that experience high temperatures are at an increased level of risk. The cumulative adverse impact of fire retardants on chinook salmon abundance includes not only the acute mortality immediately following a misapplication, but also the delayed mortality once exposed salmon enter seawater (Dietrich et al. 2013). While not FRC-specific, stream-type Chinook Salmon in the US have reduced survival during seawater entry after exposure to fire retardant at sub-lethal concentrations; however, lethal doses were also estimated to exist if retardant was dropped directly on streams (Dietrich et al. 2013, 2014).

4.1.9.4. Garbage & Solid Waste

This threat category include rubbish and other solid materials including those that entangle wildlife. This includes municipal waste, litter from cars, flotsam and jetsam from recreational boats, waste that entangles wildlife, construction debris, abandoned fishing gear, micro plastics (IUCN-CMP threat category 9.4).

Microplastics are barely visible plastic particulate matter in the form of small fragments, fibres, and granules, and are becoming an emerging contaminant of concern due to their global abundance and widespread distribution (Desforges et al. 2015). The ingestion of microplastics is considered to be a physical threat to FRC, as accumulation of plastic can block the intestinal tract leading to mortality. Microplastics also pose a threat to planktonic prey species of FRC, as particles may entangle feeding appendages and/or block or abrade internal organs resulting in reduced feeding, poor condition, injury, and mortality (Cole and Newton 2013).

Indiscriminate feeders in the water column maybe at particular risk because they might mistake microplastics for natural food items of the same size (Desforges et al. 2015). It has been suggested that suspension and filter feeding zooplankton are exposed the most to microplastics, as these feeding modes are used to concentrate food from large volumes of water (Kaposi et al. 2014; Moore 2008). Recent research conducted in the Strait of Georgia by Desforges et al. (2015) has provided an ecological context for transmission of microplastics to higher trophic level organisms, specifically Pacific salmon including Chinook. This study demonstrated two types zooplankton critically important to juvenile FRC, copepods and euphausiids, are ingesting microplastics in the open ocean, leading to the subsequent accumulation of these contaminants in fish predating on them.

The exposure to microplastics may be considerable for Pacific salmon species; juvenile salmon were estimated to consume 2–7 microplastic particles per day, and returning adult salmon were estimated to consume ≤91 particles per day. While the authors conclude this study is speculative, they provide a sense of the possible scale for exposure to microplastics, and raise questions about risks to populations of ecologically and economically important species (Desforges et al. 2015).

Fishing nets, ropes and traps are often lost in storms, snags or when they're run over by other vessels, and can cause detrimental impacts to fish and other animals when encountered. Lost fishing gear continues to catch fish in the water column, which in turn can attract predators that may also become entangled. An estimated 800,000 tonnes of “ghost” fishing gear is lost to the ocean each year, yet it is currently unknown what the extent of lost fishing gear is in coastal waters of BC (Emerald Sea Protection Society 2019)[27].

This is an unknown impact, because we don't know how severely chinook will be impacted by micro plastics or fishing gear, but there is little doubt there is some impact and that this is a threat.

4.1.9.5. Air-Borne Pollution

This threat category includes atmospheric pollutants from point and nonpoint sources. This includes acid rain, smog from vehicle emissions, excess nitrogen deposition, radioactive fallout, wind dispersion of pollutants or sediments, smoke from forest fires or wood stoves (IUCN-CMP threat category 9.5).

Air currents transport airborne chemicals that may be photodegraded by the sun’s rays, or deposited to the ground either by wet or dry deposition or by gas absorption (Blais 2005). Some contaminants such as PCBs, dioxins, furans, DDT, dieldrin, chlordanes, and hexachlorobenzene have an extraordinary capacity for long-range transport, as demonstrated by the presence of these contaminants in foodwebs in remote northern regions of Canada where production of these chemicals is absent (Dewailly et al. 1989; Gilman et al.1997; Blais 2005). Other air-borne contaminates such as coal dust from loaded rail cars, conveyor belts, and returning empty trains during loading processes can be introduced into the surrounding environment (Johnson and Bustin 2006).

Snowpack accumulation is an important contributor of contaminants to mountain lakes (Blais et al. 2001), with maximum contaminant loading typically occurring during the snowmelt period (Blais 2005). Snowflakes are very effective scavengers of contaminants from the air (Blais 2005), providing a significant mechanism of transporting anthropogenic-derived pollution through air currents. Some contaminants may volatilize back in the air as the snowpack

[27] Emerald Sea Protection Society. 2019. Lost Fishing Gear - A Global Challenge. (Accessed Jully 22, 2020)

matures, while those compounds with higher water solubilities (like HCHs) tend to become dissolved in meltwater and return to the soil as the snow melts (Wania 1997; Blais 2005). Rapid rates of snow-melt typically results in a pulse of contaminants to surface streams and lakes (Blais et al. 2001).

The threat from air-borne contaminants to FRC is pervasive, as there is virtually no place on Earth that is untouched by these chemicals (Blais 2005). While there is a growing body of evidence suggesting air-borne pollution may contribute to declining environmental conditions, there is currently no way to quantify the effects on FRC. The level of impact for this threat is uncertain, but the anticipated impacts of air-borne pollutants are expected to have a low to medium level of impacts with a low level of causal certainty due to the lack of information.

Table 46. DFO threats assessment calculator results for impacts from Household Sewage and Urban Waste Water for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Household Sewage & Urban Waste Water	DU2	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 47. DFO threats assessment calculator results for impacts from Industrial & Military Effluents for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Industrial & Military Effluents	DU2	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 48. DFO threats assessment calculator results for impacts from Agriculture & Forestry Effluents for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Agriculture & Forestry Effluents	DU14	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU2	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 49. DFO threats assessment calculator results for impacts from Garbage & Solid Waste for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Garbage & Solid Waste	DU2	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 50. DFO threats assessment calculator results for impacts from Air-Bourne Pollution for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Air-Borne Pollution	DU2	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Low-Medium	Low	Low-Medium (4)	Historical/ Current/ Anticipatory	Continuous	Extensive

4.1.10. Geological Events

4.1.10.1. Volcanoes

This threat involves volcanic events such as eruptions, emissions, and volcanic glasses (IUCN-CMP threat category 10.1).

Canada has five potentially active volcanic areas, four of which lie within BC (Garibaldi, Wells Gray-Clearwater, Stikine, and Anahim) (Natural Resources Canada 2019[28]). Future volcanic activity cannot currently be predicted with certainty, so no level of impact can be assigned for this threat. The threat extent is, however, pervasive in scope since there is ongoing volcanic activity in BC, and would likely have severe impacts on FRC.

4.1.10.2. Earthquakes & Tsunamis

This threat includes earthquakes and associated events such as tsunamis (IUCN-CMP threat category 10.2).

Geological and geophysical activity is gathered along the western coasts of Vancouver Island, Washington, and Oregon. Records show that major Cascadia earthquakes accompanied by destructive tsunamis have an average recurrence of 500 years in this region (Clague and Bobrowsky 1999; Clague, Munro, and Murty 2003). As with the threat of volcanic activity, it cannot be accurately predicted when these activities will occur, therefore the level of impact on FRC could not be scored.

4.1.10.3. Avalanches & Landslides

This threat includes avalanches, landslides, and mudslides (IUCN-CMP threat category 10.2). Avalanches and landslides are considered as a threat and not a limiting factor, since anthropogenic activities have caused significant declines in FRC Chinook abundance, increasing their vulnerability to impacts from landslides.

Landslides can block migration of both adult and juvenile fish, destroy habitat, and alter habitat conditions by introducing unnaturally high concentrations of sediment. Avalanches and landslides can occur naturally or from human driven cumulative impacts, and are expected to increase in frequency in North America with Climate Change (Gariano and Guzzetti 2016). Recent hydrological modeling work projects nearly half of the Fraser River basin (45%) will transition from a snow-dominated hydrograph in the 1990s to a primarily rain-dominated regime by the 2080s (Islam et al. 2019). The same study projected a nearly 25 day advance of spring freshet by the 2050s, and 40 days by the 2080s relative to the 1990s. This extended freeze thaw period, paired with an increased frequency of rain events, can have profound effects on slope stability and increase the occurrence of landslides. Roads related to forestry have also been attributed to landslides in some systems (Trombulak and Frissell 2000), with years and decades passing before the cumulative impacts to slope stability are realized. If the debris from landslides is not mitigated, landslides have the potential to extirpate entire demes by cutting off passage or burying spawning gravel. The historical slide at Hells gate (1914) and the recent Big Bar landslide (2018) represent the worst case scenario of a slide.

The Seton watershed is prone to episodic landslides that can have significant negative impacts on FRC from DU8 (MFR-Portage), and the area is projected to see to a substantial increase in the frequency of extreme rainfall events and a moderate increase in their intensity with climate change (BGC 2018). The most recent and significant events have occurred on Whitecap Creek,

[28] Natural Resources Canada. 2019. Where are Canada’s volcanoes? (Accessed July 22, 2020)

a tributary to the Portage River that meets 670 m downstream of Anderson lake, where ongoing sedimentation issues from landslide events threaten FRC from this DU. In September 2015 a debris flood and channel avulsion occurred on Whitecap Creek that deposited large amounts of sediment into Portage River, resulting in a complete blockage for approximately 170 m that prevented outflow from Anderson Lake and caused flooding around the lakeshore (BGC 2018). The following year in November 2016, another channel avulsion occurred in Whitecap Creek that resulted in an approximate 75% blockage of Portage River (BGC 2018). These events occurred in high quality spawning habitat and there are no alternate spawning grounds in the DU.

In late 2018, a significant landslide occurred in a narrow and remote portion of the Fraser River near Big Bar, BC, inhibiting passage to all returning salmon that spawn above the blockage. FRC DUs affected by the slide are DUs 9 (MFR-Spring), 10 (MFR-Summer), and 11 (UFR-Spring), the three of which encompass a major portion of the Fraser Basin with a combined area of 94,470 km^2 (COSEWIC 2019). The Big Bar slide has created a barrier to adult FRC migration that depends on Fraser River discharge levels, and based on conditions observed in 2019, adult FRC are unable to migrate by the slide at river discharge levels that are common during May, June and July. Radio-telemetry data collected in the summer of 2019 identify that the slide area is a near complete barrier at discharge levels above 2300 $m^3 \cdot s^{-1}$ monitored at Big Bar Ferry on the Fraser River just downstream of the slide. There are no recent records of discharge at Big Bar (series stopped in 1976). As such, the nearest downstream hydrometric station on the Fraser River, at Texas Creek with a continuous record since 1951, was used as a proxy for the discharge at Big Bar. The threshold value at Texas Creek was adjusted to account for lateral inputs between the two sites (e.g. Seton River, Seton Power Generation Station, and Bridge River) and this adjusted value was used to forecast the likely impact of the slide if no remediation work is completed. We estimated a discharge value of 2300 cms at Big Bar is equivalent to 2500 cms at Texas Creek. The number of days when specific Chinook Salmon populations are likely to encounter discharges greater than 2500 $m^3 \cdot s^{-1}$ were calculated based on the historical data from Texas Creek. The calculations use the freshwater entry date range and a migration rate of 34 $km \cdot day^{-1}$ from Hague and Patterson (2009) to determine the range of dates fish would encounter the rock slide area and the corresponding flows. On average, Slim Creek (DU11), Nechako (DU10) and Tete Juane (DU11), and the Upper Chilcotin River (DU9) are likely to encounter flows > 2500 $m^3 \cdot s^{-1}$ for 79%, 68%, and 51% of there migration (Table 22). The populations selected for this analysis represent the range of encounter rates for Chinook populations from relatively low to high levels of impact. Encounter rates will be sensitive to the migration rate, which is based on limited and uncertain data. However, changing the migration rate will likely have little impact on encounter rates due to high temporal correlation of flows from one day to the next.

It should be noted it is assumed the Big Bar landslide will be a multi-year impediment for FRC that spawn above the slide. Due to the significant portion of the migration being blocked by the Big Bar slide, if this threat is not eliminated it is likely to result in the extirpation of these DUs, and hence the threat was ranked Extreme accordingly. For all the DUs that migrate through the Fraser Canyon, the threat extent is extensive as there is a possibility of a landslide blocking passage in the Canyon. DU8 (MFR-Portage) is ranked as High because there are ongoing sediment issues in Portage Creek from the November 2016 landslide at Whitecap Creek (footprint in spawning habitat), and there are no alternate spawning grounds. Currently returns in this DU are so low there are insufficient spawners to effectively dislodge fine sediments from the gravels. DU7 (MFR-Nahatlatch) is a medium risk, because like DU8, there is a single spawning site, which if impacted by a landslide would affect the entire spawning grounds. DUs 2 (LFR-Harrison),4 (LFR-Upper Pitt) and 5 (LFR-Summer) are medium risk because there are unstable slopes in the area (e.g. Meager Creek) that could negatively impact these DUs, however the threat extent is negligible because it is unlikely for a landslide to impact the entire DU. DUs 14 (STh-Bessette), 16 (NTh-Spring) and 17 (NTh-Summer) are ranked low to medium, because while there is the possibility of a landslide occurring in the Fraser Canyon that would impact the entire DU, it is less likely that a landslide will occur in these DU watersheds.

Table 51. DFO threats assessment calculator results for impacts from Avalanches and Landslides for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Avalanches & Landslides	DU2	Unlikely	High	Medium	Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Negligible
	DU4	Unlikely	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Negligible
	DU5	Unlikely	High	Medium	Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Negligible
	DU7	Unlikely	High	Medium	Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU8	Known	High	Medium	High (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU9	Known	Extreme	High	Extreme (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Extreme	High	Extreme (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Extreme	High	Extreme (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Unlikely	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU16	Unlikely	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU17	Unlikely	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive

4.1.11. Climate change

4.1.11.1. Habitat Shifting & Alteration

This threat involves major changes in habitat composition and location, and includes sea-level rise, desertification, tundra thawing, coral bleaching, shifts in the hydrological regime due to climate change (IUCN-CMP threat category 11.1).

This category encompasses a large suite of complex and inter-related issues that threaten FRC. As FRC occupy both marine and freshwater habitats at different life stages, they are exposed to a variety of habitats subject to environmental shifts resulting from climate change. This section is broken into two parts, and discusses current trends in the marine and freshwater environments occupied or transited by FRC.

Marine Habitat

In a recent report evaluating threats to FRC by Riddell et al. (2013), the panel concluded that habitat conditions during the first year of marine residency were likely a key driver for recent trends in survival and productivity. Climate driven changes in the North Pacific Ocean constitute a significant risk to FRC, and there is an accumulating body of evidence supporting that these changes are occurring.

The rapid increase in anthropogenic-derived CO_2 over the past two centuries has led to a decrease in ocean surface pH by 0.1 units through air–sea gas exchange, and approximately a 30% increase in hydrogen ion concentration. The ocean is projected to drop an additional 0.3–0.4 pH units by the end of this century (Mehrbach et al. 1973; Lueker, Dickson, and Keeling 2000; Caldeira and Wickett 2003; Caldeira et al. 2007; Feely et al. 2009; Guinotte and Fabry 2008). Caldeira and Wickett (2003) suggest that oceanic absorption of fossil-fuel-derived CO_2 may result in larger pH changes over the next several centuries than any inferred from the geological record of the past 300 million years, with the possible exception of those resulting from rare, extreme events. The rate and degree at which ocean acidification is occurring may exceed many marine organism's ability to adapt to changing environmental conditions (Hoegh-Guldberg and Bruno 2010), yet there is currently little research to date looking at the effects on salmon of elevated CO_2 in the marine environment (Williams et al. 2019). The latter authors also demonstrate juvenile ocean-phase Coho Salmon are sensitive to neurobehavioral disruption induced by exposure to climate change-associated elevated CO_2 in the Puget Sound region, suggesting other salmon such as FRC may share a sensitivity to rising CO_2 levels.

There has been a steady increase in North Pacific Ocean temperatures of 0.1°C to 0.3°C per year from 1950 to 2009 (Poloczanska et al. 2013; Holsman et al. 2018), and future temperatures are projected to increase 1.0–1.5 °C by 2050 relative to 2000 (Overland and Wang 2007). Of more imminent concern are marine heat waves in the Northeast Pacific Ocean, which have become a threat to FRC and other Pacific salmon species in recent years. Between 2013-2017, a warm water anomaly commonly referred to as "the Blob" created unprecedented shifts in marine ecosystems along the Pacific coast of North America, altering marine animal distributions that affected predation and competition, created regions of low productivity and nutrients, and impacted several fisheries including salmon (Cavole et al. 2016). Concurrent to this anomaly was a strong El Niño event that further increased temperatures in late 2015 to early 2016, to the hottest observed throughout the 137 years of ocean temperature monitoring (Grant, MacDonald, and Winston 2019). During this event ocean surface temperatures were 3-5°C above seasonal averages, extending down to depths of 100 m (Bond et al. 2015; Ross and Robert 2018; Smale et al. 2019). The warm temperatures caused shifts in the distribution of zooplankton communities, driving lipid-poor southern copepod species northward while reducing numbers of lipid-rich subarctic and boreal copepods (Young and Galbraith 2018; Galbraith and

Young 2019). Increases in temperature also increase the metabolic requirements of salmon, therefore food consumption must increase accordingly (Grant, MacDonald, and Winston 2019). Without a concurrent increase in prey quality or quantity, salmon growth and survival will decrease under warming conditions (Holsman et al. 2018). For example, in recent years Chinook body weight for a given length declined (Daly et al. 2017). Predation also can intensify in warmer ocean conditions, increasing mortality of salmon during these periods (Holsman et al. 2012).

Climate modeling has shown that "the Blob" marine heat wave cannot be explained without anthropogenic inputs, and extreme anomalies such as this will occur with increasing frequency in the coming decades under warming climatic conditions (Walsh et al. 2018). The development of a new anomalous expanse of warm water along the Pacific Coast, designated the "Northeast Pacific Marine Heatwave of 2019" (NOAA Fisheries 2019[29]), supports these predictions. This new anomaly resembles the early stages of "the Blob" and is currently on trajectory be as strong as the first event, yet cold water upwelling along the coast has so far held the warm expanse offshore (NOAA Fisheries 2019). It is currently unknown how this anomaly develop and what the potential impacts on Pacific salmon will be, yet this highlights the ongoing threat of shifting ocean conditions for FRC.

Freshwater Habitat

There is also a growing body of evidence indicating that there will be future climate change-induced impacts within the freshwater habitat of FRC through changes in snowpack, groundwater availability, and discharge regimes, all of which are known to influence stream temperature (Brown 2002). These issues can profoundly affect the quantity, availability and quality of freshwater rearing habitats, particularly for stream-type Chinook Salmon due to their extended freshwater residence (Brown et al. 2019). Chinook Salmon might be particularly sensitive to changes in freshwater habitat, given their site-specific adaptations to spawning and rearing habitats (Grant et al. 2019). These changes can also affect ocean-type Chinook with respect to access to floodplain habitats immediately post-emergence (Brown 2002). Recent studies have reported both observed and projected changes in runoff timing and magnitude within the Fraser River basin as a result of the changing climate, with an advance of the spring freshet and reduced summer peak flow in the main stem of the Fraser River and its major tributaries (Shrestha et al. 2012; Kang et al. 2014, 2016; Islam and Déry 2017). Surface hydrology modeling of the Fraser River basin between 1949 - 2006 demonstrated a 19% decline in the contribution of snow to runoff generation for the main stem Fraser River at Hope, owing to a 1.48 °C overall rise in mean annual air temperatures over the study period (Kang et al. 2014). More recent hydrology modeling projects almost half of the Fraser River basin (45 %) will transition from a snow-dominated hydrograph in the 1990s to a primarily rain-dominated regime by the 2080s (Islam et al. 2019). The same study projected a nearly 25 day advance of spring freshet by the 2050s, and 40 days by the 2080s relative to the 1990s. At a regional scale, an ensemble of 30 projections to 2070 show that warming will be greater in the Interior portions of southern BC when compared to the coastal region (Pike et al. 2010; COSEWIC 2018). The earlier onset of spring freshet and reduced flows in late summer could create challenges for rearing juveniles and for spring and summer run FRC DUs, and in some streams inhibit conditions necessary to achieve successful spawning and rearing (Porter and Nelitz 2009).

[29] NOAA Fisheries. 2019. New Marine Heatwave Emerges off West Coast, Resembles “The Blob”. (Accessed July 22, 2020)

Interaction Between Marine and Freshwater

Warmer regional temperatures also influence interactions between freshwater and marine ecosystems (Grant et al. 2019). In general, warming and freshening of the upper ocean is projected during this century which will continue to reduce sea ice and increase ocean stratification (Bush and Lemmen 2019). Earlier snowmelt, increased precipitation, and melting of ice on land are some of the factors contributing to the freshening of the coastal Northeast Pacific surface waters (Bonsal et al. 2019; Greenan et al. 2019). Fresher and warmer surface waters increase ocean stratification, which limits the supply of nutrient rich deep ocean waters to the sunlit surface waters in the spring-to-fall growing season (Grant et al. 2019). This limits the nutrients available to support algal growth at the base of the salmon food web (Bush and Lemmen 2019).

Ranking

The threat from habitat shifting and alteration is pervasive for all Chinook DUs. DU2 was deemed to be least threatened from habitat shifting and alteration due to their limited freshwater life stage; however, their reliance on estuarine and nearshore marine habitats makes them highly susceptible to shifts in ocean conditions. As there was a high level of uncertainty surrounding the level of impact on FRC from shifting marine conditions, DU2 was assigned a low-high level of impact. At the Threats Workshop it was determined that while there could be minimal impacts, the aforementioned rapidly changing ocean conditions, temperature in particular, may have much worse implications for FRC productivity and survival warranting the large uncertainty range. The remaining DUs were assigned a medium-high level of impact due to the multitude of threats related to habitat shifting and alteration in both marine and freshwater habitat.

4.1.11.2. Droughts

This threat category involves periods in which rainfall falls below the normal range of variation, and loss of surface water resources (IUCN-CMP threat category 11.2).

Droughts are occurring with increased frequency in BC with the changing climate. Drought conditions are most likely to affect stream-type FRC due to their extended residence time in freshwater, and in particular, spring-run stream-type FRC as they generally inhabit and spawn in streams that are dependent on precipitation and buffering from groundwater inputs. These systems are in general unstable when compared to rivers typically utilized by summer-run stream-type FRC, which are buffered by large lakes that tend to provide more stable flows, thereby reducing the impacts from drought conditions. Drought can create migration barriers to salmon, lead to direct mortality of eggs and juvenile FRC, reduce habitat availability through over-crowding, and increase the prevalence of disease and transmission of pathogens. While not FRC-specific, a recent example (2019) of the latter occurred in coastal Oregon following extended low water conditions that led to concentrations of Chinook Salmon in the lower Wilson River during the pre-spawn period, where significant die-offs occurred resulting from, or exacerbated by the spread of *Cryptobia* infection (Oregon Department of Fish and Wildlife 2019)[30].

The population level impact from drought is unknown for all DUs with the exception of DUs 9 and 14, which are both anticipated to be at risk from droughts. DU9 was assigned a low to

[30] Oregon Department of Fish and Wildlife. 2019. Die-off prompts ODFW to close Wilson River to salmon angling. (Accessed July 21, 2020)

medium level of risk as this DU experiences drought conditions regularly, and does not have large lakes to buffer the impacts. Areas within DU9 have regularly experienced level 2 and 3 drought conditions (dry, and very dry respectively) in recent years (BC MOE 2019[31]) resulting in unprecedented low water levels (Hennig 2018[32]). Reduced wetted area of streams, paired with drying of spawning grounds likely impact this DU to some degree in the future. Droughts are pervasive in DU9 and the causal certainty is high, yet there was some uncertainty regarding the level of impact. At the threats workshop it was determined that the impacts from droughts were at least low, but a more substantial impact on DU9 could not be ruled out. Therefore the level of impact was assigned a Low to Medium (1-30%) score.

Most threatened from drought conditions is DU14. In both 2015 and 2017 the South Thompson basin experienced repeated weeks of Level 4 drought conditions (extremely dry) (BC MOE 2019[31]). Of particular concern is Duteau Creek, a sensitive stream that regularly experiences drought conditions (i.e. reduced wetted width of stream, drying up of redds). DU14 was assigned a medium level of impact due to reoccurring extreme drought conditions.

For all other DUs the impacts of drought could not be predicted. They exist either in wetter watersheds that are less likely to experience droughts (DUs 5, 11, 16, 17), or are buffered by large lakes (DUs 2 and 10) or groundwater inputs (DUs 4, and 7) that will likely mitigate the effects of a drought. While many of the streams within these DUs may not be directly be affected by drought conditions, areas in which juvenile fish from these DUs disperse to and rear in could be negatively impacted. In Element 4, three main dispersal strategies are discussed for fry and juvenile FRC following emergence, one of which involves immediate dispersal from natal streams downstream into the mainstem, side channels, and small tributaries of the lower Fraser River. Between 2015-2019, the lower Fraser experienced Level 3 (Very Dry) drought conditions for consecutive weeks on numerous occasions, with Level 4 (Extremely Dry) conditions reported in both 2015 and 2017 (BC Province Drought Information Portal). While there is considerable uncertainty surrounding habitat use and juvenile distribution in the lower Fraser River (particularly at the DU-level), it is possible that Chinook from all DUs rearing in the lower Fraser may be negatively impacted by drought conditions. As such, the remaining DUs were assigned a threat risk of Unknown, as while there is a possibility all DUs could suffer population declines, we have insufficient evidence to substantiate or reject this

4.1.11.3. Temperature Extremes

This threat category includes periods in which temperatures exceed or go below the normal range of variation. This includes events such as heat waves, cold spells, temperature changes, and disappearance of glaciers/sea ice (IUCN-CMP threat category 11.3). Freshwater temperature impacts will be considered here, but marine temperature impacts will be considered in section 4.1.11.1 (IUCN-CMP threat category 11.1).

The frequency of temperature extremes within BC and the Fraser River Basin is increasing as a result of climate change, which may lead to significant impacts on FRC. Mean annual air temperatures warmed by 1.4 °C between 1949 and 2006 across the Fraser River basin (Kang et al. 2014). Local air temperatures were particularly warm from 2015 to 2018, coinciding with "the Blob" in the Northeast Pacific Ocean (Grant et al. 2019). A warmer climate will intensify some weather extremes, and increase the severity and frequency of extreme hot temperatures (Bush

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[31] **Error! Bookmark not defined.**BC Ministry of Environment (MOE). 2019. British Columbia Drought Information Portal. (Accessed July 21, 2020)

[32] Hennig, C. 2018. "Unprecedented low water levels" in northern, central B.C. raise fears for future of wildlife. (Accessed July 22, 2020)

and Lemmen 2019). Salmon upstream migration is energetically demanding even in optimal conditions, and these demands are exacerbated when temperatures fall outside the optimal range for salmon. Salmon that migrate to their spawning grounds in summer months are experiencing more stress and greater depletion of their energy reserves, negatively impacting swim performance and survival (Tierney et al. 2009; Eliason et al. 2011; Burt et al. 2012; Sopinka et al. 2016). See section ELEMENT 10: NATURAL FACTORS THAT WILL LIMIT SURVIVAL AND RECOVERYfor a detailed description of the thermal limits of Chinook Salmon. Fraser Chinook Salmon-specific thermal limits during migration have not been researched to date but studies on Columbia and Willamette Rivers both suggest that migratory difficulties and prespawn mortality occur when temperatures exceed 20 degrees Celsius (Goniea et al. 2006; Bowerman et al. 2018). Summer temperatures of 20 degrees and above in the Fraser are already known to occur during the summer migration period for Fraser Chinook (DFO EWatch) and the duration of these above average temperature events are predicted to increase (Morrison et al. 2002).

As with drought impacts, it was difficult to assign a threat rating for temperature impacts, and most DUs were scored as known for the same reasons stated above in section 4.1.11.2. DU8 was again not scored as it is very unlikely to experience temperature extremes due to the large reservoir upstream.

DU9 and DU11 are both spring-run yearling populations, and thus are more sensitive to extreme temperature events as they occupy/utilize more unstable, groundwater and surface runoff mediated systems. DU10, while being in similar geographic area as DUs 9 and 11, is less at risk from temperature impacts, as the spawning grounds are below large lakes which regulate temperature and flows.

DU14 was anticipated to have the highest level of impact from temperature extremes, due to considerable water extraction for the water supply of the City of Vernon and the surrounding area. Streams in this DU are small and there is little in the way of groundwater inputs to buffer high air temperatures or to provide thermal refugia. Prolonged periods of hot weather in the summer months can lead to stream temperatures in excess of 20°C in DU14. Chinook from this DU may be able to move out of those streams and into the Mid Shuswap when temperatures exceed thermal limits, but sometimes fish get trapped by flows becoming subsurface due to drought and water extraction. As such, temperature extremes were deemed to have a medium level of impact on this DU.

4.1.11.4. Storms & Flooding

This threat includes extreme precipitation and/or wind events. These events include thunderstorms, tropical storms, hurricanes, cyclones, tornados, hailstorms, ice storms or blizzards, dust storms, erosion of beaches during storms, changes in the flood regimes due to climate change (IUCN-CMP threat category 11.4)

There are numerous drivers of shifting hydrological regimes in the Fraser River basin resulting in increases in flood frequency. Rain-dominated hydrographic systems in coastal BC (Grant, MacDonald, and Winston 2019) are experiencing more extreme conditions, reflecting the greater variability in climate conditions (Grant, MacDonald, and Winston 2019). These conditions include greater variation between wet and dry conditions in the summer, and increased frequency and magnitude of storms and rainfall events (Pike et al. 2010). Mean annual air temperatures warmed by 1.4 °C between 1949 and 2006 across the Fraser River basin while total annual precipitation remained stable, despite a significant change in its type from snowfall to rainfall (Kang et al. 2016). This has impacted the accumulation and duration of seasonal snowpack by an approximate 19% decline in the contribution of snow to the hydrological regime (Choi et al. 2010; Kang et al. 2014; Picketts et al. 2017), resulting in a 10-

day advance of the Fraser River's spring freshet (between 1949 and 2006) and subsequent reductions in summer flows (Kang et al. 2016). Despite decreasing snow accumulation at lower elevations, combinations of increased melt rates and more rainfall during the freshet period provide possible mechanisms for higher flood flows (Shrestha, Schnorbus, and Cannon 2015). Freshet flooding is influenced by annual winter accumulation of snowpack, paired with snowmelt runoff and specific temperature/rainfall conditions in the spring period (BC Ministry of Environment, Lands and Parks 1999). Some BC rivers are exhibiting more flash flooding, potentially leading to increased egg losses from scouring (Holtby and Healey 1986; Lisle 1989; Lapointe et al. 2000), or increased mortality of rearing juveniles where flood refugia are not available (COSEWIC 2019). Flash flooding may occur as a result of intense rainstorms, particularly affecting small to moderate sized streams throughout the province (BC Ministry of Environment, Lands and Parks 1999). Pest infestations (mountain pine beetle, spruce beetle) are another manifestation of climate change that have been shown to increase the frequency and intensity of flooding events through reduced interception, increased snowpacks, reduced times of concentration and altered timing of snowmelt runoff (Winkler et al. 2008; EDI 2008; APEGBC 2016).

Of the DUs discussed in this RPA, DU4 (LFR-Upper Pitt) was deemed to be at greatest risk from flooding events. This DU lies within a steep, U-shaped valley that collects and concentrates flows through critical habitat. Any major flooding events could therefore impact all Chinook Salmon from this DU, hence the pervasive threat extent and medium level of impact.

Flooding occurs regularly in DU9 (MFR-Spring), and many of the stream systems within the DU area are unstable and vulnerable to such events. The threat from flooding for DU9 was anticipated to be broad in extent as not all systems within the DU are prone to flooding events and their associated risks, and the level of impact was deemed to have an uncertainty range of low to medium (1-30%). The majority of other DUs (DU7 MFR-Nahatlatch, DU10 MFR-Summer, DU11 UFR-Spring, DU14 STh-Bessette, DU16 NTh-Spring, and DU17 NTh-Summer) were assigned this same level of impact, however, flooding is expected to affect a smaller proportion of these DUs, hence a reduced threat extent.

DU2 (LFR-Harrison) and DU5 (LFR-Summer) were anticipated to be affected by flooding to a lesser degree, having a low level of impact on a restricted portion of the population. DU8 (MFR-Portage) was deemed to not be threatened by flood events, because it was felt that the threat from a storm would be a landslide which is scored in section Avalanches & Landslides.

Table 52. DFO threats assessment calculator results for impacts from Habitat Shifting & Alteration for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Habitat Shifting & Alteration	DU2	Known	Low-High	High	Low-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU4	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU7	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU8	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU9	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU11	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU14	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU17	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive

Table 53. DFO threats assessment calculator results for impacts from Droughts for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Droughts	DU2	Remote	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU4	Remote	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU5	Remote	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU7	Likely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU9	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU10	Likely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU11	Likely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU14	Known	Medium	High	Medium (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Likely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU17	Likely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	For DU8 this is not anticipated to be a threat							

Table 54. DFO threats assessment calculator results for impacts from Temperature Extremes for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Temperature Extremes	DU2	Remote	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU4	Remote	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU5	Remote	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU7	Unlikely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU9	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU10	Remote	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU11	Unlikely	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU14	Known	Medium	High	Medium (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU16	Unlikely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	DU17	Unlikely	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
	For DU8 this is not anticipated to be a threat.							

Table 55. DFO threats assessment calculator results for impacts from Storms & Flooding for all DUs. Note that categories are a slight modification of the COSEWIC Categories. Refer to the text for extensive comments on each threat and to DFO (2014b) for a detailed description of each factor level in the table.

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Storms & Flooding	DU2	Remote	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU4	Known	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive
	DU5	Likely	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Recurrent	Restricted
	DU7	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Restricted
	DU9	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Broad
	DU10	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Restricted - Narrow
	DU11	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Restricted - Narrow
	DU14	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Restricted - Narrow
	DU16	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Restricted - Narrow
	DU17	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Restricted - Narrow
	For DU8 this is not anticipated to be a threat.							

4.1.12. Summary

The COSEWIC threats calculator generates an estimated overall threat risk with a low and a high value to express the uncertainty in the rankings at the individual threat level (i.e. when a range such as Low-Medium was used). The overall scores are based on the number of threats impacting a DU and their relative ratings (from low to extreme). Two medium level threats and a high threat result in a High overall score. Two high and two medium threats, or an extreme score on any threat, results in an Extreme overall score. The lower range value of the overall score for all the DUs under consideration was determined to be either High or Extreme, and the upper range of the overall score was estimated to be Extreme for all the DUs assessed in the workshop. This resulted in High to Extreme or simply Extreme ratings for all DUs. In other words, over the next three generations, it is expected that there will be a population level decline of 31-100% for DUs with a High to Extreme risk level and a 71% to 100% population level decline for DUs with an Extreme risk level. The summary table below (Table 56) provides the comments from the threats workshop that accompany the overall rating. The threats tables for each individual DU are provided in Appendix G.

Table 56. The overall threat rating from the COSEWIC threats calculator workshop with summary comments.

DU	Overall Threat Risk	Comments from Threats Workshop
DU2 - Lower Fraser Ocean Fall	High - Extreme	*31-100% population level decline expected over the next three generations* DU2 was assigned an overall impact rating of High to Extreme. This DU has a single spawning site in the Harrison River below Harrison Lake, and while situated in a highly developed area, the spawning habitat is relatively stable and will likely not be directly impacted by anthropogenic-related activities in the near future. This is the only ocean-type population assessed in this RPA; in addition to inhabiting the Fraser River estuary, Salish Sea, and the western coast of Vancouver Island, FRC from DU2 transit and rear in Puget Sound and other coastal areas of Washington and Oregon and are thereby threatened by anthropogenic activities in the US in addition to activities within Canada. It was determined at the Threats Workshop that predicting a 100% reduction in population size might not be reasonable, but that the possibility of having a loss of greater than 70% was certainly reasonable given the observed trends in abundance and the cumulative effects of the threats described in Element 8. This rating was based on threats from competition with hatchery fish, climate change, pollution, existing fisheries harvest rates and declining trends in marine survival. DU2 is particularly sensitive to the loss of estuarine and ephemeral habitats, predation by pinnipeds and pollution compared to other Fraser DUs, due to its reliance on coastal habitats in highly developed areas of both Canada and the US. It is also likely that this

DU	Overall Threat Risk	Comments from Threats Workshop
		DU has been over-harvested in some of the last 25 years, as a result of mixed stock fisheries. *Highest Ranked Threats: Aquaculture (H-M), Climate Change (H-L), Pollution (M), Fishing (M-L), Other Ecosystem Modifications (M-L), Invasives (M-L),Gravel Extraction (M-L)*
DU4 - Lower Fraser Stream Summer	High - Extreme	*31-100% population level decline predicted over the next three generations* DU4 was assigned an overall impact rating of High to Extreme. Of the stream-type DUs assessed in this RPA, DU4 has the shortest migration distance through the highly developed and impacted habitat in the lower Fraser River to the Pitt River, which is largely undeveloped from the mouth of Pitt Lake to spawning grounds in the Upper Pitt River. This DU has multiple spawning sites in several small tributaries to the Upper Pitt River, and while currently not confirmed, likely in the mainstem of the Upper Pitt as well. However, it is important to note that escapement data are only available for one tributary of the Upper Pitt River (Blue Creek), and the trend that we are observing at this site may or may not be representative of other parts of the DU. DU4 is most threatened by climate change impacts, logging activities, flood and landslide events, recreational activities in the Upper Pitt watershed, invasive species in the lower Fraser River, and declining trends in marine survival. This DU is particularly sensitive to the effects of climate change as its freshwater habitat lies within an area with a mixed rain- and snow-dominated hydrograph, which is shifting towards the former with increasing air temperatures in BC. This DU also lies within an area surrounded by steep, and in some cases, unstable slopes that if a landslide were to occur, it could eliminate the entire spawning deme. Less precipitation in coastal areas accumulating as snow, and the earlier and more rapid onset of freshet has led to an increased risk of flood and landslide events and subsequent sedimentation issues in these areas. *Highest Ranked Threats: Climate Change (H-M), Other Ecosystem Modifications (M-L), Recreational Activities (M-L), Fishing (M-L), Invasives (M-L), Pollution (M-L)*

DU	Overall Threat Risk	Comments from Threats Workshop
DU5 - Lower Fraser Stream Summer	High - Extreme	*31-100% population level decline expected over the next three generations* DU5 was assigned an overall impact rating of High to Extreme. This DU has multiple spawning sites in tributaries to Harrison Lake, the mainstem Lillooet River and several tributaries to the Lillooet River. It is highly probable that historic spawning habitats in the Lillooet River have been dredged in addition to suffering impacts from sedimentation due to the Meager Creek landslide. There is considerable uncertainty associated with this DU, as Big Silver Creek is the only system for which reliable escapement data exist. DU5 is most threatened by climate change, pollution, natural systems modification, fishing impacts, invasive species in the lower Fraser River, and declining trends in marine survival. As with DU4, this DU lies within an area surrounded by steep, and sometimes unstable slopes and is particularly sensitive to the effects of climate change as it lies within a mixed rain- and snow-dominated hydrograph which is currently shifting to the former with increasing air temperatures. Due to the low escapements currently being observed in this DU, participants at the Threats Workshop agreed it was reasonable to predict the possibility of extinction within the next three generations, assuming that the trends in Big Silver Creek represent the remainder of the DU. *Highest Ranked Threats: Climate Change (H-M), Other Ecosystem Modifications (M-L), Fishing (M-L), Invasives (M-L), Pollution (M-L)*
DU7 - Middle Fraser Stream Spring	High - Extreme	*31-100% population level decline expected over the next three generations* DU7 was assigned an overall impact rating of High to Extreme. This is a single spawning site DU with all fish spawning in the Nahatlatch River, and there is no alternative spawning habitat available if current habitat is degraded. It was agreed at the Threats Workshop that 100% reduction over the next three generations might not be reasonable, but that the possibility of having a loss of over 70% was certainly reasonable and may have already occurred. Recently, there have been years where less than 10 spawners have been counted in the system. The main threats facing this DU are from climate change, pollution, natural systems modifications, fishing impacts, and declining trends in marine survival. Shifting habitat conditions such as reduced snowpack accumulation and the earlier onset of freshet in particular can potentially

DU	Overall Threat Risk	Comments from Threats Workshop
		inhibit conditions for FRC to achieve successful spawning and rearing. In addition, DU7 lies within a steep valley and any major landslide or flood event would impact all habitat downstream of the event. *Highest Ranked Threats: Climate Change (H-M), Other Ecosystem Modifications (M-L), Fishing (M-L), Pollution (M-L)*
DU8 - Middle Fraser Stream Fall	Extreme	*71-100% population level decline expected over the next three generations* DU8 was assigned an overall impact rating of Extreme. This DU has a single spawning site in Portage Creek between Seton and Anderson Lakes, and impacts to this spawning habitat may have profound negative effects on the DU. This DU is impacted by Seton Dam as all FRC must to transit through a fishway to reach spawning grounds in Portage Creek, and may have negative effects on FRC migration. In recent years some escapement estimates for the DU have been less than 100 fish. The main threats facing this DU are landslides, climate change, dams and water management, natural systems modifications, fishing impacts, and declining trends in marine survival. Recent landslides and subsequent sedimentation issues in Whitecap Creek have significantly impacted the ability of the population to successfully spawn, and the frequency of such event are anticipated to increase in the future. Additionally, the early fall return of this DU overlaps with the return migrations of more abundant Chinook stocks and other salmon species for which there are directed fisheries, leading to slightly higher concern for the impact of bycatch on this DU compared to the others assessed in this RPA. *Highest Ranked Threats: Landslides (H), Climate Change (H-M), Dams and Water Management (M), Fishing (M-L), Other Ecosystem Modifications (M-L), Pollution (M-L)*
DU9 - Middle Fraser Stream Spring	Extreme	*71-100% population level decline expected over the next three generations* DU9 was assigned an overall impact rating of Extreme. This DU spans the largest geographic area of all DUs assessed in this RPA, with many spawning sites throughout the Interior Fraser. Most spawning sites for this DU are located above the recent Big Bar landslide which has created a barrier to adult FRC migration at certain discharge levels. Passage observed past Big Bar during the summer of 2019 was not sufficient to maintain these

DU	Overall Threat Risk	Comments from Threats Workshop
		populations over multiple generations. In addition, other serious threats identified were from natural systems modification due to changes in catchment surfaces from forestry and fires, as well as from climate change, pollution, dams and water management, fishing impacts, and declining trends in marine survival. Due to the high levels of disturbance in the watersheds of this DU, it is particularly sensitive to climate change impacts. DU9 is a spring return population and the fish spawn in smaller and relatively unstable systems that rely heavily on precipitation and groundwater inputs. As such, these systems are more sensitive to the effects of climate change and extreme weather events such as droughts and flooding. Less precipitation accumulating as snow, the earlier onset of freshet, and extreme weather events such as drought can lead to conditions that inhibit successful spawning and rearing in these systems. *Highest Ranked Threats: Landslides (H), Climate Change (H-M), Other Ecosystem Modifications (H-M), Pollution (M), Dams and Water Management (M-L), Fishing (M-L)*
DU10 - Middle Fraser Stream Summer	Extreme	*71-100% population level decline expected over the next three generations* DU10 was assigned an overall impact rating of Extreme. This DU spans a large, albeit smaller geographic area than DU9, and contains many spawning sites in the Interior Fraser. All spawning sites for this DU are located above the recent Big Bar landslide which has created a barrier to adult FRC migration at certain discharge levels. Passage observed past Big Bar this past summer will not maintain these populations over multiple generations. In addition to the Big Bar landslide, the main threats facing this DU are climate change, natural systems modifications, fishing impacts, pollution, and declining trends in marine survival. DU10 is a summer return-timed group of populations that spawn in river systems that are buffered by large lakes, and are thereby, generally less sensitive to the impacts of shifting habitat conditions and modifications to catchment surfaces compared to rivers in DU9. However, these factors are still anticipated to have a negative overall effect on the productivity of these stocks. *Highest Ranked Threats: Landslides (H), Climate Change (H-M), Other Ecosystem Modifications (M-L), Fishing (M-L), Pollution (M-L)*

DU	Overall Threat Risk	Comments from Threats Workshop
DU11 - Upper Fraser Stream Spring	Extreme	*71-100% population level decline expected over the next three generations* DU11 was assigned an overall impact rating of Extreme. As with DUs 9 and 10, this DU spans a large geographic area in the Interior Fraser and has many spawning sites. FRC from DU11 have the longest migration distance to reach spawning grounds of all FRC DUs, and are therefore the most sensitive to disruptions in their return migration. All spawning sites in this DU are located above the Big Bar landslide, which has created a barrier to adult FRC migration at certain discharge levels. It was determined at the Threats Workshop that this DU is in serious peril and that if passage issues at the Big Bar Slide are not resolved, it would likely result in its extirpation. Other major threats to this DU include climate change, natural systems modifications, fishing impacts, pollution, and declining trends in marine survival. This DU is in a less dire situation than DU9 and 10, because of the cooler, wetter climate, and comparatively less disturbance in the watersheds overall. However, this DU is at higher risk of continued destabilization due to logging than DUs 9 and 10, and is potentially at higher risk for additional other modifications to catchment surfaces through fire or forest pests. *Highest Ranked Threats: Landslides (H), Climate Change (H-M), Other Ecosystem Modifications (M-L), Fishing (M-L), Pollution (M-L)*
DU14 - South Thompson Stream Spring	Extreme	*71-100% population level decline expected over the next three generations* DU14 was assigned an overall threat rating of Extreme. Fish from this DU spawn in a small geographic area within Bessette Creek and several of its tributaries. DU14 lies within a historically drought and temperature sensitive area, and the surrounding landbase is highly developed for agricultural use. Escapement estimates to this DU have been well under 100 fish in the past several generations, and participants at the Threats Workshop determined that the extirpation of this DU within the next three generations was plausible. The main threats facing this DU are water use, modifications to catchment surfaces, climate change, agricultural impacts, pollution, and declining trends in marine survival. Water extraction, paired with the effects of climate change have severely impacted this DU, and these threats are very unlikely to diminish or be successfully moderated in the near future. The impacts of cattle, both

DU	Overall Threat Risk	Comments from Threats Workshop
		on stream banks and in stream beds, was identified as an additional threat to DU14. Cattle are routinely observed in streams within spawning grounds during aerial surveys, indicating the likelihood of additional impacts from cattle eroding stream banks and/or trampling FRC redds. *Highest Ranked Threats: Dams and Water Management (E-H), Ecosystem Modifications (E-H), Climate Change (H-M), Other Pollution (M), Agriculture (M-L), Fishing (M-L), Invasives (M-L)*
DU16 - North Thompson Stream Spring	High - Extreme	*31-100% population level decline expected over the next three generations* DU16 was assigned a threat impact of High to Extreme. This DU has multiple spawning sites in the North Thompson River and several of its tributaries upstream of Vavenby. The principal threats facing this DU are climate change, pollution, natural systems modifications, fishing, landslides, and declining trends in marine survival. DU16 is a spring returning population and in general, adults spawn in systems heavily reliant on precipitation and groundwater inputs. This DU, however, lies within a wetter area than the Middle Fraser DUs, thus it may be less sensitive to the effects of shifting climatic conditions, and was thereby considered to be at less risk than DUs 9 and 10. There was some discussion about ranking this DU as High, rather than as High to Extreme, but given the uncertainty of possible oil spill events in the future (related to the Trans Mountain Pipeline) in addition to the aforementioned threats, participants at the Threats Workshop agreed that this was an appropriate ranking. *Highest Ranked Threats: Climate Change (H-M), Pollution (M), Other Ecosystem Modifications (M-L), Fishing (M-L), Landslides (M-L)*
DU17 - North Thompson Stream Summer	High - Extreme	*31-100% population level decline expected over the next three generations* DU17 was assigned a threat impact of High to Extreme. This DU has multiple spawning sites in the North Thompson River and several of its tributaries downstream of Clearwater and Mahood lakes. As with DU16, the principal threats facing this DU are climate change, pollution, natural systems modifications, fishing, landslides, and declining trends in marine survival. This DU lies within a wetter climatic area than the Middle Fraser DUs, therefore it was deemed to be less sensitive to the effects of shifting climatic conditions. Further to this,

DU	Overall Threat Risk	Comments from Threats Workshop
		DU17 is comprised of summer returning populations which are somewhat buffered from the effects of shifting climatic conditions, and are anticipated to be less threatened than DU16. At the workshop, there was discussion about ranking this DU as High rather than High to Extreme, but given the uncertainty of possible oil spill events in the future (related to the Trans Mountain Pipeline) in addition to the aforementioned threats, it was agreed this was an appropriate ranking. *Highest Ranked Threats: Climate Change (H-M), Pollution (M), Other Ecosystem Modifications (M-L), Fishing (M-L), Landslides (M-L)*

Table 57. Overall threat ranking for FRC DUs assessed. Note this table displays the combined threat ranking of the multiple threat categories contained in each of the overarching major threat categories provided in the table.

COSEWIC Major Threat Category	DU2	DU4	DU5	DU7	DU8	DU9	DU10	DU11	DU14	DU16	DU17
Residential and commercial development	Low	Low	Low	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
Agriculture & aquaculture (Hatchery competition)	High-Medium	Low	Low	Low	Low	Low	Low	Low	Medium-Low	Low	Low
Energy production & mining	Medium-Low	N/A	Low	Low	Low	Medium	Low	Low	Low	Low	Low
Transportation & service corridors	Unknown	Unknown	Unknown	Unknown	Unknown	Negligible	Negligible	Negligible	Unknown	Low	Low
Biological resource use (Fishing)	High-Low	High-Low	High-Low	High-Low	High-Low	High-Low	High-Low	High-Low	High-Low	High-Low	High-Low
Human intrusions & disturbance	Negligible	Medium-Low	Negligible	Negligible	Negligible	Low	Negligible	Low	Low	Low	Low
Natural systems modifications (Water management, ecosystems modifications)	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium	High-Medium	Medium-Low	Medium-Low	Extreme - High	Medium-Low	Medium-Low
Invasive & other problematic species & genes	Medium-Low	Medium-Low	Medium-Low	Low	Low	Low	Low	Low	Medium-Low	Low	Low
Pollution (From all sources and threats)	Medium	Medium-Low	Medium-Low	Medium-Low	Medium-Low	Medium	Medium-Low	Medium-Low	Medium	Medium	Medium
Geological events (Landslides)	Unknown	Unknown	Unknown	Unknown	High	Extreme	Extreme	Extreme	Unknown	Medium-Low	Medium-Low
Climate change & severe weather (Shifting habitats)	High-Low	High-Medium	High-Medium	High-Medium	High-Medium	High-Medium	High-Medium	High-Medium	High-Medium	High-Medium	High-Medium
OVERALL THREAT RANKING	Extreme-High	Extreme-High	Extreme-High	Extreme-High	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme-High	Extreme-High

4.2. ELEMENT 9: ACTIVITIES MOST LIKELY TO THREATEN THE HABITAT PROPERTIES IDENTIFIED IN ELEMENTS 4-5

The majority of Threats in Element 8 may impact habitat properties from Elements 4-5. The pathways have been described throughout Element 8 and the primary threats associated with each DU are highlighted in section Summary.

4.3. ELEMENT 10: NATURAL FACTORS THAT WILL LIMIT SURVIVAL AND RECOVERY

Natural limiting factors are defined as "non-anthropogenic factors that, within a range of natural variation, limit the abundance and distribution of a wildlife species or a population" (DFO 2014). *It is important to note that natural limiting factors or processes may be exacerbated by anthropogenic activities; they can then become a threat. By default, a natural limiting factor would be scored as having a "Low" Threat Risk in the calculator unless there are other factors (anthropogenic threats) that are exacerbating natural levels of variation or impacts to a population. As almost all of the natural limiting factors are affected by anthropogenic induced climate change or landscape level development, they are intertwined with existing threats and impacts.*

4.3.1. Biological and physiological limits

Temperature is one of the most important environmental influences on salmonid biology (Carter 2005), and is strongly tied to the evolutionary histories of salmonids in the Pacific Northwest and their historical distributions (Brannon et al. 2004). Water temperatures can affect salmonids at all life history stages, having both direct and indirect effects on the health of individual fish through a variety of mechanisms (Dunham et al. 2001; Richter and Kolmes 2005) including growth and feeding rates, metabolism, development of embryos and alevins, timing of life history events such as upstream migration, spawning, freshwater rearing, and seaward migration, and the availability of food (Carter 2005). As such, the thermal tolerances of salmonids can be considered a limiting factor for FRC at all life stages.

Salmonids are typically incapable of extracting sufficient oxygen to maintain normal bodily function even at a resting rate when temperatures are in excess of 25 °C (Clark et al. 2008). Clark et al. (2008) suggests that the critical thermal maximum for resting adult Chinook Salmon is mass dependent, and lies around 25°C for large fish (>4kg) and potentially around 27°C for smaller adult individuals. As water temperatures exceed 18°C upstream migration rate is affected and Chinook Salmon slow their rate of upstream movement. As water temperatures exceed 20°C Chinook migration can be completely stopped due to the thermal barrier these warm conditions represent, and extreme stress and accelerated mortality begins with exposure to temperatures near 21°C (Richter and Kolmes 2005; Jensen et al. 2006). Resting fish further into the maturation cycle have been observed to experience major physiological stress at temperatures as low as 16-17°C (pers comm.. Dr. Timothy Clark); however, it should be noted these results are either directly from, or inferred through tightly controlled laboratory studies and do not consider additional and confounding stressors.

The optimum temperature range for Chinook Salmon egg and hatchling survival is 5-15°C (Leitritz and Lewis 1976; Boles et al. 1988; McCullough 1999; Diewart 2007) , and upper and lower temperatures for 50% pre-hatch Chinook Salmon mortality has been reported as 16°C and 2.5-3.0°C respectively (Alderdice and Velsen 1978). There are, however, exceptions to the reported thermal limits in some stream-type FRC populations as fish are known to experience temperatures well beyond these thresholds. In the BC interior, Chinook can experience water temperatures of near 0°C for multiple weeks during egg incubation (R. Bailey pers. comm.

2019). The upper lethal temperature for Chinook Salmon fry is 25.1°C (Scott and Crossman 1973).

Literature on the effects of stress and increased water temperature indicates that prolonged exposure to warm waters may affect egg viability and sperm density. A study conducted by Jensen et al. (2006) reported Chinook held at 22°C had elevated levels of maternal cortisol, a stress related hormone that can be expressed in reaction to thermal influences, which resulted in increased mortality, reduced fork length and mass, diminished yolk-sac volume, decelerated yolk-sac utilization and, to some extent, enhanced prevalence of morphological malformations. Richter and Kolmes (2005) noted several studies in which salmonids exposed to temperatures above 13°C just before or during spawning, had severely affected gamete quality internally in maturing adults. This resulted in a loss of gamete viability that manifested in reduced fertilization rate and embryo development. As with the previous section on thermal limits during incubation, there are exceptions to these limits. While not specific to this RPA, FRC from the Nicola River can experience extreme diurnal fluctuations at spawning with overnight low water temps <10°C and daytime up to 18°C due to low flows and diurnal air temp fluctuations.

4.3.2. Predation

Predation is a source of mortality for Chinook Salmon at all life stages, yet there is a high level of uncertainty surrounding the specific rates of predation at different life stages, and the direct impacts on FRC mortality. The threat of predation begins as an egg and carries onto the entire juvenile freshwater life stage, with sources including a variety of opportunistic fish, mammal, and avian species (Sandercock 1991). While specific predation rates on Chinook Salmon are currently unknown, predatory interactions may play a significant role in mortality for certain Chinook stocks (Brown et al. 2019). Some of these interactions (i.e. pinniped predation) are influenced or exacerbated by anthropogenic activities, and as such, are considered as threats to FRC in Element 8.

Major freshwater predators of Chinook Salmon include Bull trout (*Salvelinus confluentus*), Rainbow trout (*Oncorhynchus mykiss*), Northern pikeminnow (*Ptychocheilus oregonensis*), lamprey spp. (*Lampetra spp.*) and sculpin spp. (*Cottus spp.*). Bull trout is considered a major piscivore in Fraser system lakes (both in interior and much of the coast) and anadromous bull trout are abundant and efficient piscivores in the Fraser delta area (Christensen and Trites 2011). There is evidence of declining size and abundance trends for Bull Trout in the Fraser River watershed, therefore it is unlikely Bull Trout are a major factor for the decline of salmon such as FRC (Christensen and Trites 2011). River lamprey have been indicated as a major predator of age-0 salmon in the Strait of Georgia, and were estimated to have consumed 65%, 25%, and 2.3% of the total smolt production for coho, Chinook, and sockeye, respectively, in 1991 (Beamish and Neville 1995; 2001). There is, however, little information available on the abundance and distribution of river lamprey in the Fraser River therefore the effects of their predation on FRC cannot be quantified.

River otters (*Lontra canadensis*) may predate on adult salmon in their spawning streams. Otters were identified as a threat to ESA-listed Lake Ozette Sockeye salmon in Washington State (Scordino et al. 2016). River otters have been observed in many of the rivers that Chinook inhabit within the Fraser, and have been observed killing adult Chinook Salmon in the Nicola River (R. Bailey, pers. comm. 2019). Otters are likely to be more efficient capturing salmon in smaller rivers at reduced flows, and in areas of reduced habitat complexity. Increased water temperatures reduce the swimming ability and endurance of Chinook, likely further increasing their vulnerability to otter predation. Climate change driven processes resulting in warmer water temperatures, summer low flows and loss of channel structure likely exacerbate the impact of river otters.

There are 31 known species of marine mammals that occur in waters off the Pacific coast of Canada, seven of which are known to prey on salmonids (Brown et al. 2019). These include (but are not limited to) Sea Lions (*Zalophus californianus*, *Eumetopias jubatus*), Harbour Seals *(Phoca vitulina),*White-sided Dolphins *(Lagenorhynchus obliquidens)*, and Humpback Whales *(Megaptera novaeangliae)* (Riddell et al. 2013). Predation by marine mammal species, however, are by definition considered to be a threat as anthropogenic activities are/have been exacerbating the negative effects of predation on FRC. Pinniped predation specifically has been suggested to play a significant role in declining Chinook Salmon abundance, and is discussed in detail in section Problematic Native Species.

Three distinct ecotypes of Killer Whales (*Orcinus orca*) exist in coastal waters of the northeast Pacific. Two of these ecotypes, the northern and southern resident killer whales (RKWs), have been shown to preferentially predate on adult Chinook Salmon (age ≥ 2 years at sea) despite being relatively rare in abundance when compared to other prey species (Ford and Ellis 2006; Hanson et al. 2010). Prey selectivity by RKWs may be due to Chinook Salmon's comparatively large size, high lipid content, and year-round availability in resident killer whale coastal habitat (Ford and Ellis 2006). See section 4.1.8 for a detailed description of predator interactions.

During the summer and fall months RKWs congregate in specific coastal areas to intercept salmon returning to their natal spawning streams. Although these congregations are spatially and temporally correlated with the abundance of migrating pink and sockeye salmon, extensive field studies of foraging behaviour indicate that RKWs forage selectively for Chinook Salmon and, to a lesser extent, Chum Salmon (Ford and Ellis 2006; Hanson et al. 2010; Brown et al. 2019). The whales appear to target large fish, with most being four years of age or older. Hanson et al. (2010) inferred 80–90% of Chinook Salmon prey in summer SRKWs were spawned in the Fraser watershed through genetic analysis, while only 6–14% were inferred to have originated in the Puget Sound area rivers. While only assessed during a single year and not considered in relation to relative DU abundance for that year, The authors ranked each DU in terms of inferred importance as follows: upper Fraser (DU11), middle Fraser (DU7, DU8, DU9, DU10), South Thompson River (DU14), and lower Fraser stocks (DU2, DU4, DU5). Riddell et al. (2013) discuss workshop findings that identified the South Thompson Chinook Salmon populations (DU14 included) as the dominant stocks in the diet of southern resident killer whales.

Estimates of the numbers of Chinook Salmon consumed annually by resident Killer Whales are fairly speculative as the proportion of the predator's diet that is composed of this species during winter is poorly known. Although the majority of their prey during summer is Chinook, this may not be the case during December through April, when the whales forage off the outer coast. However, if it is assumed that one-half of their year-round energetic requirements are fulfilled by predation on Chinook, about 500,000 fish may be consumed annually (Ford et al. 2010). It has also been estimated that resident Killer Whales may consume up to 100,000 Chinook during July and August in waters around Vancouver Island.

Several avian species have been identified as predators of Chinook Salmon during their seaward migration, and include the common mergansers (*Mergus merganser*), great blue herons (*Ardea Herodias*), bald eagles (*Haliaeetus leucocephalus*)*,* and belted kingfishers (*Megaceryle alcyon*) (Wood 1987a). The effects of predation during ocean migration is considered to be depensatory on salmonids, which implies that the mortality rate on salmonids increases as salmon abundance decreases (Brown et al. 2019). Avian predators of Chinook Salmon in coastal estuaries have also been identified, and include Bonaparte's Gulls (*Larus Philadelphia),* Caspian terns (*Hydroprogne caspia),* and double-breasted cormorants *Phalacrocorax auritus* (Mace 1983; Sebring et al. 2013). Ocean-type Chinook Salmon populations are vulnerable for a shorter period of time in freshwater to avian predators than stream-type populations. For ocean-type populations in coastal BC, the largest impact from avian predators occurs during the seaward migration with maximum mortality rates reported to be between 8% (Wood 1987a) and 12% (Mace 1983). Stream-type populations spend at least one year rearing in freshwater, while ocean-type populations in the interior Fraser River spend up to 5 months in freshwater before arriving in the Fraser River estuary. This extended period of freshwater residence increases the vulnerability of stream-type Chinook Salmon populations to avian predators. Although we were unable to find a direct assessment of avian predation rates on stream-type Chinook Salmon, Wood (Wood 1987b) reported that high mortality rates for Coho Salmon which have a one year stream residence (24-65% of potential smolt production).

The population dynamics of salmon sharks in the north Pacific Ocean is currently unknown, yet anecdotal reports suggest that this species has rebounded substantially since the termination of the high seas drift gillnet fishery (1992) and Canadian flying squid fishery (1987) (Okey, Wright, and Brubaker 2007; Goldman and Musick 2008; Seitz et al. 2019). Further protective measures such as amendments to the Magnuson–Stevens Conservation and Management Act (1976), including the Shark Finning Prohibition Act of 2000 and the Shark Conservation Act of 2010, have likely contributed to increases in salmon shark productivity in recent years (Seitz et al. 2019). Recent research by Seitz et al. (2019) indicates salmon shark predation may be a substantial source of oceanic mortality of large immature and maturing Chinook Salmon, both during the summer and winter and throughout a wide geographic range including the central and eastern Bering Sea and near the Aleutian Islands. This study also provided evidence of salmon sharks occupying the Bering Sea during the winter, where colder ambient water temperatures (4–6 °C) were generally thought to drive southerly movements out of these cold habitats by the onset of winter (Weng et al. 2005, 2008; Goldman and Musick 2008).

Seitz et al. (2019) postulate that large apex predators such as salmon sharks provide a specific mechanism of late-ocean mortality, ultimately contributing to the proportional decrease of older age classes of Chinook Salmon returning to the spawning grounds each year. Predation of Atlantic salmon by large predators such as porbeagle sharks (*Lamna nasus*) and Atlantic bluefin tuna (*Thunnus thynnus*) has been hypothesized as an important factor hindering the recovery of stocks from Canadian rivers (Lacroix 2014), suggesting similar effects may be occurring for FRC stocks along the Pacific coast.

There is no source of nutritious food as easily acquired and predictably available for bears as salmon (Quinn 2005). Bears can kill far more salmon than any other terrestrial predator, and in coastal regions, salmon can constitute the majority of annual diet for brown (*Ursus arctos*) and black (*U. americanus*) bears (Hilderbrand et al. 1999a, 1999b; Reimchan 2000; Mowat and Heard 2006). Bears congregate along salmon-bearing streams during their return migration (Quinn 2005) and tend to kill the largest and newest-arrived salmon (Ruggerone et al. 2000). Bears will feed selectively on body parts of salmon that provide the most concentrated supply of fat, particularly the brains and eggs from females (Gende et al. 2001, 2004), leaving the uneaten portions of the carcasses in the stream, along stream banks, or in the nearby forest where they are available for scavengers and decomposers (Reimchan 2000; Gende et al. 2001). While not FRC-specific, a multi-year predation study in Bristol Bay, Alaska, reported less than 25% of the total biomass was consumed from 4,218 sockeye salmon killed by bears (Quinn 2005). It has been suggested that selective pressure on large salmon from populations in small streams where predation is more intense can lead to the evolution of salmon that are younger and smaller in size when compared to those of nearby streams with lower predation rates (Quinn et al. 2001). There is currently no comprehensive source of data for bear predation on salmon in BC. As a result, the extent of bear predation on all FRC DUs is unknown; however, it unlikely bear predation is a significant contributing factor to current declining trends in abundance due to a strong and long-standing evolutionary linkage between these species.

Christensen and Trites (2011) identified a multitude of co-occurring species that posed potential predation risks for Fraser River sockeye populations, many of which overlap with FRC DUs. Their study also identified a number of information gaps surrounding the abundance and population trends of these co-occurring species, and the need for better monitoring of their abundance and distribution to better understand their influence on Chinook Salmon through predation, particularly those targeting Chinook in their early freshwater life stage.

Table 58. Predators likely encountered by FRC.

Predator Group	Common name	Scientific name
Freshwater Fish	Bull trout	*Salvelinus confluentus*
	Burbot	*Lota Lota*
	Coho Salmon	*Oncorhyncus kisutch*
	Cutthroat trout	*Oncorhyncus clarkii clarkii*
	Dolly Varden	*Salvelinus malma*
	Lake trout	*Salvelinus namaycush*
	Largemouth bass	*Micropterus salmoides*
	Northern pikeminnow	*Ptychocheilus oregonensis*
	Rainbow trout/steelhead	*Oncorhyncus mykiss*
	River lamprey	*Lampetra ayresi*
	Sculpin spp.	*Cottus spp.*
	Smallmouth bass	*Micropterus dolomieu*
	Yellow perch	*Perca flavescens*
Marine Fish	Blue shark	*Prionace glauca*
	Pacific hake	*Merluccius productus*
	Pacific mackerel	*Scomber japanicus*
	Pacific sleeper shark	*Somniosus pacificus*
	Salmon shark	*Lamna diprosis*
	Spiny dogfish	*Squalus acanthias*
Avian	Double crested cormorant	*Phalacrororax auritus*
	Common merganser	*Mergus merganser*
	Gulls	*Larus spp.*
	Caspian tern	*Hydroprogne caspia*
	Bald eagle	*Haliaeetus leucocephalus*
	Osprey	*Pandion haliaetus*
Mammals	California sea lion	*Zalophus californianus*
	Dall's porpoise	*Phocoenoides dalli*
	Harbour seal	*Phocavitulina richardsi*
	Harbour porpoise	*Phocoena phocoena*
	Humpback whale	*Megaptera novaeangliae*
	Killer whale (residents)	*Orcinus orca*
	Northern fur seal	*Callorhinus ursinus*
	Pacific White-sided dolphin	*Lagenorhynchus obliquidens*
	Steller sea lion	*Eumetopias jubatus*
	Brown bear	*Ursus arctos*
	Black bear	*Ursus americanus*
	Coyote	*Canis latrans*
	Wolf	*Canis lupus*

4.3.3. Competition

Competition with Pacific salmon is present over a variety of habitats in both freshwater and marine environments. In freshwater streams, resource limitations coupled with high densities of hatchery fish suggest competition may significantly affect wild fish during their juvenile life stages, and constitute an important determinant of lifetime fitness (Tatara and Berejikian 2012). Interspecific competition within native assemblages of anadromous salmonids is minimized, as these species occupy somewhat different ecological niches both spatially or temporally (Hearn 1987; Quinn 2005). Competition for spawning area and displacement of redds made by conspecifics can be a major source of compensatory dynamics in salmon, yet at current population abundances for FRC, competition for spawning areas is likely lower than historic levels in most streams. It should be noted, however, this competition may be exacerbated by returning hatchery-origin individuals (discussed in detail in section Marine & Freshwater Aquaculture).

There is evidence that jellyfish populations in coastal ecosystems may be on the rise (Brotz et al. 2012; Purcell 2012), and it has been suggested pose a form of indirect exploitative competition to Pacific salmon. Jellyfish also have several characteristics that place them in an influential position to restructure energy flow through pelagic food webs: high rates of growth and reproduction, broad planktivorous diets, and apparently few predators as adults (Condon et al. 2012; Robinson et al. 2014). A recent study by (Weil et al. 2019) reported *Hyperiamedusarum,* an amphipod parasite of the fried-egg jellyfish, was prevalent in juvenile ocean-type Chinook diets in southeastern Vancouver Island, occurring in 47%, 36% and 29% of Chinook Salmon diets sampled in 2014 (N = 79), 2015 (N = 360) and 2016 (N = 761) respectively. The authors highlight that these results contrast with earlier results of (Argue et al. 1986), who did not report *H. medusarum* in the diets of Coho or Chinook Salmon sampled in the same region between 1973 and 1976. These results highlight the ongoing shifts in the marine environment that can lead to changes in prey and competitor species composition as seen in the above example.

Disease, predation, and competition are an interrelated and complex suite of factors, and the former two can exacerbate the degree of competition experienced by salmon such as FRC. For example, diseases caused by parasites and pathogens often change the behaviour of salmon such that they become more susceptible to predation or are left at a competitive disadvantage (Miller et al. 2014). High competition can result in exposure to higher predation and the threat of predators may incur vigilance costs that causes schooling behaviour and increases local competition. Although these interrelations are difficult to quantify, there are several anthropogenic factors that hypothetically or empirically have been shown to affect certain aspects of each. There is uncertainty in how natural competition may be affecting FRC, but cumulative impacts from other threats may exacerbate competition in ocean or freshwater environments.

4.4. ELEMENT 11: DISCUSSION OF THE POTENTIAL ECOLOGICAL IMPACTS OF THREATS FROM ELEMENT 8 TO THE TARGET SPECIES AND OTHER CO-OCCURRING SPECIES, CURRENT MONITORING EFFORTS, AND KNOWLEDGE GAPS

Co-occurring species typically take on the forms of predators, competitors, or prey, all of which will have a different relationship with regards to the threats that may impact Chinook Salmon abundance or behaviour. Predators will typically be negatively impacted by threats if the abundance of Chinook Salmon decreases; however, some threats may benefit predators by changing Chinook behaviour or ability to perceive predators. Possible threats that may have a positive impact for predators include heavy metal effluents that impact the chemosensory capabilities of Chinook Salmon or certain levels of sediment suspension may reduce a Chinook Salmon's ability to see but not affect some predators, thus increasing the likelihood a predator will succeed. Competitors will generally benefit from lower abundances of Chinook Salmon, but if a competitor has similar habitat or prey requirements that are also being impacted by various threats then they will correspondingly be impacted negatively. Competitors in the marine environment may be most at risk of similar threats to ocean productivity as Chinook Salmon are. Impacts to ocean productivity is also a direct impact to marine prey species of Chinook Salmon, who would normally benefit from reductions in Chinook Salmon abundance.

Most of the threats that would impact habitat features would also impact many of the co-occurring species. For example, any terrestrial predator would be impacted by changes to the watershed catchment such as decreases in forests or increased urbanization. Trees and riparian vegetation are also directly impacted as they are the habitat features that are often destroyed. In addition to habitat destruction, riparian vegetation can be impacted by declining salmon populations through a reduction in nutrient inputs from carcases (Hocking and Reynolds 2011). While the impact of reduced nutrients will varying in each watershed, it is likely to have a larger effect in smaller nutrient poor watersheds (Hocking and Reynolds 2011). Changes to freshwater flow through dams and irrigation will affect all aquatic species, most in a negative way. Some introduced and invasive species may benefit from increased temperature regimes in freshwater because they have physiological tolerance to high temperatures and can outcompete native species. The Ministry of Environment currently surveys introduced aquatic species and management action to eradicate them in several systems has occurred.

There are significant knowledge gaps surrounding FRC, particularly for the Spring and Summer 5_2 populations; the following is a brief summary of the main sources of uncertainty identified during this RPA process:

- FRC freshwater distribution spans a large geographical area within the Fraser Basin and much of this habitat has not been thoroughly studied. Furthermore, the marine distribution of FRC is poorly known due to a lack of CWT indicator programs for these DUs, and as a result, some of the distribution information reported in this RPA is inferred from limited data
- Although we have a basic understanding of the freshwater and marine biology of FRC, for most DUs we lack specific information such as egg-to-fry survival, detailed freshwater habitat use, productivity, stock-recruit data, and freshwater and marine survival information.
- There is no current smolt to age-3 survival data or harvest rate information for 10 of 11 DUs due to a lack of appropriate assessment information. For DUs 4 (LFR-Upper Pitt) and 5 (LFR-Summer), there is only moderate to high quality relative abundance data from one tributary in each DU, which may not represent changes at the DU level. For DUs 4, 5, 7 (MFR-Nahatlatch), 8 (MFR-Portage) and 14 (STh-Bessette), there have been no recent CWT releases and subsequent marine recoveries, thus all distributional information for those DUs is inferred.
- The impacts of fisheries (both targeted and non-targeted at Chinook) is currently limited or unknown for the majority of DUs. DU2 is the only population with a long-standing time series of CWT data; therefore, much of the information surrounding fisheries is inferred for the remaining DUs using the assessment of DU2 as a point of reference.
- There are significant gaps in our knowledge of current invasive species distributions, and their potential effects on FRC in both marine and freshwater environments. One species of particular concern is the European Green Crab, which is currently present in several locations within the Salish Sea, and is anticipated to continue to expand its range in BC.

- There are a multitude of sources for pollution in the Fraser River drainage, yet there is currently limited available information surrounding the effects of these contaminates on FRC, and how they affect FRC survival in both marine and freshwater environments.
- It is currently unknown what effects future large-scale increases in hatchery production will have on FRC, and whether these increases will lead to increased competition for finite and limited ecological resources between hatchery-origin and wild salmon in the Fraser River.

Without this information it is particularly difficult to assess stock status or set meaningful recovery targets that can be quantified. Part 2 of this RPA process will provide a more extensive list of recommended future research needs.

5. CONCLUDING REMARKS

The trend in abundance for each DU was reassessed following the (COSEWIC 2019), and none are showing signs of recovery. A workshop was convened to elicit expert opinion to examine threats and limiting factors to recovery of each DU. Based on the results of the threats workshop, all eleven DUs were considered to be at high or extreme risk, due to the severity and number of threats that each of the DUs are facing. Widespread freshwater habitat degradation related to insect infestations, wildfire and logging, and declining marine survival, all exacerbated by climate change are principal threats impeding recovery. Given that most of the DUs are stream-type, and have a greater reliance on freshwater habitat than ocean-types, the results of the workshop are not surprising. Based on the assessments completed during the workshop, all assessed DUs are at considerable risk of extinction in the next few generations if these threats are not mitigated.

Alleviating the multiple and complex threats to these DUs will be difficult, especially as many are exacerbated by climate change. Further, it is very difficult to restore vegetation and functional hydrographs from such widely impacted areas. It will be critical to ensure that efforts are appropriately coordinated through effective governance to successfully mitigate the cumulative impacts of these diverse threats. Additional research will be essential for improved prediction of outcomes, and to develop approaches to mitigate the impacts of the threats and limiting factors, especially under a more variable and constantly changing climate.

The second, and concluding report on the recovery potential assessments for these DUs will be forthcoming in 2020. That report will attempt to propose recovery targets for each DU, provide assessments of the potential to reach those targets under various assumptions of threat-mitigation, and generate DU-specific advice on amounts of harm that may be permissible while still achieving positive population growth.

6. REFERENCES CITED

Alderdice, D.F., and Velsen, F.P.J. 1978. Relation Between Temperature and Incubation Time for Eggs of Chinook Salmon (*Oncorhynchus tshawytscha*). J. Fish. Res. Board Canada 35(1): 69–75. doi:10.1139/f78-010.

Alderman, S.L., Dindia, L.A., Kennedy, C.J., Farrell, A.P., and Gillis, T.E. 2017a. Proteomic analysis of sockeye salmon serum as a tool for biomarker discovery and new insight into the sublethal toxicity of diluted bitumen. Comp. Biochem. Physiol. 22: 157–166. doi:10.1016/j.cbd.2017.04.003.

Alderman, S.L., Lin, F., Farrell, A.P., Kennedy, C.J., and Gillis, T.E. 2017b. Effects of diluted bitumen exposure on juvenile sockeye salmon: From cells to performance. Environ. Toxicol. Chem. 36(2): 354–360. doi:10.1002/etc.3533.

Alila, Y., and Beckers, J. 2001. Using numerical modelling to address hydrologic forest management issues in British Columbia. Hydrol. Process. 15(18): 3371–3387. doi:10.1002/hyp.1038.

Alsaadi, F., Hodson, P. V., and Langlois, V.S. 2018. An Embryonic Field of Study: The Aquatic Fate and Toxicity of Diluted Bitumen. Bull. Environ. Contam. Toxicol. 100: 8–13. Springer US. doi:10.1007/s00128-017-2239-7.

Anderson, D., Moggridge, H., Warren, P., and Shucksmith, J. 2014. The impacts of 'run-of-river' hydropower on the physical and ecological condition of rivers. Water Environ. J. 29(2): 268–276. doi:10.1111/wej.12101.

Argue, A., Hillaby, B., and Shepard, C. 1986. Distribution, timing, change in size, and stomach contents of juvenile chinook and Coho salmon caught in Cowichan Estuary and Bay, 1973, 1975, 1976. Can. Tech. Rep. Fish. Aquat. Sci. No. 1431.

Arkoosh, M.R., Boylen, D., Dietrich, J., Anulacion, B.F., GinaYlitalo, Bravo, C.F., Johnson, L.L., Loge, F.J., and Collier, T.K. 2010. Disease susceptibility of salmon exposed to polybrominated diphenyl ethers (PBDEs). Aquat. Toxicol. 98(1): 51–59. doi:10.1016/j.aquatox.2010.01.013.

Arkoosh, M.R., Casillas, E., Clemons, E., Kagley, A.N., Olson, R., Reno, P., and Stein, J.E. 1998. Effect of pollution on fish diseases: Potential impacts on salmonid populations. J. Aquat. Anim. Health 10(2): 182–190. doi:10.1577/1548-8667(1998)010<0182:EOPOFD>2.0.CO;2.

Arkoosh, M.R., Casillas, E., Clemons, E., McCain, B., and Varanasi, U. 1991. Suppression of immunological memory in juvenile chinook salmon (*Oncorhynchus tshawytscha*) from an urban estuary. Fish Shellfish Immunol. 1(4): 261–277. doi:10.1016/S1050-4648(05)80065-8.

Arostegui, M.C., Smith, J.M., Kagley, A.N., Spilsbury-Pucci, D., Fresh, K.L., and Quinn, T.P. 2017. Spatially clustered movement patterns and segregation of subadult chinook salmon within the salish sea. Mar. Coast. Fish. 9(1): 1–12. doi:10.1080/19425120.2016.1249580.

Baird, R.W. 2001. Status of Harbour Seals, Phoca vitulina, in Canada. Can. Field-Naturalist 115(4): 663–675.

Bakke, T.A., and Harris, P.D. 1998. Diseases and parasites in wild Atlantic salmon (Salmo salar) populations. Can. J. Fish. Aquat. Sci. 55(SUPPL.1): 247–266. doi:10.1139/d98-021.

Ballard, T.M., and Krueger, W.C. 2005. Cattle and salmon II: Inference of Animal Activity From GPS Collar Data on Free-Ranging Cattle. Rangel. Ecol. Manag. 58(3): 274–278. doi:10.2111/1551-5028(2005)58.

Barnes, W.J. 1999. The Rapid Growth of a Population of Reed Canarygrass (Phalaris arundinacea L.) and Its Impact on Some River bottom Herbs. J. Torrey Bot. Soc. 126(2): 133–138.

Barnett-Johnson, R., Grimes, C.B., Royer, C.F., and Donohoe, C.J. 2007. Identifying the contribution of wild and hatchery Chinook salmon (*Oncorhynchus tshawytscha*) to the ocean fishery using otolith microstructure as natural tags. Can. J. Fish. Aquat. Sci. 64: 1683–1692. doi:10.1139/F07-129.

Barton, B.A., Schreck, C., Ewing, R.D., and Patino, R. 1985. Changes in plasma cortisol during stress and smoltification in Coho Salmon, *Oncorhynchus kisutch*. Gen. Comp. Endocrinol. 59(3): 468–471.

Bass, A.L., Hinch, S.G., Teffer, A.K., Patterson, D.A., and Miller, K.M. 2017. A survey of microparasites present in adult migrating Chinook salmon (*Oncorhynchus tshawytscha*) in south-western British Columbia determined by high-throughput quantitative polymerase chain reaction. J. Fish Dis. 40(4): 453–477. doi:10.1111/jfd.12607.

Bayley, P.B. 1991. The flood pulse advantage and the restoration of river-floodplain systems. Regul. Rivers Res. Manag. 6(2): 75–86. doi:10.1002/rrr.3450060203.

BC Ministry of Agriculture. 2016. Agricultural Land Use Inventory: Fraser Valley Regional District, Summer 2011-2013 (Reference No. 800.510-24.2013). Abbotsford, B.C. (Accessed July 21, 2020)

BC Ministry of Forestry. 2004. Quesnel timber supply area. Rationale for annual allowable cut (AAC) determination, effective 1 October 2004. 63 p.

BC Ministry of Forests and Range. 2005. Merritt timber supply area. Rationale for annual allowable cut (AAC) determination, effective 1 July 2005. 63 p.

Beacham, T.D., Gould, A.P., Withler, R.E., Murray, C.B., and Barner, L.W. 1987. Biochemical Genetic Survey and Stock Identification of Chum Salmon (*Oncorhynchus keta*) in British Columbia. Can. J. Fish. Aquat. Sci. 44(10): 1702–1713. doi:10.1139/f87-209.

Beacham, T.D., and Murray, C.B. 1990. Temperature, Egg Size, and Development of Embryos and Alevins of Five Species of Pacific Salmon: A Comparative Analysis. Trans. Am. Fish. Soc. 119(6): 927–945. doi:10.1577/1548-8659(1990)119<0927:tesado>2.3.co;2.

Beacham, T.D., Supernault, K.J., Wetklo, M., Deagle, B., Labaree, K., Irvine, J.R., Candy, J.R., Miller, K.M., Nelson, R.J., and Withler, R.E. 2003. The geographic basis for population structure in Fraser River chinook salmon (*Oncorhynchus tshawytscha*). Fish. Bull. 101(2): 229–242.

Beakes, M.P., Moore, J.W., Hayes, S.A., and Sogard, S.M. 2014. Wildfire and the effects of shifting stream temperature on salmonids. Ecosphere 5(5): 1–14. doi:10.1890/ES13-00325.1.

Beamer, E.M., and Henderson, R.A. 1998. Juvenile Salmonid Use of Natural and Hydromodified Stream Bank Habitat in the Mainstem Skagit River, Northwest Washington. State of Idaho Department of Fish and Game. Skagit System Cooperative Research Department. 52 p.

Beamish, R., and Neville, C. 1995. Pacific salmon and Pacific herring mortalities in the Fraser River plume caused by river lamprey (*Lampetra ayresi*). Can. J. Fish. Aquat. Sci. 52: 644–650.

Beamish, R.J., Lange, K.L., Neville, C.M., Sweeting, R.M., and Beacham, T.D. 2011. Structural patterns in the distribution of ocean- and stream-type juvenile chinook salmon populations in the Strait of Georgia in 2010 during the critical early marine period. North pacific Anadromous Fish Commision. Doc. 1354.

Beamish, R.J., and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Prog. Oceanogr. 49(1–4): 423–437. doi:10.1016/S0079-6611(01)00034-9.

Beamish, R.J., and Neville, C.M. 2001. Predation-based mortality on juvenile salmon in the Strait of Georgia. Tech. Rep. North Pacific Anadromous Fish Comm. 2(October): 11–13. doi:10.13140/RG.2.2.32170.00968.

Becker, D. 1973. Food and growth parameters of juvenile chinook salmon, Oncorhynchus tshawytscha, In Central Columbia River. Fish. Bull. 71(2): 387–400.

Bell, R. 1958. Time, Size, and Estimated Numbers of Seaward Migrations of Chinook Salmon and Steelhead Trout in the Brownlee-Oxbow Section of the Middle Snake River. *In* Journal of Chemical Information and Modeling. Boise, Idaho, U.S.A. doi:10.1017/CBO9781107415324.004.

Berejikian, B., and Ford, M. 2003. Review of relative fitness of hatchery and natural salmon. National Marine Fisheries Service, Northwest Fisheries Science Center. Seattle, WA. NMFSNWFSC-61. 29 p.

Beschta, R., Bilby, R., Brown, G., Holtby, L., and Hofstra, T. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. Streamside Manag. For. Fish. Interact.: 191–232. (Accessed Jul 21, 2020)

BGC. 2018. Squamish-Lillooet Regional District Seton Portage Integrated Hydrogeomorphic Assessment. BCG Engineering Inc. Pemberton, BC. 355 p. (Accessed Jul 21, 2020)

Birtwell, I., Levings, C., Macdonald, J., and Rogers, I. 1988. A review of fish habitat issues in the Fraser River system. Water Pollut. Res. J. Canada 23(1): 1–30.

Birtwell, I.K., Nassichuk, M.D., Beune, H., and Gang, M. 1987. Deas Slough, Fraser River Estuary, British Columbia: general description and some aquatic characteristics. Can. Manuscr. Rep. Fish. Aquat. Sci. 1926: 45 p.

Bisson, P.A., and Bilby, R.E. 1982. Avoidance of Suspended Sediment by Juvenile Coho Salmon. North Am. J. Fish. Manag. 4: 371–374. doi:10.1577/1548-8659(1982)2<371:AOSSBJ>2.0.CO;2.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Trans. Am. Fish. Soc. 100(3): 423–438.

Bjornn, T.C., and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. *In* Meehan W.R. (Ed.): Influence of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. pp. 83–138.

Bladon, K.D., Segura, C., Cook, N.A., Bywater-Reyes, S., and Reiter, M. 2018. A multicatchment analysis of headwater and downstream temperature effects from contemporary forest harvesting. Hydrol. Process. 32(2): 293–304. doi:10.1002/hyp.11415.

Blais, J.M. 2005. Biogeochemistry of persistent bioaccumulative toxicants: Processes affecting the transport of contaminants to remote areas. Can. J. Fish. Aquat. Sci. 62(1): 236–243. doi:10.1139/f04-226.

Blais, J.M., Schindler, D.W., Sharp, M., Braekevelt, E., Lafreniĕre, M., McDonald, K., Muir, D.C.G., and Strachan, W.M.J. 2001. Fluxes of semivolatile organochlorine compounds in Bow Lake, a high-altitude, glacier-fed, subalpine lake in the Canadian rocky mountains. Limnol. Oceanogr. 46(8): 2019–2031. doi:10.4319/lo.2001.46.8.2019.

Boles, G.L., Turek, S., Maxwell, C., and McGill, D.M. 1988. Water Temperature Effects on Chinook Salmon (*Oncorhychus tshawytscha*) with Emphasis on the Sacremento River. A Literature Review. State of California Department of Water Resources, Northern District. 97 p.

Bollens, S., vanden Hooff, R., Butler, M., Cordell, J., and Frost, B. 2010. Feeding ecology of juvenile pacific salmon (*Oncorhynchus spp*.) in a northeast pacific fjord: Diet, availability of zooplankton, selectivity for prey, and potential competition for prey resources. Fish. Bull. 108(4): 393–407.

Bond, N.A., Cronin, M.F., Freeland, H., and Mantua, N. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophys. Res. Lett. 42(9): 3414–3420. doi:10.1002/2015GL063306.

Bonsal, B.R., Peters, D.L., Seglenieks, F., Rivera, A., and Berg, A. 2019. Changes in freshwater availability across Canada; Chapter 6 in Canada's Changing Climate Report. pp. 261–342.

Booth, D.B., Hartley, D., and Jackson, R. 2002. Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts1. J. Am. Water Resour. Assoc. 38(3): 835–845. doi:10.1111/j.1752-1688.2002.tb01000.x.

Bowerman, T., Roumasset, A., Keefer, M.L., Sharpe, C.S., and Caudill, C.C. 2018. Prespawn Mortality of Female Chinook Salmon Increases with Water Temperature and Percent Hatchery Origin. Trans. Am. Fish. Soc. 147(1): 31–42. doi:10.1002/tafs.10022.

Bradford, M.J. 1994. Trends in the Abundance of Chinook Salmon Oncorhynchus tshawyfscha) of the Nechako River, British Columbia. Can. J. Fish. Aquat. Sci. 51: 965–974.

Bradford, M.J., Higgins, P.S., Korman, J., and Sneep, J. 2011. Test of an environmental flow release in a British Columbia river: Does more water mean more fish? Freshw. Biol. 56(10): 2119–2134. doi:10.1111/j.1365-2427.2011.02633.x.

Bradford, M.J., and Irvine, J.R. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Can. J. Fish. Aquat. Sci. 57(1): 13–16. doi:10.1139/f99-283.

Bradford, M.J., and Taylor, G.C. 1997. Individual variation in dispersal behaviour of newly emerged chinook salmon (*Oncorhynchus tshawytscha*) from the Upper Fraser River, British Columbia. Can. J. Fish. Aquat. Sci. 54(7): 1585–1592. doi:10.1139/cjfas-54-7-1585.

Bradford, M.J., Tovey, C.P., and Herborg, L.M. 2008a. Biological Risk Assessment for Yellow Perch (*Perch flavescens*) in British Columbia. Can. Sci. Advis. Sec. Res. Doc 2008/073: vi + 27.

Bradford, M.J., Tovey, C.P., and Herborg, L.M. 2008b. Biological Risk Assessment for Northern Pike (*Esox lucius*), Pumpkinseed (*Lepomis gibbosus*), and Walleye (*Sander vitreus*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc 2008/074: viii + 46.

Brannon, E.L., Currens, K.P., and Lichatowich, J.A. 1999. Review of Artificial Production of Anadromous and Resident Fish in the Columbia River Basin, Part I: A Scientific Basis for Columbia River Production Program. Northwest Power Planning Council, Document 99-4 (April 1999).

Brannon, E.L., Powell, M.S., Quinn, T.P., and Talbot, A. 2004. Population structure of Columbia River Basin chinook salmon and steelhead trout. *In* Reviews in Fisheries Science. doi:10.1080/10641260490280313.

Braun, D.C., Moore, J.W., Candy, J., and Bailey, R.E. 2016. Population diversity in salmon: Linkages among response, genetic and life history diversity. Ecography (Cop.). 39(3): 317–328. doi:10.1111/ecog.01102.

Bravo, C.F., Curtis, L.R., Myers, M.S., Meador, J.P., Johnson, L.L., Buzitis, J., Collier, T.K., Morrow, J.D., Laetz, C.A., Loge, F.J., and Arkoosh, M.R. 2011. Biomarker responses and disease susceptibility in juvenile rainbow trout *Oncorhynchus mykiss* fed a high molecular weight PAH mixture. Environ. Toxicol. Chem. 30(3): 704–714. doi:10.1002/etc.439.

Brett, J.R., Clarke, W.C., and Shelbourn, J.E. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile chinook salmon *Oncorhynchus tshawytscha*. Can. Tech. Rep. Fish. Aquat. Sci. (1127): 1–29.

Brotz, L., Cheung, .W.L., Kleisner, K., Pakhomov, E., and Pauly, D. 2012. Increasing Jellyfish Populations: Trends in Large Marine Ecosystems. Hydrobiologia 690(1): 3–20. doi:10.1007/s10750-012-1039-7.

Brown, G., S.J. Baillie, M.E. Thiess, J.R. Candy, C.K. Parken, G. Pestal, Willis, D.M. 2013. Pre-COSEWIC assessment of southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) populations. CSAP 2012/13 P23.

Brown, G., Riddell, B., Chen, D., and Bradford, M. 2001. A biologically-based escapement goal for Harrison River fall Chinook (Draft). Pacific Scientific Advice Review Committee, Salmon Subcommittee Working Paper S2001-16.

Brown, G.S., Baillie, S.J., Thiess, M.E., Bailey, R.E., Candy, J.R., Parken, C.K., and Willis, D.M. 2019. Pre-COSEWIC review of southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) conservation units, Part I: background. Can. Sci. Advis. Sec. Res. Doc. 2019/11(April): vii + 67 pp.

Brown, T.., Runciman, B., Bradford, M.., and Pollard, S. 2009a. Biological Synopsis of Yellow Perch in British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2883: 36 p.

Brown, T., Runciman, B., Pollard, S., and Grant, A. 2009b. Biological Synopsis of Largemouth Bass (Micropterus. Can. Manuscr. Rep. Fish. Aquat. Sci. 2884: V+27.

Brown, T.G. 2002. Floodplains, flooding, and salmon rearing habitats in British Columbia: A review. DFO Can. Sci. Advis. Sec. Res. Doc 2002/007: 1–155.

Brown, T.G., Runciman, B., Pollard, S., Grant, A.D.A., and Bradford, M.J. 2009c. Biological Synopsis of Smallmouth Bass (*Micropterus dolomieu*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2887: 58.

Brown, T.G., White, E., Kelly, D., Rzen, L., and Rutten, J. 1994. Availability of juvenile chinook salmon to predators along the margins of the Nechako and Stuart river, B.C. Can. Manuscr. Rep. Fish. Aquat. Sci. 2245: 34.

Brown, T.G., and Winchell, P. 2002. Use of Shuswap Lake foreshore by juvenile salmonids. Paper given at Institute of Ocean Science, Victoria, B.C. at MEHSD all staff meeting on Nov 27/2002.

Brown, T.G., and Winchell, P. 2004. Fish Community of Shuswap Lake's Foreshore. Can. Tech. Rep. Fish. Aquat. Sci. 2568: 60.

Brown, T.J., Whitehouse, T.R., and Levings, C.D. 1989. Beach seine data from the Fraser River at the north arm and main arm, and Agassiz during 1987-88. Can. Data Rep. Fish. Aquat. Sci. 737: 134 p.

Van Bruggen, A.H.C., He, M.M., Shin, K., Mai, V., Jeong, K.C., Finckh, M.R., and Morris, J.G. 2018. Environmental and health effects of the herbicide glyphosate. Sci. Total Environ. 616–617: 255–268. doi:10.1016/j.scitotenv.2017.10.309.

Brusven, M.A., Meehan, W.R., and Ward, J.F. 1986. Summer Use of Simulated Undercut Banks by Juvenile. North Am. J. Fish. Manag. 6: 32–37.

Buhl, K.J., and Hamilton, S.J. 1998. Acute toxicity of fire-retardant and foam-suppressant chemicals to early life stages of chinook salmon (*Oncorhynchus tshawytscha*). Environ. Toxicol. Chem. 17(8): 1589–1599. doi:10.1897/1551-5028(1998)017<1589:ATOFRA>2.3.CO;2.

Burdick, D.M., and Short, F.T. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. Environ. Manage. 23(2): 231–240. doi:10.1007/s002679900182.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish Wildl. Serv. Fish. Bull. 52: 94–110. doi:10.1038/nature02831.1.

Burt, J.M., Hinch, S.G., and Patterson, D.A. 2012. Developmental temperature stress and parental identity shape offspring burst swimming performance in sockeye salmon (*Oncorhynchus nerka*). Ecol. Freshw. Fish 21(2): 176–188. doi:10.1111/j.1600-0633.2011.00535.x.

Bush, E., and Lemmen, D. 2019. Canada's Changing Climate Report. Government of Canada, Ottawa, ON. (Accessed July 21, 2020)

Bustard, D.R. 1986. Some differences between coastal and interior stream ecosystems and the implication to juvenile fish production. Pages 117-126, in J.H. Patterson (ed.), Proceedings of the Workshop on Habitat Improvements, Whistler, B.C. Can. Tech. Rep. Fish. Aquat. Sci.: 117–126.

Caldeira, K., Archer, D., Barry, J.P., Bellerby, R.G.J., Brewer, P.G., Cao, L., Dickson, A.G., Doney, S.C., Elderfield, H., Fabry, V.J., Felly, R.A., Gattuso, J.P., Haugan, P.M., Hoegh-Guldberg, O., Jain, A.K., Kleypas, J.A., Langdon, C., Orr, J.C., Ridgwell, A., Sabine, C.L., Seibel, B.A., Shirayama, Y., Turley, C., Watson, A.J., and Zeebe, R.E. 2007. Comment on "Modern-age buildup of CO2 and its effects on seawater acidity and salinity" by Hugo A. Loáiciga. Geophys. Res. Lett. 34(18): 3–5. doi:10.1029/2006GL027288.

Caldeira, K., and Wickett, M.E. 2003. Anthropogenic carbon and ocean pH. Nature 425(6956): 365. doi:10.1038/425365a.

Cambary, J.A. 2003. Impact on indigenous species biodiversity caused by the globalisation of alien recreation freshwater fisheries. Hydrobiologia 500: 217–230. doi:8.

Campbell, P.M., and Devlin, R.H. 1997. Increased CYP1A1 and Ribosomal Protein L5 Gene Expression: The Response of Juvenile Chinook Salmon to Coal Dust Exposure. Aquat. Toxicol. 38(1–3): 1–15.

Candy, J.R., Irvine, J.R., Parken, C.K., Lemke, S.L., Bailey, R.E., Wetklo, M., and Jonsen, K. 2002. A discussion paper on possible new stock groupings (Conservation Units) for Fraser River Chinook Salmon. Can. Sci. Advis. Sec. Res. Doc. 2002/085. 57 p.

Carey, A.J., Lanksbury, J., Niewolny, L.A., West, J.E., Ylitalo, G., Johnson, L., and O'Neill, S.M. 2017. Assessing the threat of toxic contamination to early marine survival of Chinook salmon from Puget Sound. *In* Salish Sea Ecosystem Conference.

Carlson, S.M., and Satterthwaite, W.H. 2011. Weakened portfolio effect in a collapsed salmon population complex. Can. J. Fish. Aquat. Sci. 68(9): 1579–1589. doi:10.1139/f2011-084.

Carter, K. 2005. The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage. Implications for Klamath Basin TMDLs. Quality (August).

Casillas, E., McCain, B.B., Arkoosh, M., and Stein, J.E. 1997. Estuarine Pollution and Juvenile Salmon Health: Potential Impact on Survival. *In* Estuarine and ocean survival of Northeastern Pacific Salmon: Proceedings of the workshop. *Edited by* R.L. Emmett and M.H. Schiewe. U.S. Dep. Commer. NOAA Tech. Memo. p. 313.

Cathey, H., and Campbell, L. 1975. Security lighting and its impact on the landscape. J. Arboric. 1: 181–187.

Cavole, L., Demko, A., Diner, R., Giddings, A., Koester, I., Pagniello, C., Paulsen, M.-L., Ramirez-Valdez, A., Schwenck, S., Yen, N., Zill, M., and Franks, P. 2016. Biological Impacts of the 2013–2015 Warm-Water Anomaly in the Northeast Pacific: Winners, Losers, and the Future. Oceanography 29(2): 273–285. doi:10.5670/oceanog.2016.32.

Chalifour, L., Scott, D.C., MacDuffee, M., Iacarella, J.C., Martin, T.G., and Baum, J.K. 2019. Habitat use by juvenile salmon, other migratory fish, and resident fish species underscores the importance of estuarine habitat mosaics. Mar. Ecol. Prog. Ser. 625: 145–162. doi:10.3354/meps13064.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Trans. Am. Fish. Soc. 117: 1–21. doi:10.1097/00000658-193404000-00017.

Chapman, D.W., and Knudsen, E. 1980. Channelization and Livestock Impacts on Salmonid Habitat and Biomass in Western Washington. Trans. Am. Fish. Soc. 109: 357–363. doi:10.1577/1548-8659(1980)109<357:CALIOS>2.0.CO;2.

Chasco, B., Kaplan, I.C., Thomas, A., Acevedo-Gutiérrez, A., Noren, D., Ford, M.J., Hanson, M.B., Scordino, J., Jeffries, S., Pearson, S., Marshall, K.N., and Ward, E.J. 2017. Estimates of chinook salmon consumption in Washington State inland waters by four marine mammal predators from 1970 to 2015. Can. J. Fish. Aquat. Sci. 74(8): 1173–1194. doi:10.1139/cjfas-2016-0203.

Chittenden, C.M., Sweeting, R., Neville, C.M., Young, K., Galbraith, M., Carmack, E., Vagle, S., Dempsey, M., Eert, J., and Beamish, R.J. 2018. Estuarine and marine diets of out-migrating Chinook Salmon smolts in relation to local zooplankton populations, including harmful blooms. Estuar. Coast. Shelf Sci. 200: 335–348. doi:10.1016/j.ecss.2017.11.021.

Choi, G., Robinson, D.A., and Kang, S. 2010. Changing northern hemisphere snow seasons. J. Clim. 23(19): 5305–5310. doi:10.1175/2010JCLI3644.1.

Christensen, V., and Trites, A.W. 2011. Predation on Fraser River Sockeye Salmon. Cohen Commission Technical Report 8. (Accessed July 21, 2020)

Di Cicco, E., Ferguson, H.W., Schulze, A.D., Kaukinen, K.H., Li, S., Vanderstichel, R., Wessel, Ø., Rimstad, E., Gardner, I.A., Hammell, K.L., and Miller, K.M. 2017. Heart and skeletal muscle inflammation (HSMI) disease diagnosed on a British Columbia salmon farm through a longitudinal farm study. *In* PLoS ONE. doi:10.1371/journal.pone.0171471.

Clague, J.J., and Bobrowsky, P.T. 1999. The Geological Signature of Great Earthquakes off Canada's West Coast. Geosci. Canada 26(1): 15 p.

Clague, J.J., Munro, A., and Murty, T. 2003. Tsunami hazard and risk in Canada. Nat. Hazards 28(June): 433–461.

Clark, T.D., Sandblom, E., Cox, G.K., Hinch, S.G., and Farrell, A.P. 2008. Circulatory limits to oxygen supply during an acute temperature increase in the Chinook salmon (Oncorhynchus tshawytscha). Am. J. Physiol. - Regul. Integr. Comp. Physiol. 295(5): 1631–1639. doi:10.1152/ajpregu.90461.2008.

Cohen, B.I. 2012. The Uncertain Future of Fraser River Sockeye. Volume 1: The Sockeye Fishery. (Accessed July 21, 2020)

Cole, E., and Newton, M. 2013. Influence of streamside buffers on stream temperature response following clear-cut harvesting in western Oregon. Can. J. For. Res. 43(11): 993–1005. doi:10.1139/cjfr-2013-0138.

Collie, J.S., Peterman, R.M., and Walters, C.J. 1990. Experimental harvest policies for a mixed-stock fishery: Fraser River sockeye salmon, *Oncorhynchus nerka*. Can. J. Fish. Aquat. Sci. 47(1): 145–155. doi:10.1139/f90-015.

Collins, S.F., Baxter, C. V., Marcarelli, A.M., and Wipfli, M.S. 2016. Effects of experimentally added salmon subsidies on resident fishes via direct and indirect pathways. Ecosphere 7(3): 1–18. doi:10.1002/ecs2.1248.

Condon, R.H., Graham, W.M., Duarte, C.M., Pitt, K.A., Lucas, C.H., Haddock, S.H.D., Sutherland, K.R., Robinson, K.L., Dawson, M.N., Decker, M.B., Mills, C.E., Purcell, J.E., Malej, A., Mianzan, H., Uye, S., Gelcich, S., and Madin, L.P. 2012. Questioning the Rise of Gelatinous Zooplankton in the World's Oceans. Bioscience 62(2): 160–169. doi:10.1525/bio.2012.62.2.9.

Connor, W.P., Burge, H.L., Waitt, R., and Bjornn, T.C. 2002. Juvenile Life History of Wild Fall Chinook Salmon in the Snake and Clearwater Rivers. North Am. J. Fish. Manag. 22(3): 703–712. doi:10.1577/1548-8675(2002)022<0703:jlhowf>2.0.co;2.

COSEWIC. 2017. COSEWIC assessment and status report on the Chinook Salmon *Oncorhynchus tshawytscha*, Okanagan population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 62 pp.

COSEWIC 2019. COSEWIC assessment and status report on the Chinook Salmon *Oncorhynchus tshawytscha*, Designatable Units in Southern British Columbia (Part One – Designatable Units with no or low levels of artificial releases in the last 12 years), in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxxi + 283 pp.

Counihan, T.D., Hardiman, J.M., Burgess, D.S., Simmons, K.E., Holmberg, G., Rogala, J.A., and Polacek, R.R. 2012. Assessing Native and Introduced Fish Predation on Migrating Juvenile Salmon in Priest Rapids and Wanapum Reservoirs, Columbia River, Washington, 2009–11. U.S. Department of the Interior; U.S. Geological Survey. Report 2012–1130.

Coutant, C.C., and Whitney, R.R. 2000. Fish Behavior in Relation to Passage through Hydropower Turbines: A Review. Trans. Am. Fish. Soc. 129(2): 351–380. doi:10.1577/1548-8659(2000)129<0351:fbirtp>2.0.co;2.

Cramer, S.P. 1990. Contribution of Sacremento Basin hatcheries to ocean catch and river escapement of fall chinook salmon. California Department of Water Resources. Sacramento, CA.

Crooks, J.A. 2002. Characterizing ecosystem-level consequences of biological invasions: The role of ecosystem engineers. Oikos 97(2): 153–166. doi:10.1034/j.1600-0706.2002.970201.x.

CTC. 2018. 2017 Exploitation rate analysis and Model calibration. Pacific Salmon Commission Joint Chinook Technical Committee, Report TCCHINOOK. 18(01): 135 p.

Cullon, D.L., Yunker, M.B., Alleyne, C., Dangerfield, N.J., O'Neill, S., Whiticar, M.J., and Ross, P.S. 2009. Persistent organic pollutants in Chinook Salmon (*Oncorhynchus tshawytscha*): Implications for resident killer whales of British Columbia and adjacent waters. Environ. Toxicol. Chem. 28(1): 148–161. doi:10.1897/08-125.1.

D'Eon-Eggertson, F., Dulvy, N.K., and Peterman, R.M. 2015. Reliable Identification of Declining Populations in an Uncertain World. Conserv. Lett. 8(2): 86–96. doi:10.1111/conl.12123.

Daly, E.A., Brodeur, R.D., and Auth, T.D. 2017. Anomalous ocean conditions in 2015: Impacts on spring Chinook salmon and their prey field. Mar. Ecol. Prog. Ser. 566(September 2014): 168–182. doi:10.3354/meps12021.

Daughton, C., and Brooks, B. 2011. Active Pharmaceutical Ingredients and Aquatic Organisms. Environ. Contam. Biota: 287–347. doi:10.1201/b10598-10.

David, A.T., Simenstad, C.A., Cordell, J.R., Toft, J.D., Ellings, C.S., Gray, A., and Berge, H.B. 2016. Wetland Loss, Juvenile Salmon Foraging Performance, and Density Dependence in Pacific Northwest Estuaries. Estuaries and Coasts 39(3): 767–780. doi:10.1007/s12237-015-0041-5.

Debruyn, A.M.H., Ikonomou, M.G., and Gobas, F.A.P.C. 2004. Magnification and toxicity of PCBs, PCDDs, and PCDFs in upriver-migrating pacific salmon. Environ. Sci. Technol. 38(23): 6217–6224. doi:10.1021/es049607w.

Déry, S.J., Hernández-Henríquez, M.A., Owens, P.N., Parkes, M.W., and Petticrew, E.L. 2012. A century of hydrological variability and trends in the Fraser River Basin. Environ. Res. Lett. 7(2). doi:10.1088/1748-9326/7/2/024019.

Desforges, J.P.W., Galbraith, M., and Ross, P.S. 2015. Ingestion of Microplastics by Zooplankton in the Northeast Pacific Ocean. Arch. Environ. Contam. Toxicol. 69(3): 320–330. Springer US. doi:10.1007/s00244-015-0172-5.

Dewailly, E., Nantel, A., Weber, J.P., and Meyer, F. 1989. High levels of PCBs in breast milk of inuit women from arctic quebec. Bull. Environ. Contam. Toxicol. 43(5): 641–646. doi:10.1007/BF01701981.

Dextrase, A.J., and Mandrak, N.E. 2006. Impacts of alien invasive species on freshwater fauna at risk in Canada. Biol. Invasions 8(1): 13–24. doi:10.1007/s10530-005-0232-2.

DFO. 2010. Proceedings of the National Workshop on Six Invasive Fishes Risk Assessment in British Columbia; March 4-6, 2008. DFO Can. Sci. Advis. Secr. Proc. Ser. 2009/040.

DFO. 2011. Science Advice from a Risk Assessment of Smallmouth Bass (*Micropterus dolomieu*) In British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/085.

DFO. 2013. Review and Update of Southern BC Chinook Conservation Unit Assignments. DFO Can. Sci. Advis. Secr. Sci. Resp. 2013/022.

DFO. 2014. Guidance on assessing threats, ecological risk and ecological impacts for species at risk. DFO Can. Sci. Advis. Secr. Sci. Advis. Rep. 2014/013.

DFO. 2016. Review of long term monitoring results from small hydro projects to verify impacts of instream flow diversion on fish and fish habitat. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/048.

DFO. 2018a. Science information to support consultation on BC Chinook Salmon fishery management measures in 2018. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/035.

Dietrich, J.P., Van Gaest, A.L., Strickland, S.A., Hutchinson, G.P., Krupkin, A.B., and Arkoosh, M.R. 2014. Toxicity of PHOS-CHEK LC-95A and 259F fire retardants to ocean- and stream-type Chinook salmon and their potential to recover before seawater entry. Sci. Total Environ. 490: 610–621. Elsevier B.V. doi:10.1016/j.scitotenv.2014.05.038.

Dietrich, J.P., Myers, M.S., Strickland, S.A., Van Gaest, A., and Arkoosh, M.R. 2013. Toxicity of forest fire retardant chemicals to stream-type chinook salmon undergoing parr-smolt transformation. Environ. Toxicol. Chem. 32(1): 236–247. doi:10.1002/etc.2052.

Diewart, R. 2007. Habitat requirements for ten Pacific salmon life-history strategies. Prepared for Fisheries and Oceans Canada, Habitat and Enhancement Branch (Unpublished Data).

Dobson, D., Holt, K., and Davis, B. 2019. A technical review of the Fraser River Chinook management approach. DFO Can. Sci. Advis. Sec. Res. Doc. x +271 pp. (In Revision)

Dorava, J.M., and Moore, G.W. 1997. Effects of boatwakes on streambank erosion Kenai River, Alaska. US Geological Survey; Alaska Department of Fish and Game. (Accessed July 21, 2020)

Dorner, B., Catalano, M.J., and Peterman, R.M. 2018. Spatial and temporal patterns of covariation in productivity of chinook salmon populations of the northeastern pacific ocean. Can. J. Fish. Aquat. Sci. 75(7): 1082–1095. doi:10.1139/cjfas-2017-0197.

Douglas, T. 2006. Review of groundwater-salmon interactions in British Columbia. Watershed Watch Salmon Society and Walter & Duncan Gordon Foundation. Watershed Watch Salmon Society. (Accessed July 21, 2020)

Doutaz, D. 2019. Columbia river northern pike - investigating the ecology of British Columbia's new apex invasive freshwater predator. MSc Thesis. Thompson Rivers University. (Accessed July 21, 2020)

Ducommun, G. 2013. ATK Source Report on Chinook Salmon (*Oncorhynchus tshawytscha*) (Vancouver Island, Sunshine Coast, and Fraser River populations) in Canada. Prepared for Aboriginal Traditional Knowledge Sub-Committee of the Committee on the Status of Endangered Wildlife in.

Duffy, E.J., and Beauchamp, D.A. 2011. Rapid growth in the early marine period improves the marine survival of Chinook salmon (*Oncorhynchus tshawytscha*) in Puget Sound, Washington. Can. J. Fish. Aquat. Sci. 68(2): 232–240. doi:10.1139/F10-144.

Duffy, E.J., Beauchamp, D.A., Sweeting, R.M., Beamish, R.J., and Brennan, J.S. 2010. Ontogenetic Diet Shifts of Juvenile Chinook Salmon in Nearshore and Offshore Habitats of Puget Sound. Trans. Am. Fish. Soc. 139(3): 803–823. doi:10.1577/t08-244.1.

Dunford, W. 1975. Space and food utilization by salmonids in marsh habitats of the Fraser River estuary. MSc Thesis. University of Toronto.

Dunham, J., Lockwood, J., and Mebane, C. 2001. Salmonid distributions and temperature. Prepared as Part of Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA-910-D-01-002.

EDI Environmental Dynamics Inc. 2008. Mountain Pine Beetle Infestation: Hydrological Impacts. Report for The B.C. Ministry of Environment Mountain Pine Beetle Action Team.

El-Sabaawi, R., Dower, J., Kainz, M., and Mazumder, A. 2009. Interannual variability in fatty acid composition of the copepod Neocalanus plumchrus in the Strait of Georgia, British Columbia. Mar. Ecol. Prog. Ser. 382: 151–161. doi:10.3354/meps07915.

Eliason, E.J., Clark, T.D., Hague, M.J., Hanson, L.M., Gallagher, Z.S., Jeffries, K.M., Gale, M.K., Patterson, D.A., Hinch, S.G., and Farrell, A.P. 2011. Differences in thermal tolerance among sockeye salmon populations. Science (80-.). 332(6025): 109–112. doi:10.1126/science.1199158.

English, K.K., Bailey, R.E., and Robichaud, D. 2007. Assessment of Chinook Salmon returns to the Fraser River watershed using run reconstruction techniques, 1982-04. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/020. vi + 76.

English, K.K., Peacock, D., and Spilsted, B. 2006. North and Central Coast Core Stock Assessment Program for Salmon. Report prepared for the Pacific Salmon Foundation and Fisheries and Oceans Canada. 81 p.

Fairchild, W.L., Swansburg, E.O., Arsenault, J.T., and Brown, S.B. 1999. Does an association between pesticide use and subsequent declines in catch of Atlantic salmon (*Salmo salar*) represent a case of endocrine disruption? Environ. Health Perspect. 107(5): 349–357. doi:10.2307/3434538.

Fausch, K.D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Can. J. Zool. 62(3): 441–451. doi:10.1139/z84-067.

Fedorenko, A.Y., and Pearce, B.C. 1982. Trapping and coded wire tagging of wild juvenile chinook salmon in the South Thompson/Shuswap River System 1976, 1979, 1980. Can. Manuscr. Rep. Fish. Aquat. Sci. 1677: 63.

Feely, R, Orr, J, Fabry, VJ, Kleypas, CL, Sabin, CL. 2009. Present and future changes in seawater chemistry due to ocean acidification. Geophys. Monogr. Ser. 183: 175–188.

Feist, B.E., Buhle, E.R., Arnold, P., Davis, J.W., and Scholz, N.L. 2011. Landscape ecotoxicology of coho salmon spawner mortality in urban streams. PLoS One 6(8). doi:10.1371/journal.pone.0023424.

Ferguson, R. I., M. Church, C.D.R., and Venditti, and J.G. 2015. Reconstructing a sediment pulse: Modeling the effect of placer mining on Fraser River, Canada. J. Geophys. Res. Earth Surf. 120: 1–19. doi:10.1002/2013JF002871.

Ferguson, J.W., Healey, M., Dugan, P., and Barlow, C. 2011. Potential effects of dams on migratory fish in the Mekong River: Lessons from salmon in the fraser and Columbia Rivers. Environ. Manage. 47(1): 141–159. doi:10.1007/s00267-010-9563-6.

Fleming, I.A. 2002. The ability of released, hatchery salmonids to breed and contribute to the natural productivity of wild populations. *In* Hatcheries and the Protection of Wild Salmon, Speaking for the Salmon Series, Continuing Studies in Science at Simon Fraser University. *Edited by* C. Orr, P. Gallaugher, and J. Penikett. Simon Fraser University, Burnaby, BC. pp. 32–40.

Fleming, J.O., Nathan, J.S., McPerson, C., and Levings, C.D. 1987. Survey of juvenile salmonids in gravity-fed irrigation ditches, Nicola and Coldwater River valleys, 1985. Can. Data Rep. Fish. Aquat. Sci. 622: 50.

Foote, C.J., and Brown, G.S. 1998. Ecological relationship between freshwater sculpins (genus Cottus) and beach-spawning sockeye salmon (*Oncorhynchus nerka*) in Iliamna Lake, Alaska. Can. J. Fish. Aquat. Sci. 55: 1524–1533. doi:10.1139/f98-034.

Ford, J.K.., Wright, B.., Ellis, G.., and Candy, J.R. 2010. Chinook salmon predation by resident killer whales: seasonal and regional selectivity, stock identity of prey, and consumption rates. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/101.

Ford, J.K.B., and Ellis, G.M. 2006. Selective foraging by fish-eating killer whales *Orcinus orca* in British Columbia. Mar. Ecol. Prog. Ser. 316: 185–199. doi:10.3354/meps316185.

Francis-Floyd, R., Watson, C., Petty, D., and Pouder, D. 2009. Ammonia in Aquatic Systems. *In* University of Florida, IFAS Extension. (Accessed July 21, 2020)

FRAP. 1998. Wild, threatened, and lost streams of the lower Fraser valley: summary report. *In* Fraser River Action Plan. Lower Fraser Valley Stream Review, Vol 3. Vancouver, BC.

Fresh, K.L., Wyllie-Echeverria, T., Wyllie-Echeverria, S., and Williams, B.W. 2006. Using light-permeable grating to mitigate impacts of residential floats on eelgrass Zostera marina L. in Puget Sound, Washington. Ecol. Eng. 28(4): 354–362. doi:10.1016/j.ecoleng.2006.04.012.

Fulton, R.J. 1969. Glacial Lake history, southern interior plateau, British Columbia. Geological Survey of Canada, Department of Energy, Mines and Resources.

Galat, D.L., and Zweimüller, I. 2001. Conserving large-river fishes: Is the highway analogy an appropriate paradigm. J. North Am. Benthol. Soc. 20(2): 266–279. doi:10.2307/1468321.

Galbraith, M., and Young, K. 2019. West Coast British Columbia zooplankton biomass anomalies 2018. *In* State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2019. Can. Tech. Rep. Fish. Aquat. Sci. No. 3314, Sidney, BC. p. 257.

Gallardo, B., Clavero, M., Sánchez, M.I., and Vilà, M. 2016. Global ecological impacts of invasive species in aquatic ecosystems. Glob. Chang. Biol. 22(1): 151–163. doi:10.1111/gcb.13004.

Gardner, J., Peterson, D.L., Wood, A., and Maloney, V. 2004. Making Sense of the Debate about Hatchery Impacts: Interactions Between Enhanced Pacific Coast. Pacific Fisheries Resource Conservation Council, Vancouver, BC, Canada. (Accessed July 21, 2020)

Garette, C.L. 1980. Fraser River Estuary Study Water Quality: Toxic Oranic Contaminants. Vancouver, BC. (Accessed July 21, 2020)

Gariano, S.L., and Guzzetti, F. 2016. Landslides in a changing climate. Earth-Science Rev. 162: 227–252. doi:10.1016/j.earscirev.2016.08.011.

Garver, K.A., Johnson, S.C., Polinski, M.P., Bradshaw, J.C., Marty, G.D., Snyman, H.N., Morrison, D.B., and Richard, J. 2016. Piscine orthoreovirus from western North America is transmissible to atlantic salmon and sockeye salmon but fails to cause heart and skeletal muscle inflammation. PLoS One 11(1): 1–17. doi:10.1371/journal.pone.0146229.

Gende, S.M., Quinn, T.P., Hilborn, R., Hendry, A.P., and Dickerson, B. 2004. Brown bears selectively kill salmon with higher energy content but only in habitats that facilitate choice. Oikos 104(3): 518–528. doi:10.1111/j.0030-1299.2004.12762.x.

Gende, S.M., Quinn, T.P., and Willson, M.F. 2001. Consumption choice by bears feeding on salmon. Oecologia 127(3): 372–382. doi:10.1007/s004420000590.

Gilman, A., Dewailly, E., Feeley, M., Jerome, V., Kuhnlein, H., Kwavnick, B., Neve, S., Tracy, B., Usher, P., Van Oostdam, J., Walker, J., and Wheatley, B. 1997. Chapter 4: Human Health. In Canadian Arctic Contaminant Assessment Report. Indian and Northern Affairs Canada, Northern Contaminants Program, Ottawa, ON. (Accessed July 21, 2020)

Gjessing, E., Lygren, E., Berglind, L., Gulbrandsen, T., and Skaane, R. 1984. Effect of highway runoff on lake water quality. Sci. Total Environ. 33: 245–257.

Gladden, J.E., and Smock, L.A. 1990. Macroinvertebrate distribution and production on the floodplains of two lowland headwater streams. Freshw. Biol. 24(3): 533–545. doi:10.1111/j.1365-2427.1990.tb00730.x.

Goldman, K.J., and Musick, J.A. 2008. The Biology and Ecology of the Salmon Shark, Lamna Ditropis. *In* Sharks of the Open Ocean: Biology, Fisheries and Conservation. pp. 95–104. doi:10.1002/9781444302516.ch8.

Goniea, T.M., Keefer, M.L., Bjornn, T.C., Peery, C.A., Bennett, D.H., and Stuehrenberg, L.C. 2006. Behavioral Thermoregulation and Slowed Migration by Adult Fall Chinook Salmon in Response to High Columbia River Water Temperatures. Trans. Am. Fish. Soc. 135(2): 408–419. doi:10.1577/t04-113.1.

Goodman, D. 1975. A synthesis of the impacts of proposed expansion of the Vancouver International Airport and other developments on the fisheries resources of the Fraser River estuary. Vol. I and II, Section II. *In* Fisheries resources and food web components of the Fraser River estuary and an assessment of the impacts of proposed expansion of the Vancouver International Airport and other developments on these resources. Department of Environment, Fisheries, and Marine Services. (Accessed July 21, 2020)

Gordon, J., Arbeider, M., Scott, D., Wilson, S.M., and Moore, J.W. 2015. When the Tides Don't Turn: Floodgates and Hypoxic Zones in the Lower Fraser River, British Columbia, Canada. Estuaries and Coasts 38(6): 2337–2344. doi:10.1007/s12237-014-9938-7.

Graham, C.C., and Russell, L.R. 1979. An investigation of juvenile salmonid utilization of the delta-lakefront area of the Adams River, Shuswap Lake. Can. Fish. Mar. Serv. 1508: 32.

Grant, S.C., MacDonald, B.L., and Winston, M.L. 2019. State of the Canadian Pacific Salmon: Responses to Changing Climate and Habitats. Can. Tech. Rep. Fish. Aquat. Sci. 3332: 50 p.

Grant, W.S. 2012. Understanding the adaptive consequences of hatchery-wild interactions in Alaska salmon. Environ. Biol. Fishes 94(1): 325–342. doi:10.1007/s10641-011-9929-5.

Gray, C., and Tuominen, T. 1999. Health of the Fraser River aquatic ecosystem. Volumes I, II : a synthesis of research conducted under the Fraser River Action Plan. Vancouver, BC. doi:10.1142/9781848163256_0003.

Greenan, B.J.W., James, T.S., Loder, J.W., Pepin, P., Azetsu-Scott, K., Ianson, D., Hamme, R.C., Gilbert, D., Tremblay, J.-E., Wang, X.L., and Perrie, W. 2019. Chapter 7: Changes in Oceans Surrounding Canada. In Canada's Changing Climate Report. pp. 343–423.

Greene, C.M., Jensen, D.W., Pess, G.R., Steel, E.A., and Beamer, E. 2005. Effects of Environmental Conditions during Stream, Estuary, and Ocean Residency on Chinook Salmon Return Rates in the Skagit River, Washington. Trans. Am. Fish. Soc. 134(6): 1562–1581. doi:10.1577/t05-037.1.

Gregory, R. 1993. Effect of Turbidity on the Predator Avoidance Behaviour of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 50: 241–246. doi:10.1139/f93-027.

Gregory, R., and Northcote, T. 1993. Surface, planktonic, and benthic foraging by juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in turbid laboritory conditions. Can. J. Fish. Aquat. Sci. 50: 233–240.

Gregory, R.S., and Levings, C.D. 1996. The effects of turbidity and vegetation on the risk of juvenile salmonids, Oncorhynchus spp., to predation by adult cutthroat trout, O. clarkii. Environ. Biol. Fishes 47(3): 279–288. doi:10.1007/BF00000500.

Gregory, R.S., and Levings, C.D. 1998. Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon. Trans. Am. Fish. Soc. 127(2): 275–285. doi:10.1577/1548-8659(1998)127<0275:trpomj>2.0.co;2.

Gregory, S.V., Schwartz, J.S., Hall, J.D., Wildman, R.C., and Bisson, P.A. 2008. Hydrological and Biological Responses to Forest Practices. *In* Hydrological and Biological Responses to Forest Practices. *Edited by* J.D. Stednick. Springer Science. pp. 237–257. doi:10.1007/978-0-387-69036-0.

Groot, C. 1995. Physiological Ecology of Pacific Salmon. *Edited By* L. Margolis and W.C. Clarke. University of British Columbia Press, Vancouver, BC.

Guinotte, J.M., and Fabry, V.J. 2008. Ocean acidification and its potential effects on marine ecosystems. Ann. N. Y. Acad. Sci. 1134: 320–342. doi:10.1196/annals.1439.013.

Hafs, A.W., Harrison, L.R., Utz, R.M., and Dunne, T. 2014. Quantifying the role of woody debris in providing bioenergetically favorable habitat for juvenile salmon. Ecol. Modell. 285: 30–38. Elsevier B.V. doi:10.1016/j.ecolmodel.2014.04.015.

Hague, M.J., and Patterson, D.A. 2009. Chapter 3: Reconstructing thermal and flow history of key Pacific salmon populations along their freshwater migration through the Fraser River, British Columbia. SEF Final Report. Fisheries and Oceans Canada.

Hallock, R.J., Fry, D.H., and LaFaunce, D.A. 1957. The use of wire fyke traps to estimate the runs of adult salmon and Steelhead Salmon in the Sacramento River. Calif. Fish Game 43: 271–298.

Halyk, L.C., and Balon, E.K. 1983. Structure and ecological production of the fish taxocene of a small floodplain system. Can. J. Zool. 61(11): 2446–2464. doi:10.1139/z83-326.

Ham, D, Church, M. 2012. Morphodynamics of an extended bar complex, Fraser River, British Columbia. Earth Surf. Process. Landforms 37(10): 1074–1089.

Hanson, M.B., Baird, R.W., Ford, J.K.B., Hempelmann-Halos, J., Van Doornik, D.M., Candy, J.R., Emmons, C.K., Schorr, G.S., Gisborne, B., Ayres, K.L., Wasser, S.K., Balcomb, K.C., Balcomb-Bartok, K., Sneva, J.G., and Ford, M.J. 2010. Species and stock identification of prey consumed by endangered southern resident killer whales in their summer range. Endanger. Species Res. 11(1): 69–82. doi:10.3354/esr00263.

Haughian, S.R., Burton, P.J., Taylor, S.W., and Curry, C.L. 2012. Expected Effects of Climate Change on Forest Disturbance Regimes in British Columbia. BC J. Ecosyst. Manag. 13(1): 1–24.

Haught, S., and von Hippel, F.A. 2011. Invasive pike establishment in Cook Inlet Basin lakes, Alaska: Diet, native fish abundance and lake environment. Biol. Invasions 13(9): 2103–2114. doi:10.1007/s10530-011-0029-4.

Healey, M. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon (*Oncorhynchus nerka*) and implications for management. Can. J. Fish. Aquat. Sci. 68(4): 718–737. doi:10.1139/f2011-010.

Healey, M., and Heard, W. 1984. Inter- and Intra-Population Variation in the Fecundity of Chinook Salmon (*Oncorhynchus tshawytscha*) and its Relevance to Life History Theory. Rivers 41: 476–483.

Healey, M.C. 1980. Utilization of the Nanaimo River Estuary by Juvenile Chinook Salmon Oncorhynchu Tshawytscha. Fish. Bull. 77(3): 653–668.

Healey, M.C. 1983. Coastwide distribution and ocean migration patterns of stream- and ocean-type Chinook salmon, *Oncorhynchus tshawytscha*. Can. Field-Naturalist 97(4): 427–433.

Healey, M.C. 1986. Optimum size and age at maturity in Pacific salmon and effects of size-selective fisheries. Can. Spec. Publ. Fish. Aquat. Sci. 89: 39–52.

Healey, M.C. 1991. Life history of Chinook Salmon (Oncorhynchus tshawytscha). *In* Pacific Salmon Life Histories. *Edited by* C. Groot and L. Margolis. pp. 311–394.

Healey, M.C. 2001. Patterns of gametic investment by female stream- and ocean-type chinook salmon. J. Fish Biol. 58(6): 1545–1556. doi:10.1006/jfbi.2001.1559.

Healey, M.C., and Jordan, F.P. 1982. Observations on juvenile Chum Salmon and Chinook Salmon and spawning Chinook Salmon in the Nanaimo River, British Columbia, during 1975-1981. Can. Manuscr. Rep. Fish. Aquat. Sci. 1659: 1–31.

Hearn, W.E. 1987. Interspecific Competition and Habitat Segregation among Stream-Dwelling Trout and Salmon: A Review. Fisheries 12(5): 24–31. doi:10.1577/1548-8446(1987)012<0024:icahsa>2.0.co;2.

Heintz, R.A., Rice, S.D., Wertheimer, A.C., Bradshaw, R.F., Thrower, F.P., Joyce, J.E., and Short, J.W. 2000. Delayed effects on growth and marine survival of pink salmon Oncorhynchus gorbuscha after exposure to crude oil during embryonic development. Mar. Ecol. Prog. Ser. 208: 205–216. doi:10.3354/meps208205.

Hendry, A.P., and Berg, O.K. 1999. Secondary sexual characters, energy senescence, and the cost of reproduction sockeye salmon. Can. J. Zool. 77(11): 1663–1675. doi:10.1139/z99-158.

Herring, S.C., Hoerling, M.P., Peterson, T.C., and Stott, P.A. 2014. Explaining extreme events of 2013 from a climate perspective. Bull. Am. Meteorol. Soc. 95(9): S1–S96. doi:10.1175/BAMS-D-13-00085.1.

Hertz, E., Trudel, M., El-Sabaawi, R., Tucker, S., Dower, J., Beacham, T., Edwards, A., and Mazumder, A. 2016. Hitting the moving target: Modelling ontogenetic shifts with stable isotopes reveals the importance of isotopic turnover. J. Anim. Ecol. 85(3): 681–691. doi:10.1111/1365-2656.12504.

Hetrick, N.J., Brusven, M.A., Bjornn, T.C., Keith, R.M., and Meehan, W.R. 1998. Effects of Canopy Removal on Invertebrates and Diet of Juvenile Coho Salmon in a Small Stream in Southeast Alaska. Trans. Am. Fish. Soc. 127(6): 876–888. doi:10.1577/1548-8659(1998)127<0876:eocroi>2.0.co;2.

Higgins, S., and Vander Zanden, M. 2010. What a difference a species makes: a meta–analysis of dreissenid mussel impacts on freshwater ecosystems. Ecol. Monogr. 80(1): 179–196. doi:10.1890/07-1861.1.

Hilderbrand, G. V., Hanley, T.A., Robbins, C.T., and Schwartz, C.C. 1999a. Role of brown bears (*Ursus arctos*) in the flow of marine nitrogen into a terrestrial ecosystem. Oecologia 121(4): 546–550. doi:10.1007/s004420050961.

Hilderbrand, G. V., Jenkins, S.G., Schwartz, C.C., Hanley, T.A., and Robbins, C.T. 1999b. Effect of seasonal differences in dietary meat intake on changes in body mass and composition in wild and captive brown bears. Can. J. Zool. 77(10): 1623–1630. doi:10.1139/z99-133.

Hill, D., Beachler, M., and Johnson, P. 2002. Hydrodynamic impacts of commercial Jet-boating on the Chilkat river, Alaska. Pennsylvania State University, Department of Civil & Environmental Engineering. 115 p.

Hill, N.P., McIntyre, A.E., Perry, R., and Lester, J.N. 1990. Behavior of chlorophenoxy herbicides during primary sedimentation. J. Water Pollut. Control Fed. 57(1): 60–67.

Hillman, T.W., Griffith, J.S., and Platts, W.S. 1987. Summer and Winter Habitat Selection by Juvenile Chinook Salmon in a Highly Sedimented Idaho Stream. Trans. Am. Fish. Soc. 116(2): 185–195. doi:10.1577/1548-8659(1987)116<185:sawhsb>2.0.co;2.

Hocking, M.D., and Reynolds, J.D. 2011. Impacts of salmon on riparian plant diversity. Science (80-.). 331(6024): 1609–1612. doi:10.1126/science.1201079.

Hoffnagle, T., and Fivizzani, A. 1998. Effect of Three Hatchery Lighting Schemes on Indices of Smoltification in Chinook Salmon. Progress. Fish-Culturist 60(3): 179–191. doi:10.1577/1548-8640(1998)060<0179:EOTHLS>2.0.CO;2.

Hogan, D.L., and Luzi, D.S. 2010. Channel Geomorphology: Fluvial Forms, Processes, and Forest Management Effects. *In* Compendium of Forest Hydrology and Geomorphology in British Columbia Volume 1 of 2. pp. 331–371. (Accessed July 21, 2020)

Holsman, K., Hollowed, A., Ito, S., Bograd, S., Hazen, E., King, J., Mueter, F., and Perry, R.I. 2018. Climate change impacts, vulnerabilities and adaptations: North Pacific and Pacific Arctic marine fisheries. *In* Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options.

Holsman, K.K., Scheuerell, M.D., Buhle, E., and Emmett, R. 2012. Interacting Effects of Translocation, Artificial Propagation, and Environmental Conditions on the Marine Survival of Chinook Salmon from the Columbia River, Washington, U.S.A. Conserv. Biol. 26(5): 912–922. doi:10.1111/j.1523-1739.2012.01895.x.

Holtby, L.B., and Healey, M.C. 1986. Selection for Adult Size in Female Coho Salmon. Can. J. Fish. Aquat. Sci. 43(10): 1946–1959.

Howard, B.R. 2019. The context-dependent spread and impacts of invasive marine crabs. PhD Thesis. Simon Fraser University.

Hyatt, K.D., McQueen, D.J., Shortreed, K.S., and Rankin, D.P. 2004. Sockeye salmon (*Oncorhynchus nerka*) nursery lake fertilization: Review and summary of results. Environ. Rev. 12(3): 133–162. doi:10.1139/a04-008.

Indo, H.P., Yen, H.C., Nakanishi, I., K.I., M., Tamura, M., Nagano, Y., Matsui, H., Gusev, O., Cornette, R., Okuda, T., Minamiyama, Y., Ichikawa, H., Suenaga, S., Oki, M., Sato, T., Ozawa, T., St. Clair, D.K., and Majima, H.J. 2015. A mitochondrial superoxide theory for oxidative stress diseases and aging. J. Clin. Biochem. Nutr. 56(1): 49–56. doi:10.3164/jcbn.14.

Irvine, J.R. 1986. Effects of varying discharge on the downstream movement of salmon fry, Oncorhynchus tshawytscha Walbaum. J. Fish Biol. 28(1): 17–28. doi:10.1111/j.1095-8649.1986.tb05137.x.

Irvine, J.R., and Fukuwaka, M.A. 2011. Pacific salmon abundance trends and climate change. ICES J. Mar. Sci. 68(6): 1122–1130. doi:10.1093/icesjms/fsq199.

Islam, S., and Déry, S.J. 2017. Evaluating uncertainties in modelling the snow hydrology of the Fraser River Basin, British Columbia, Canada. Hydrol. Earth Syst. Sci. 21(3): 1827–1847. doi:10.5194/hess-21-1827-2017.

Islam, S.U., Hay, R.W., Déry, S.J., and Booth, B.P. 2019. Modelling the impacts of climate change on riverine thermal regimes in western Canada’s largest Pacific watershed. Sci. Rep. 9(1). doi:10.1038/s41598-019-47804-2.

Jeffres, C.A., Opperman, J.J., and Moyle, P.B. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environ. Biol. Fishes 83(4): 449–458. doi:10.1007/s10641-008-9367-1.

Jensen, J.T., McLean, W.E., Sweeten, T., Damon, W., and Berg, C. 2006. Puntledge River High Temperature Study: Influence of High Water Temperature on Adult Summer Chinook Salmon (Oncorhynchus tshawytscha) in 2004 and 2005. Can. Tech. Rep. Fish. Aquat. Sci. 2662: 1–47.

Johnson, R., and Bustin, R.M. 2006. Coal dust dispersal around a marine coal terminal (1977-1999), British Columbia: The fate of coal dust in the marine environment. Int. J. Coal Geol. 68(1-2 SPEC. ISS.): 57–69. doi:10.1016/j.coal.2005.10.003.

Junk, W.J., Bayley, P.B., and Sparks, R.E. 1989. The Flood pulse Concept in River-Floodplain Systems. Can. Spec. Publ. Fish. Aquat. Sci. 106: 110–127. doi:10.1016/j.matchemphys.2012.10.032.

Kang, D.H., Gao, H., Shi, X., Islam, S.U., and Déry, S.J. 2016. Impacts of a Rapidly Declining Mountain Snowpack on Streamflow Timing in Canada's Fraser River Basin. Sci. Rep. 6: 1–8. doi:10.1038/srep19299.

Kang, D.H., Shi, X., Gao, H., and Déry, S.J. 2014. On the Changing Contribution of Snow to the Hydrology of the Fraser River Basin, Canada. J. Hydrometeorol. 15(4): 1344–1365. doi:10.1175/jhm-d-13-0120.1.

Kaposi, K.L., Mos, B., Kelaher, B.P., and Dworjanyn, S.A. 2014. Ingestion of microplastic has limited impact on a marine larva. Environ. Sci. Technol. 48(3): 1638–1645. doi:10.1021/es404295e.

Karatayev, A.Y., Burlakova, L.E., and Padilla, D.K. 2002. Impacts of Zebra Mussels on Aquatic Communities and their Role as Ecosystem Engineers. *In* Invasive Aquatic Species of Europe. Distribution, Impacts, and Management. *Edited by* E. Leppakoski, S. Gollasch, and S. Olenin. Kluwer Academic Publishers. pp. 433–434. doi:10.1007/978-94-015-9956-6_43.

Keefer, M.L., Clabough, T.S., Jepson, M.A., Johnson, E.L., Peery, C.A., and Caudill, C.C. 2018. Thermal exposure of adult Chinook salmon and steelhead: Diverse behavioral strategies in a large and warming river system. PLoS One 13(9): 1–29. doi:10.1371/journal.pone.0204274.

Kelly, B.C., Ikonomou, M.G., MacPherson, N., Sampson, T., Patterson, D.A., and Dubetz, C. 2011. Tissue residue concentrations of organohalogens and trace elements in adult Pacific salmon returning to the Fraser River, British Columbia, Canada. Environ. Toxicol. Chem. 30(2): 367–376. doi:10.1002/etc.410.

Kennedy, L.A., Juanes, F., and El-Sabaawi, R. 2018. Eelgrass as Valuable Nearshore Foraging Habitat for Juvenile Pacific Salmon in the Early Marine Period. Mar. Coast. Fish. 10(2): 190–203. doi:10.1002/mcf2.10018.

Kjelson, M.A., Raquel, P.F., and Fisher, F.W. 1981. Influences of Freshwater Inflow on Chinook Salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin Estuary. California Department of Fish and Game. Stockton, CA. (Accessed July 21, 2020)

Lacroix, G.L. 2014. Large pelagic predators could jeopardize the recovery of endangered Atlantic salmon. Can. J. Fish. Aquat. Sci. 71: 343–350. doi:10.1139/cjfas-2012-0270.

Laderoute, L., and Bauer, B. 2013. River Bank Erosion and Boat Wakes Along the Lower Shuswap River, British Columbia. Final Project Report Submitted to the Regional District of North Okanagan, Fisheries and Oceans, Canada. 72 p.

Langer, O., Hietkamp, F., and Farrell, M. 2000. Human population growth and the sustainability of urban salmonid streams in the Lower Fraser Valley. *In* Sustainable Fisheries Management: Pacific Salmon. *Edited by* E.E. Knudsen, C.R. Cleveland, R. Steward, D.D. MacDonald, J.E. Williams, and D.W. Reiser. CRC Press, New York, NY. pp. 349–361.

Lapointe, M., Eaton, B., Driscoll, S., and Latulippe, C. 2000. Modelling the probability of salmonid egg pocket scour due to floods. Can. J. Fish. Aquat. Sci. 57(6): 1120–1130. doi:10.1139/f00-033.

Lehnert, S.J., Pitcher, T.E., Devlin, R.H., and Heath, D.D. 2016. Red and white Chinook salmon: Genetic divergence and mate choice. Mol. Ecol. 25(6): 1259–1274. doi:10.1111/mec.13560.

Leitritz, E., and Lewis, R. 1976. Trout and salmon culture. Fish Bulletin 164 - State of California, Department of Fish and Game. 197 p.

Letey, J. 2001. Causes and consequences of fire-induced soil water repellency. Hydrol. Process. 15(15): 2867–2875. doi:10.1002/hyp.378.

Levin, P.S., and Tolimieri, N. 2001. Differences in the impacts of dams on the dynamics of salmon populations. Anim. Conserv. 4(4): 291–299. doi:10.1017/S1367943001001342.

Levin, P.S., Zabel, R.W., and Williams, J.G. 2001. The road to extinction is paved with good intentions: Negative association of fish hatcheries with threatened salmon. Proc. R. Soc. London, Britain 268: 1153–1158. doi:10.1098/rspb.2001.1634.

Levings, C.D. 1982. Short term use of a low tide refuge in a sandflat by juvenile chinook, (Oncorhynchus tshawytscha), Fraser River estuary. Can. Tech. Rep. Fish. Aquat. Sci. No. 1111: 1–33.

Levings, C.D., Conlin, K., and Raymond, B.A. 1991. Intertidal habitats used by juvenile chinook salmon (*Oncorhynchus tshawytscha*) rearing in the North Arm of the Fraser River estuary. Mar. Pollut. Bull. 22(1): 20–26.

Levings, C.D., and Lauzier, R.B. 1991. Extensive use of the Fraser River basin as winter habitat by juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Zool. 69(7): 1759–1767. doi:10.1139/z91-245.

Levings, C.D., McAllister, C.D., and Chang, B.D. 1986. Differential use of the Campbell River estuary, British Columbia, by wild and hatchery-reared juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 4: 1386–1397.

Levit, S.M. 2010. A Literature Review of Effects of Cadmium on Fish. *In* The Nature Conservancy. (Accessed July 21, 2020)

Levy, D., Northcote, T., and Birch, G. 1979. Juvenile salmon utilization of tidal channels in the Fraser River estuary, British Columbia. Westwater Research Centre Technical Report, No. 23. Vancouver, B.C. University of B.C. 17p.

Levy, D.A., and Northcote, T.G. 1982. Juvenile Salmon Residency in a Marsh Area of the Fraser River Estuary. Can. J. Fish. Aquat. Sci. 39(2): 270–276. doi:10.1139/f82-038.

Levy, D.A., Yesaki, I., and Christensen, B. 1990. Impacts of log storage upon epilimnetic dissolved oxygen and juvenile sockeye salmon in Babine Lake, British Columbia. Water Res. 24(3): 337–343. doi:10.1016/0043-1354(90)90010-4.

Lewis, A., and Ganshorn, K. 2007. Literature Review of Habitat Productivity Models for Pacific Salmon Species. Ecofish Research Ltd., Report prepared for Fisheries and Oceans, Canada, Habitat Management Division. Vancouver, BC. 101 p.

Lewis, A., and Levings, C. 1988. Sampling of juvenile chinook salmon in Slim Creek, Quesnel, Salmon and Eagle Rivers (Fraser River System). Report prepared by Environcon Pacific Limited. 59 pp. + Appendix.

Lewis, B., Grant, W.S., Brenner, R.E., and Hamazaki, T. 2015. Changes in size and age of chinook salmon oncorhynchus tshawytscha returning to Alaska. PLoS One 10(6): 1–17. doi:10.1371/journal.pone.0130184.

Likens, G. 1972. Eutrophication and aquatic ecosystems. Am. Soc. Limnol. Oceanogr. Spec. Symp. 1: 3–13.

Lisle, T.E. 1989. Channel-dynamic control on the establishment of riparian trees after large floods in northwestern California. Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990s. Gen. Tech. Rep. PSW-11.

Loftus, W., and Lenon, H. 1977. Food Habits of the Salmon Smolts, Oncorhynchus tshawytscha and 0. keta, from the Salcha River, Alaska. Trans. Am. Fish. Soc. 106(3): 235–240.

Ludyanskiy, M.., Mcdonald, D., and Macneill, D. 1993. Impact of the Zebra Mussel , Bivalve Invader a Dreissena polymorpha is rapidly colonizing hard surfaces throughout waterways of the United States and Canada. Bioscience 43(8): 533–544.

Luedke, W., Dobson, D., and Mathias, K. 2019. 2017 Terminal Abundance of WCVI Chinook Salmon. Report to the Northern Endowment Fund. Pacific Salmon Commission, March 2019 Report. (Accessed July 21, 2020)

Lueker, T.J., Dickson, A.G., and Keeling, C.D. 2000. Ocean pCO2 calculated from DIC, TA, and the Mehrbach equations for K1 and K2: Validation using laboratory measurements of CO2 in gas and seawater at equilibrium. Abstr. Pap. Am. Chem. Soc. 217: U848–U848.

Macdonald, J.S., Levings, C.D., McAllister, C.D., Fagerlund, U.H.M., and McBride, J.R. 1988. A field experiment to test the importance of estuaries for chinook salmon (*Onchyrhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 45: 1366–1377.

Macdonald, S.J., Birtwell, I.K., and Kruzynski, G.M. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Can. J. Fish. Aquat. Sci. 44(6): 1233–1246. doi:10.1139/f87-146.

Mace, P. 1983. Bird Predation on Juvenile Salmonids in the Big Qualicum Estuary, Vancouver Island. Can. Tech. Rep. Fish. Aquat. Sci. (1176): 92.

Mackas, D., Galbraith, M., Faust, D., Masson, D., Young, K., Shaw, W., Romaine, S., Trudel, M., Dower, J., Campbell, R., Sastri, A., Bornhold Pechter, E., Pakhomov, E., and El-Sabaawi, R. 2013. Zooplankton time series from the strait of georgia: Results from year-round sampling at deep water locations, 1990-2010. Prog. Oceanogr. 115: 129–159. doi:10.1016/j.pocean.2013.05.019.

Mains, E.M., and Smith, J.M. 1964. The distribution, size, time, and current preferences of seaward migrant Chinook Salmon in the Columbia and Snake rivers. Fish. Res. Pap. 2: 5–43.

Mamurekli, D. 2010. Environmental impacts of coal mining and coal utilization in the UK. Acta Montan. Slovaca 15(2): 134–144.

Massey, W. 2017. Assessing the impact of riprap bank stabilization on fish habitat: A study of Lowland and Appalachian streams in Southern Québec. MSc Thesis. Concordia University.

McCullough, D. 1999. A Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. *In* Water Resource Assessment, U.S. doi:10.1089/gyn.2016.0069.

McLeod, C.L., and O'Neil, J.P. 1983. Major range extensions of anadromous salmonids and first record of chinook salmon in the Mackenzie River drainage. Can. J. Zool. 61(9): 2183–2184. doi:10.1139/z83-287.

McPhail, J.D. 2007. Field Key to Freshwater Fishes of British Columbia. The University of Alberta Press, Edmonton, AB. 696p.

Mcphail, J.D., and Carveth, R. 1994. Field Key to the Freshwater Fishes of British Columbia. Province of British Columbia, Resources Inventory Committee. (Accessed July 21, 2020)

McPhail, J.D., and Lindsey, C.C. 1970. Freshwater fishes of northwestern Canada and Alaska. Bull. J. Fish. Res. Board Canada: 381.

Meador, J.P. 2014. Do chemically contaminated river estuaries in Puget Sound (Washington, USA) affect the survival rate of hatchery-reared Chinook salmon? Can. J. Fish. Aquat. Sci. 71(1): 162–180. doi:10.1139/cjfas-2013-0130.

Meador, J.P., Yeh, A., and Gallagher, E.P. 2018. Adverse metabolic effects in fish exposed to contaminants of emerging concern in the field and laboratory. Environ. Pollut. 236: 850–861. Elsevier Ltd. doi:10.1016/j.envpol.2018.02.007.

Meehan. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. Am. Fish. Soc. Spec. Publ. No. 19.

Mehrbach, C., Culberson, C.H., Hawley, J.E., and Pytkowicx, R.M. 1973. Measurement of the Apparent Dissociation Constants of Carbonic Acid in Seawater At Atmospheric Pressure. Limnol. Oceanogr. 18(6): 897–907. doi:10.4319/lo.1973.18.6.0897.

Melville, C., Ramos-Espinoza, D., Braun, D., and Mccubbing, D. 2015. Bridge River Water Use Plan Lower Bridge River Adult Salmon and Steelhead Enumeration Implementation Year 3 Reference: BRGMON-3. Vancouver, BC. (Accessed July 21, 2020)

Miller, K.M., Günther, O.P., Li, S., Kaukinen, K.H., and Ming, T.J. 2017. Molecular indices of viral disease development in wild migrating salmon†. Conserv. Physiol. 5(1). doi:10.1093/conphys/cox036.

Miller, K.M., Teffer, A., Tucker, S., Li, S., Schulze, A.D., Trudel, M., Juanes, F., Tabata, A., Kaukinen, K.H., Ginther, N.G., Ming, T.J., Cooke, S.J., Hipfner, J.M., Patterson, D.A., and Hinch, S.G. 2014. Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines. Evol. Appl. 7: 812–855. doi:10.1111/eva.12164.

Minchella, D.J., and Scott, M.E. 1991. Parasitism: A cryptic determinant of animal community structure. Trends Ecol. Evol. 6(8): 250–254. doi:10.1016/0169-5347(91)90071-5.

Ministry of Envirornment Lands and Parks. 1999. Guidelines for Management of Flood Protection Works in British Columbia.

Mitchell, D.G., Chapman, P.M., and Long, T.J. 1987. Acute toxicity of Roundup® and Rodeo® herbicides to rainbow trout, chinook, and coho salmon. Bull. Environ. Contam. Toxicol. 39(6): 1028–1035. doi:10.1007/BF01689594.

Moore, C.J. 2008. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environ. Res. 108(2): 131–139. doi:10.1016/j.envres.2008.07.025.

Moore, M., Kohler, S., and Cheers, M. 2006. Artificial light at night in freshwater habitats and its potential ecological effects. *In* Ecological consequences of artificial night lighting. Island Press, Washington, DC. pp. 365–384.

Moore, M. V., Pierce, S.M., Walsh, H.M., Kvalvik, S.K., and Lim, J.D. 2000. Urban light pollution alters the diel vertical migration of Daphnia . SIL Proceedings, 1922-2010 27(2): 779–782. doi:10.1080/03680770.1998.11901341.

Moore, R.D., and Wondzell, S.M. 2005. Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review. J. Am. Water Resour. Assoc.: 763–784.

Moran, P., Teel, D.J., Banks, M.A., Beacham, T.D., Bellinger, M.R., Blankenship, S.M., Candy, J.R., Garza, J.C., Hess, J.E., Narum, S.R., Seeb, L.W., Templin, W.D., Wallace, C.G., and Smith, C.T. 2013. Divergent life-history races do not represent Chinook salmon coast-wide: The importance of scale in Quaternary biogeography. Can. J. Fish. Aquat. Sci. 70(3): 415–435. doi:10.1139/cjfas-2012-0135.

Morrison, J., Quick, M.C., and Foreman, M.G.G. 2002. Climate change in the Fraser River watershed: Flow and temperature projections. J. Hydrol. 263(1–4): 230–244. doi:10.1016/S0022-1694(02)00065-3.

Mossop, B., and Bradford, M.J. 2004. Importance of large woody debris for juvenile chinook salmon habitat in small boreal forest streams in the upper Yukon River basin, Canada. Can. J. For. Res. 34(9): 1955–1966. doi:10.1139/X04-066.

Mote, P.W., Parson, E.A., Hamlet, A.F., Keeton, W.S., Lettenmaier, D.P., Mantua, N., Miles, E.L., Peterson, D.W., Peterson, D.L., Slaughter, R., and Snover, A.K. 2003. Preparing for climate change: the water, salmon, and forests of the Pacific Northwest. Clim. Change 61: 45–88.

Mount, C., Norris, S., Thompson, R., and Tesch, D. 2011. GIS modelling of fish habitat and road crossings for the prioritization of culvert assessment and remediation. Streamline Watershed Manag. Bull. 14(2): 7–13.

Mowat, G., and Heard, D.C. 2006. Major components of grizzly bear diet across North America. Can. J. Zool. 84(3): 473–489. doi:10.1139/z06-016.

Murray, C.B., and Rosenau, M.L. 1989. Rearing of Juvenile Chinook Salmon in Nonnatal Tributaries of the Lower Fraser River, British Columbia. Trans. Am. Fish. Soc. 118(3): 284–289. doi:10.1577/1548-8659(1989)118<0284:rojcsi>2.3.co;2.

Myers, J., Kope, R., Bryant, G., Teel, D., Lierheimer, L., Wainwright, T., Grant, W., Waknitz, F., Neely, K., and Lindley, S. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. NOAA Tech. Memo. NMFS-NWFSC-35.

Neilson, J.D., and Banford, C.E. 1983. Chinook salmon (*Oncorhynchus tshawytscha*) spawner characteristics in relation to redd physical features. Can. J. Zool. 61(7): 1524–1531. doi:10.1139/z83-205.

Nelitz, M., and Porter, M. 2009. A future outlook on the effects of climate change on coho salmon (*Oncorhynchus kisutch*) habitats in the CaribooChilcotin. Prepared by ESSA Technologies Ltd. for Fraser Salmon and Watersheds Program, B.C. Ministry of Environment, and Pacific Fisheries Reso.

Nelitz, M., Porter, M., Parkinson, E., Wieckowski, K., Marmorek, D., Bryan, K., Hall, A., and Abraham, D. 2012. Evaluating the status of Fraser River sockeye salmon and role of freshwater ecology in their decline. Cohen Comm. Tech. Rep. 3: 222.

Nelson, A.D., and Church, M. 2012. Placer mining along the Fraser River, British Columbia: The geomorphic impact. Geol. Soc. Am. Bull. 124(7–8): 1212–1228. doi:10.1130/B30575.1.

Nelson, B.. 2018. Wild Chinook salmon productivity is negatively related to seal density, and not related to hatchery releases in the Pacific Northwest. Can. J. Fish. Aquat. Sci 76(3): 447–462.

Netboy, A. 1958. Salmon of the Pacific Northwest: Fish vs. Dams. Binfords & Mort, Portland, OR.

Nightingale, B., Longcore, D., and Simenstad, C. 2006. Artificial night lighting and fishes. *In* Ecological consequences of artificial night lighting. *Edited by* C. Rich and T. Longcore. Island Press, Washington, DC. pp. 257–276.

Nikl, L., Wernick, B., Geest, J. Van, Hughes, C., and Mcmahen, K. 2016. Mount Polley Mine Embankment Breach: Overview of Aquatic Impacts and Rehabilitation. Proc. Tailings Mine Waste: 845–856.

Northcote, T., Johnston, N., and Tsumura, K. 1979. Feeding relationships and food web structure of lower Fraser River fishes. University of British Columbia, Westwater Research Center Tech. Rep. 16. 73 p.

O'Neill, S.M., and West, J.E. 2009. Marine Distribution, Life History Traits, and the Accumulation of Polychlorinated Biphenyls in Chinook Salmon from Puget Sound, Washington. Trans. Am. Fish. Soc. 138(3): 616–632. doi:10.1577/t08-003.1.

Ohlberger, J., Ward, E.J., Schindler, D.E., and Lewis, B. 2018. Demographic changes in Chinook salmon across the Northeast Pacific Ocean. Fish Fish. 19(3): 533–546. doi:10.1111/faf.12272.

Okey, T.A., Wright, B.A., and Brubaker, M.Y. 2007. Salmon shark connections: North Pacific climate change, indirect fisheries effects, or just variability? Fish Fish. 8(4): 359–366. doi:10.1111/j.1467-2979.2007.00262_2.x.

Olesiuk, PF, Ellis, GM, Smith, TG, Flostrand, L., Warby, S. 1996. Predation by Harbour Seals (*Phoca vitulina*) on outmigrating salmon (*Oncorhynchus spp.*) fry and smolts in the lower Puntledge River, British Columbia. PSARC working paper S96-12. 112p.

Olesiuk, P. 2010. Prey requirements and salmon consumption by Steller Sea Lions (*Eumetopias jubatus*) in southern British Columbia and Washington State. DFO Can. Sci. Advis. Sec. Res. Doc 2009/105. vi + 157 p.

Overland, J.E., and Wang, M. 1998. Future Climate of the North Pacific Ocean. North Pacific Temp. Clim. Patterns 4(26): 283–288. doi:10.1111/j.

Owens, P.N., Gateuille, D.J., Petticrew, E.L., Booth, B.P., and French, T.D. 2019. Sediment-associated organopollutants, metals and nutrients in the Nechako River, British Columbia: a current study with a synthesis of historical data. Can. Water Resour. J. 44(1): 42–64. doi:10.1080/07011784.2018.1531063.

Parken, C.K., Candy, J.R., Irvine, J.R., and Beacham, T.D. 2008. Genetic and Coded Wire Tag Results Combine to Allow More-Precise Management of a Complex Chinook Salmon Aggregate. North Am. J. Fish. Manag. 28(1): 328–340. doi:10.1577/m06-110.1.

Pearce, F. 2010. The impact of climate change on the British Isles. New Sci. 206(2765): 49. doi:10.1016/s0262-4079(10)61509-6.

Perkin, E.K., Hölker, F., Richardson, J.S., Sadler, J.P., Wolter, C., and Tockner, K. 2011. The influence of artificial light on stream and riparian ecosystems: Questions, challenges, and perspectives. Ecosphere 2(11). doi:10.1890/ES11-00241.1.

Perry, T.D., and Jones, J.A. 2017. Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. Ecohydrology 10(2): 1–13. doi:10.1002/eco.1790.

Petticrew, E., Gantner, N., Albers, S., and Owens, P. 2015. Initial Impacts of the Mount Polley Tailings Pond Breach on Adjacent Aquatic Ecosystems. Geophys. Res. Abstr. 17. doi:10.1093/her/14.1.51.

Pickering, A.D., and Christie, P. 1980. Sexual differences in the incidence and severity of ectoparasitic infestation of the brown trout, Salmo trutta L. J. Fish Biol. 16(6): 669–683. doi:10.1111/j.1095-8649.1980.tb03746.x.

Picketts, I.M., Parkes, M.W., and Déry, S.J. 2017. Climate change and resource development impacts in watersheds: Insights from the Nechako River Basin, Canada. Can. Geogr. 61(2): 196–211. doi:10.1111/cag.12327.

Pike, R.G., Redding, T.E., Moore, R.D., Winkler, R.D., and Bladon, K.D. 2010. Compendium of Forest Hydrology and Geomorphology in British Columbia, LMH 66, Volume 2 of 2. *In* Geomorphology. (Accessed July 21, 2020)

Pizzino, G., Irrera, N., Cucinotta, M., Pallio, G., Mannino, F., Arcoraci, V., Squadrito, F., Altavilla, D., and Bitto, A. 2017. Oxidative Stress: Harms and Benefits for Human Health. Oxid. Med. Cell. Longev. 2017. doi:10.1155/2017/8416763.

Policansky, D., and Magnuson, J.J. 1998. Genetics, metapopulations, and ecosystem management of fisheries. Ecol. Appl. 8: 119–123. doi:10.2307/2641369.

Polinski, M., and Garver, K. 2019. Characterization of piscine orthoreovirus (PRV) and associated diseases to inform pathogen transfer risk assessments in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/035. iv + 35 p.

Poloczanska, E.S., Brown, C.J., Sydeman, W.J., Kiessling, W., Schoeman, D.S., Moore, P.J., Brander, K., Bruno, J.F., Buckley, L.B., Burrows, M.T., Duarte, C.M., Halpern, B.S., Holding, J., Kappel, C. V., O'Connor, M.I., Pandolfi, J.M., Parmesan, C., Schwing, F., Thompson, S.A., and Richardson, A.J. 2013. Global imprint of climate change on marine life. Nat. Clim. Chang. 3(10): 919–925. doi:10.1038/nclimate1958.

Pon, L.B., Cooke, S.J., and Hinch, S.G. 2006. Passage Efficiency and Migration Behaviour of Salmonid Fishes at the Seton Dam Fishway. Bridge Coastal Restoration Program. 105 p. (Accessed July 21, 2020)

Poole, G.C., and Berman, C.H. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. Environ. Manage. 27(6): 787–802. doi:10.1007/s002670010188.

Porszt, E.J., Peterman, R.M., Dulvy, N.K., Cooper, A.B., and Irvine, J.R. 2012. Reliability of Indicators of Decline in Abundance. Conserv. Biol. 26(5): 894–904. doi:10.1111/j.1523-1739.2012.01882.x.

Porter, M., Casley, S., Pickard, D., Neiltz, M., and Ochoski, N. 2013. Southern Chinook Salmon Conservation Units: Habitat Indicators Report Cards. ESSA Technologies Ltd. Prepared for Fisheries and Oceans, Canada.

Power, E.A., and Northcote, T.G. 1991. Effects of Log Storage on the Food Supply and Diet of Juvenile Sockeye Salmon. North Am. J. Fish. Manag. 11(3): 413–423. doi:10.1577/1548-8675(1991)011<0413:eolsot>2.3.co;2.

Prakash, A. 1962. Seasonal Changes in Feeding of Coho and Chinook (Spring) Salmon in Southern British Columbia Waters. J. Fish. Res. Board Canada 19(5): 851–866. doi:10.1139/f62-053.

Preikshot, D., Beamish, R.J., and Neville, C.M. 2013. A dynamic model describing ecosystem-level changes in the strait of georgia from 1960 to 2010. Prog. Oceanogr. 115: 28–40. doi:10.1016/j.pocean.2013.05.020.

Price, P.W. 1980. Evolutionary Biology of Parasites. Monographs in Population Biology. Princeton University Press.

Pritchard, A., and Tester, A. 1944. Food of spring and coho salmon in British Columbia. Bull. J. Fish. Res. Board Canada 65: 23.

Purcell, J.E. 2012. Jellyfish and Ctenophore Blooms Coincide with Human Proliferations and Environmental Perturbations. Ann. Rev. Mar. Sci. 4(1): 209–235. doi:10.1146/annurev-marine-120709-142751.

Quigley, J., and Hinch, S. 2006. Effects of rapid experimental temperature increases on acute physiological stress and behaviour of stream dwelling juvenile chinook salmon. J. Therm. Biol. 31(5): 429–441. doi:10.1016/j.jtherbio.2006.02.003.

Quinn, T. 2005. The behavior and ecology of Pacific salmon and trout. University of Washington Press.

Quinn, T.P., Seamons, T.R., Vollestad, L.A., and Duffy, E. 2011. Effects of growth and reproductive history on the egg size-fecundity trade-off in steelhead. Trans. Am. Fish. Soc. 140(1): 45–51. doi:10.1080/00028487.2010.550244.

Quinn, T.P., Wetzel, L., Bishop, S., Overberg, K., and Rogers, D.E. 2001. Influence of breeding habitat on bear predation and age at maturity and sexual dimorphism of sockeye salmon populations. Can. J. Zool. 79(10): 1782–1793. doi:10.1139/cjz-79-10-1782.

Raleigh, R.F., Miller, W.J., and Nelson, P.C. 1986. Habitat suitability index models and instream flow suitability curves: Chinook Salmon. U.S. Fish Wild. Serv. Biol. Rep. 82 (10.122). 64 p.

Randall, D.J., and Tsui, T.K.N. 2002. Ammonia toxicity in fish. Mar. Pollut. Bull. 45: 17–23.

Raymond, B.A., and Shaw, D.P. 1997. Fraser River action plan resident fish condition and contaminants assessment. Water Sci. Technol. 35(2–3): 389–395. doi:10.1016/S0273-1223(96)00954-7.

Raymond, H.L. 1968. Migration Rates of Yearling Chinook Salmon in Relation to Flows and Impoundments in the Columbia and Snake Rivers. Trans. Am. Fish. Soc. 97(4): 356–359. doi:10.1577/1548-8659(1968)97[356:mroycs]2.0.co;2.

Reid, G. 1961. Stomach content analysis of troll-caught king and coho salmon, southeastern Alaska, 1957-58. United States Department of the Interior Fish and Wildlife Service. Special Scientific Report - Fisheries No. 379. Washington, D.C.

Reimchan, T.E. 2000. Some ecological and evolutionary aspects of bear–salmon interactions in coastal British Columbia. Can. J. For. Res. 78: 448–458. doi:10.1109/ICDAR.2001.953811.

Reimers, P.E. 1968. Social Behavior arnong Juvenile Fall Chinook Salrnon. J. Fish. Res. Board Canada 25(9): 2005–2008.

Rhodes, J.J., Mccullough, D.A., and Espinosa, F. Al. 1994. A Coarse Screening Process For Evaluation Of The Effects Of Land Management Activities On Salmon Spawning And Rearing Habitat In ESA Consultations. Columbia River Inter-Tribal Fish Commission Report reference #94-04, Portland, Oregon.

Rich, W.H. 1925. Growth and degree of maturity of Chinook Salmon in the ocean. Bull. Bur. Fish. 41: 15–90.

Richter, A., and Kolmes, S.A. 2005. Maximum temperature limits for chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Rev. Fish. Sci. 13(1): 23–49. doi:10.1080/10641260590885861.

Riddell, B., Bradford, M., Carmichael, R., Hankin, D., Peterman, R., and Wertheimer, A. 2013. Assessment Of Status And Factors For Decline Of Southern BC Chinook Salmon: Independent Panel's Report. Vancouver, BC.

Riebe, C.S., Sklar, L.S., Overstreet, B.T., and Wooster, J.K. 2014. Optimal reproduction in salmon spawning substrates linked to grain size and fish length. Water Resour. Res. 5(3): 2–2. doi:10.1111/j.1752-1688.1969.tb04897.x.

Robinson, C., Lapi, L., and Carter, E. 1982. Stomach Contents of Spiny Dogfish (*Squalus acanthias*) Caught near the Qualicum Fraser Rivers, April-May, 1980-1981. Can. Manuscr. Rep. Fish. Aquat. Sci. 1656: 21.

Robinson, K.L., Ruzicka, J.J., Decker, M.B., Brodeur, R.D., Hernandez, F.J., Quiñones, J., Acha, E.M., Uye, S.I., Mianzan, H., and Graham, W.M. 2014. Jellyfish, forage fish, and the world's major fisheries. Oceanography 27(4): 104–115. doi:10.5670/oceanog.2014.90.

Roed, M.A. 1995. Geology of the Kelowna area and the origin of the Okanagan valley British Columbia. Kelowna Geology Committee, Okanagan University College. Kelowna, BC. Kelowna Geology Committee.

Roni, P., Johnson, C., De Boer, T., Pess, G., Dittman, A., and Sear, D.A. 2016. Interannaul variability in the effects of physical habitat and parentage on Chinook salmon egg-to-fry survival. Can. J. Fish. Aquat. Sci 73(3): 1047–1059.

Rosecoe, D.W., Hinch, S.G., Cooke, S.J., and Patterson, D.A. 2011. Fishway Passage and Post-Passage Mortality of Up-River Migrating Sockeye Salmon in the Seton River, British Columbia. River Res. Appl. 27: 693–705. doi:10.1002/rra.

Rosenau, M., and Angelo, M. 2005. Conflicts Between Agriculture and Salmon in the Eastern Fraser Valley. Pacific Fisheries Resource Conservation Council. Vancouver, BC. 129 p + Appendix.

Roseneau, M. I. 2014. Nearshore Habitat Utilization by Spawning Lake Char and Rearing Rainbow Trout in Shuswap, Little Shuswap and Mara Lakes. Fraser Basin Council Manuscript Report. (Accessed July 21, 2020)

Ross, P.S., Kennedy, C.J., Shelley, L.K., Tierney, K.B., Patterson, D.A., Fairchild, W.L., and Macdonald, R.W. 2013. The trouble with salmon: relating pollutant exposure to toxic effect in species with transformational life histories and lengthy migrations. Can. J. Fish. Aquat. Sci. 70: 1252–1264. doi:10.1139/cjfas-2012-0540.

Ross, T., and Robert, M. 2018. La Niña and another warm year. In State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Canadian Technical Report of Fisheries and Aquatic Sciences 3266. pp. 27–32.

Ruggerone, G.T., Hanson, R., and Rogers, D.E. 2000. Selective predation by brown bears (*Ursus arctos*) foraging on spawning sockeye salmon (*Oncorhynchus nerka*). Can. J. Zool. 78(6): 974–981. doi:10.1139/z00-024.

Ruggerone, G.T., and Irvine, J.R. 2018. Numbers and Biomass of Natural- and Hatchery-Origin Pink Salmon, Chum Salmon, and Sockeye Salmon in the North Pacific Ocean, 1925–2015. Mar. Coast. Fish. 10(2): 152–168. doi:10.1002/mcf2.10023.

Runciman, J.B., and Leaf, B.R. 2009. A Review of Yellow Perch (*Perca flavascens*), Smallmouth bass (*Micropterus dolomieu*), Largemouth bass (*Micropterus salmoides*), Pumkinseed (*Lepomis gibbosus*), Walleye (*Sander vitreus*) and Northern Pike (*Esox lucius*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2882.

Russell, L.R., Graham, C.C., Sewid, A.G., and Archibald, D.M. 1980. Distribution of juvenile chinook, coho, and sockeye salmon in Shuswap Lake – 1978-1979; Biophysical inventory of littoral areas of Shuswap Lake, 1978. Can. Fish. Mar. Serv. 1479: 54 p.

Rutz, D. 1999. Movements, food availability and stomach contents of northern pike in selected Susitna River drainages, 1996-1997. Alaska Department of Fish and Game. Fishery Data Series No. 99-5. (Accessed July 21, 2020)

Saaristo, M., McLennan, A., Johnstone, C.P., Clarke, B.O., and Wong, B.B.M. 2017. Impacts of the antidepressant fluoxetine on the anti-predator behaviours of wild guppies (*Poecilia reticulata*). Aquat. Toxicol. 183: 38–45. doi:10.1016/j.aquatox.2016.12.007.

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H.M., Collen, B., Cox, N., Master, L.L., O'Connor, S., and Wilkie, D. 2008. A standard lexicon for biodiversity conservation: Unified classifications of threats and actions. Conserv. Biol. 22(4): 897–911. doi:10.1111/j.1523-1739.2008.00937.x.

Sandahl, J.F., Baldwin, D.H., Jenkins, J.J., and Scholz, N.L. 2007. A sensory system at the interface between urban stormwater runoff and salmon survival. Environ. Sci. Technol. 41(8): 2998–3004. doi:10.1021/es062287r.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). *In* Pacific Salmon life histories. UBC Press. pp. 395–446.

Schabetsberger, R., Morgan, C.A., Brodeur, R.D., Potts, C.L., Peterson, W.T., and Emmett, R.L. 2003. Prey selectivity and diel feeding chronology of juvenile chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Columbia River plume. Fish. Oceanogr. 12(6): 523–540. doi:10.1046/j.1365-2419.2003.00231.x.

DA Schmetterling, CG Clancy, T.B. 2011. Effects of Riprap Bank Reinforcement on Stream Salmonids in the Western United States. Fisheries 2415(February 2014): 37–41. doi:10.1577/1548-8446(2001)026<0006.

Schnorbus, M., Bennett, K., and Werner, A. 2010. Quantifying the water resource impacts of mountain pine beetle and associated salvage harvest operations across a range of watershed scales: Hydrologic modelling of the Fraser River Basin. *In* Canadian Forest Service, Pacific Forestry Centre, Information Report BC-X-423.

Scholz, N.L., Myers, M.S., McCarthy, S.G., Labenia, J.S., McIntyre, J.K., Ylitalo, G.M., Rhodes, L.D., Laetz, C.A., Stehr, C.M., French, B.L., McMillan, B., Wilson, D., Reed, L., Lynch, K.D., Damm, S., Davis, J.W., and Collier, T.K. 2011. Recurrent die-offs of adult coho salmon returning to spawn in Puget Sound lowland urban streams. PLoS One 6(12). doi:10.1371/journal.pone.0028013.

Schultz, M.M., Bartell, S.E., and Schoenfuss, H.L. 2012. Effects of triclosan and triclocarban, two ubiquitous environmental contaminants, on anatomy, physiology, and behavior of the fathead minnow (*Pimephales promelas*). Arch. Environ. Contam. Toxicol. 63(1): 114–124. doi:10.1007/s00244-011-9748-x.

Scordino, J.J., Gearin, P.J., Riemer, S.D., and Iwamoto, E.M. 2016. River Otter (*Lontra canadensis*) Food Habits in a Washington Coast Watershed: Implications for a Threatened Species . Northwest. Nat. 97(1): 36–47. doi:10.1898/1051-1733-97.1.36.

Scott, W., and Crossman, E. 1973. Freshwater fishes of Canada. Bull. J. Fish. Res. Board Canada: 966. doi:10.1002/iroh.19760610109.

Scrivener, C., Brown, T.C., and Andersen, B.C. 1994. Juvenile chinook salmon (*Oncorhynchus tshawytscha*) utilization of Hawk's Creek, a small and nonnatal tributary of the upper Fraser River. Can. J. Fish. Aquat. Sci. 51: 1139–1146.

Sebring, S.H., Carper, M.C., Ledgerwood, R.D., Sandford, B.P., Matthews, G.M., and Evans, A.F. 2013. Relative vulnerability of Pit-tagged subyearling fall Chinook Salmon to predation by Caspian terns and double-crested cormorants in the Columbia River estuary. Trans. Am. Fish. Soc. 142(5): 1321–1334. doi:10.1080/00028487.2013.806952.

Sedell, J., Leone, F., and Duval, W. 1991. Water transportation and storage of logs. In W.R. Meehan (ed). *In* Influence of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. *Edited by* W. Meehan. American Fisheries Society, Bethesda, Md. p. 751.

Seitz, A.C., Courtney, M.B., Evans, M.D., and Manishin, K. 2019. Pop-up satellite archival tags reveal evidence of intense predation on large immature Chinook salmon (*Oncorhynchus tshawytscha*) in the North Pacific Ocean. Can. J. Fish. Aquat. Sci. 76(9): 1608–1615. doi:10.1139/cjfas-2018-0490.

Sepulveda, A.J., Rutz, D.S., Ivey, S.S., Dunker, K.J., and Gross, J.A. 2013. Introduced northern pike predation on salmonids in southcentral Alaska. Ecol. Freshw. Fish 22(2): 268–279. doi:10.1111/eff.12024.

Shafer, D.J. 1999. The effects of dock shading on the seagrass Halodule wrightii in Perdido Bay, Alabama. Estuaries 22(4): 936–943. doi:10.2307/1353073.

Shelton, J.M. 1955. The Hatching of Chinook Salmon Eggs Under Simulated Stream Conditions. United States Fish and Wildlife Service. Progress. Fish Cult. 17(1): 16.

Shrestha, R., Schnorbus, M., Werner, A., and Berland, A. 2012. Modelling spatial and temporal variability of hydrologic impacts of climate change in the Fraser River basin, British Columbia, Canada. Hydrol. Process. 26(12): 1840–1860. doi:10.1002/hyp.

Shrestha, R.R., Schnorbus, M.A., and Cannon, A.J. 2015. A dynamical climate model-driven hydrologic prediction system for the Fraser River, Canada. J. Hydrometeorol. 16(3): 1273–1292. doi:10.1175/JHM-D-14-0167.1.

Shrimpton, J.M., Zydlewski, J.D., and Heath, J.W. 2007. Effect of daily oscillation in temperature and increased suspended sediment on growth and smolting in juvenile chinook salmon, Oncorhynchus tshawytscha. Aquaculture 273(2–3): 269–276. doi:10.1016/j.aquaculture.2007.10.009.

Smale, D., Wernberg, T., Oliver, E., Thomsen, M., Harvey, B., Straub, S., Burrows, M., Alexander, L., Benthuysen, J., Donat, M., Feng, M., Hobday, A., Holbrook, N., Perkins-kirkpatrick, S., Scannell, H., Sen Gupta, A., Payne, B., and Moore, P. 2019. Marine heatwaves threaten global biodiversity and the provision of ecosystem services. Nat. Clim. Chang. 9(4): 306–312.

Smith, O.R. 1940. Placer Mining Silt and its Relation to Salmon and Trout on the Pacific Coast. Trans. Am. Fish. Soc. (69): 225–230. doi:225-230. doi:10.1577/1548-8659(1939)69[225:PMSAIR]2.0.CO;2.

Solomon, K.R., Carr, J.A., Du Preez, L.H., Giesy, J.P., Kendall, R.J., Smith, E.E., and Van Der Kraak, G.J. 2008. Effects of atrazine on fish, amphibians, and aquatic reptiles: A critical review. Crit. Rev. Toxicol. 38(9): 721–772. doi:10.1080/10408440802116496.

Sommer, T.R., Harrell, W.C., and Nobriga, M.L. 2005. Habitat Use and Stranding Risk of Juvenile Chinook Salmon on a Seasonal Floodplain. North Am. J. Fish. Manag. 25(4): 1493–1504. doi:10.1577/m04-208.1.

Sopinka, N.M., Hinch, S.G., Healy, S.J., Raby, G.D., and Patterson, D.A. 2016. Effects of experimentally elevated egg cortisol on offspring traits in two species of wild Pacific salmon. Environ. Biol. Fishes 99(10): 717–728. doi:10.1007/s10641-016-0513-x.

Southern Resident Orca Task Force (SROTF). 2018. Southern Resident Orca Task Force: Report and Recommendations. (Accessed July 21, 2020).

Springer, J., Ludwig, R., and Kienzle, S. 2015. Impacts of Forest Fires and Climate Variability on the Hydrology of an Alpine Medium Sized Catchment in the Canadian Rocky Mountains. Hydrology 2(1): 23–47. doi:10.3390/hydrology2010023.

Spromberg, J.A., and Meador, J.P. 2006. Relating chronic toxicity responses to population-level effects: A comparison of population-level parameters for three salmon species as a function of low-level toxicity. Ecol. Modell. 199: 240–252. doi:10.1016/j.ecolmodel.2006.05.007.

Steen, R.P., and Quinn, T.P. 1999. Egg burial depth by sockeye salmon (*Oncorhynchus nerka*): implications for survival of embryos and natural selection on female body size. Can. J. Zool. 77: 836–841.

Stein, R.A., Reimers, P.E., and Hall, J.D. 1972. Social Interaction Between Juvenile Coho (*Oncorhynchus kisutch*) and Fall Chinook Salmon (*O. tshawytscha*) in Sixes River, Oregon. J. Fish. Res. Board Canada 29(12): 1737–1748. doi:10.1139/f72-275.

Stewart, G.O., Lauzier, R.B., and Murray, P.R. 1983. Juvenile salmonid studies in the North Thompson Region of B.C., 1982. Envirocon Limited, DSS Contract No. 0458 FP 576-1-0487.

Sutherland, A.J., and Ogle, D.G. 1975. Effect of jet boats on salmon eggs. New Zeal. J. Mar. Freshw. Res. 9(3): 273–282. doi:10.1080/00288330.1975.9515566.

Sutherland, T.F., Elner, R.W., and O'Neill, J.D. 2013. Roberts Bank: Ecological crucible of the fraser river estuary. Prog. Oceanogr. 115: 171–180. doi:10.1016/j.pocean.2013.05.018.

Swales, S., Lauzier, R.B., and Levings, C.D. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Can. J. Zool. 64(7): 1506–1514. doi:10.1139/z86-225.

Sykes, G.E., Johnson, C.J., and Shrimpton, J.M. 2009. Temperature and Flow Effects on Migration Timing of Chinook Salmon Smolts. Trans. Am. Fish. Soc. 138(6): 1252–1265. doi:10.1577/t08-180.1.

Tabor, R.A., Brown, G.S., and Luiting, V.T. 2004. The Effect of Light Intensity on Sockeye Salmon Fry Migratory Behavior and Predation by Cottids in the Cedar River, Washington. North Am. J. Fish. Manag. 24(1): 128–145. doi:10.1577/m02-095.

Tarbotton, M., and Harrison, P.G. 1996. A Review of the Recent Physical and Biological Development of the Southern Roberts Bank Seagrass System 1950 - 1994. Triton Consultants Ltd. 88 p.

Tatara, C.P., and Berejikian, B.A. 2012. Mechanisms influencing competition between hatchery and wild juvenile anadromous Pacific salmonids in fresh water and their relative competitive abilities. Environ. Biol. Fishes 94(1): 7–19. doi:10.1007/s10641-011-9906-z.

Taylor, E.B. 1988. Adaptive Variation in Rheotactic and Agnostic Behaviour in Newly Emerged Fry of Chinook Salmon, *Oncorhynchus tshawytscha*, from Ocean- and Stream-Type Populations. J. Chem. Inf. Model. 45: 237–243. doi:10.1017/CBO9781107415324.004.

Teel, D.J., Milner, G.B., Winans, G.A., and Grant, W.S. 2000. Genetic Population Structure and Origin of Life History Types in Chinook Salmon in British Columbia, Canada. Trans. Am. Fish. Soc. 129(1): 194–209. doi:10.1577/1548-8659(2000)129<0194:gpsaoo>2.0.co;2.

Thakur, K.K., Vanderstichel, R., Li, S., Laurin, E., Tucker, S., Neville, C., Tabata, A., and Miller, K.M. 2018. A comparison of infectious agents between hatchery-enhanced and wild out-migrating juvenile chinook salmon (*Oncorhynchus tshawytscha*) from Cowichan River, British Columbia. Facets 3(1): 695–721. doi:10.1139/facets-2017-0113.

The Association of Professional Engineers and Geoscientists of British Columbia (APEGBC). 2016. Flood Mapping in BC. 54 p.

Thomas, A.C., Nelson, B.W., Lance, M.M., Deagle, B.E., and Trites, A.W. 2017. Harbour seals target juvenile salmon of conservation concern. Can. J. Fish. Aquat. Sci. 74(6): 907–921. doi:10.1139/cjfas-2015-0558.

Thorson, J.T., Scheuerell, M.D., Buhle, E.R., and Copeland, T. 2014. Spatial variation buffers temporal fluctuations in early juvenile survival for an endangered Pacific salmon. J. Anim. Ecol. 83(1): 157–167. doi:10.1111/1365-2656.12117.

Tierney, K.B., Patterson, D.A., and Kennedy, C.J. 2009. The influence of maternal condition on offspring performance in sockeye salmon *Oncorhynchus nerka*. J. Fish Biol. 75(6): 1244–1257. doi:10.1111/j.1095-8649.2009.02360.x.

Tovey, C.P., Bradford, M.J., and Herborg, L. 2009. Biological risk assessment for Smallmouth bass (*Micropterus dolomieu*) and Largemouth bass (*Micropterus salmoides*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/075.

Trombulak, S.C., and Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. 14(1): 18–30. doi:10.1046/j.1523-1739.2000.99084.x.

Trudel, M., Fisher, J., Orsi, J.A., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Hinton, S., Fergusson, E.A., and Welch, D.W. 2009. Distribution and Migration of Juvenile Chinook Salmon Derived from Coded Wire Tag Recoveries along the Continental Shelf of Western North America. Trans. Am. Fish. Soc. 138(6): 1369–1391. doi:10.1577/t08-181.1.

Tschaplinski, P.J., and Pike, R.G. 2017. Carnation Creek watershed experiment—long-term responses of coho salmon populations to historic forest practices. Ecohydrology 10(2). doi:10.1002/eco.1812.

Tucker, S., Li, S., Kaukinen, K.H., Patterson, D.A., and Miller, K.M. 2018. Distinct seasonal infectious agent profiles in life-history variants of juvenile Fraser River Chinook salmon: An application of high-throughput genomic screening. PLoS One 13(4): 1–26. doi:10.1371/journal.pone.0195472.

Tucker, S., Trudel, M., Welch, D.W., Candy, J.R., Morris, J.F.T., Thiess, M.E., Wallace, C., and Beacham, T.D. 2011. Life history and seasonal stock-specific ocean migration of juvenile chinook salmon. Trans. Am. Fish. Soc. 140(4): 1101–1119. doi:10.1080/00028487.2011.607035.

Tutty, B.D., and Yole, F.Y.E. 1978. Overwintering chinook salmon in the upper Fraser River system. Can. Fish. Mar. Serv. 1450: 23 p.

Unwin, M.J. 1997. Fry-to-adult survival of natural and hatchery-produced chinook salmon (Oncorhynchus tshawytscha) from a common origin. Can. J. Fish. Aquat. Sci. 54(6): 1246–1254. doi:10.1139/f97-032.

USEPA. 1989. Ambient water quality criteria for ammonia (saltwater). United States Environmental Protection Agency. National Technical Information Service. Springfield, VA.

Utter, F., Milner, G., Stahl, G., and Teel, D. 1989. Genetic Population Structure of Chinook Salmon, Oncorhynchus tshawytscha, in the Pacific Northwest. Fish. Bull. (U.S.) (87): 239–264.

Vronskiy, B. 1972. Reproductive biology of the Kamchatka River chinook salmon [Oncorhynchus tshawytscha (Walbaum). J. Ichthyol. 12: 259–273.

Wan, M.T., Kuo, J.-N., and Pasternak, J. 2005. Residues of endosulfan and other selected organochlorine pesticides in farm areas of the Lower Fraser Valley, British Columbia, Canada. J. Environ. Qual. 34(1): 11186–93.

Wang, X., Thompson, D.K., Marshall, G.A., Tymstra, C., Carr, R., and Flannigan, M.D. 2015. Increasing frequency of extreme fire weather in Canada with climate change. Clim. Change 130(4): 573–586. doi:10.1007/s10584-015-1375-5.

Wania, F. 1997. Modelling the fate of non-polar organic chemicals in an ageing snow pack. Science (80-.). 35(10): 2345–2363.

Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. Can. J. Fish. Aquat. Sci. 48(Suppl.1): 124–133. doi:10.1139/f91-311.

Waples, R.S. 1999. Dispelling Some Myths about Hatcheries. Fisheries 24(2): 12–21. doi:10.1577/1548-8446(1999)024<0012:dsmah>2.0.co;2.

Waples, R.S., Teel, D.J., Myers, J.M., and Marshall, A.R. 2004. Life-history divergence in Chinook salmon: Historic contingency and parallel evolution. Evolution (N. Y). 58(2): 386–403. doi:10.1111/j.0014-3820.2004.tb01654.x.

Weil, J., Duguid, W.D.P., and Juanes, F. 2019. A hyperiid amphipod acts as a trophic link between a scyphozoan medusa and juvenile Chinook Salmon. Estuar. Coast. Shelf Sci. 223(February): 18–24. doi:10.1016/j.ecss.2019.01.025.

Welch, D.W., Rechisky, E.L., Melnychuk, M.C., Porter, A.D., Walters, C.J., Clements, S., Clemens, B.J., McKinley, R.S., and Schreck, C. 2008. Survival of migrating salmon smolts in large rivers with and without dams. PLoS Biol. 6(10): 2101–2108. doi:10.1371/journal.pbio.0060265.

Weng, K.C., Castilho, P.C., Morrissette, J.M., Landeira-Fernandez, A.M., Holts, D.B., Schallert, R.J., Goldman, K.J., and Block, B.A. 2005. Satellite tagging and cardiac physiology reveal niche expansion in salmon sharks. Science (80-.). 310(5745): 104–106. doi:10.1126/science.1114616.

Weng, K.C., Foley, D.G., Ganong, J.E., Perle, C., Shillinger, G.L., and Block, B.A. 2008. Migration of an upper trophic level predator, the salmon shark *Lamna ditropis*, between distant ecoregions. Mar. Ecol. Prog. Ser. 372: 253–264. doi:10.3354/meps07706.

West, J.E., O'Neill, S.M., and Ylitalo, G.M. 2008. Spatial extent, magnitude, and patterns of persistent organochlorine pollutants in Pacific herring (*Clupea pallasi*) populations in the Puget Sound (USA) and Strait of Georgia (Canada). Sci. Total Environ. 394(2–3): 369–378. doi:10.1016/j.scitotenv.2007.12.027.

Williams, C.R., Dittman, A.H., McElhany, P., Busch, D.S., Maher, M.T., Bammler, T.K., MacDonald, J.W., and Gallagher, E.P. 2019. Elevated CO 2 impairs olfactory-mediated neural and behavioral responses and gene expression in ocean-phase coho salmon (*Oncorhynchus kisutch*). Glob. Chang. Biol. 25(3): 963–977. doi:10.1111/gcb.14532.

Winkler, R., Rex, J., Teti, P., Maloney, D., and Redding, T. 2008. Mountain Pine Beetle Forest Practices, and Watershed Management. B.C. Min. For. Range, Res. Br., Victoria, B.C. Exten. Note 88. (Accessed July 21, 2020)

Winkler, R., Spittlehouse, D., and Boon, S. 2017. Streamflow response to clear-cut logging on British Columbia's Okanagan Plateau. Ecohydrology 10(2): 1–15. doi:10.1002/eco.1836.

Wise, M.P., Moore, G.D., and VanDine, D.F. 2004. Landslide risk case studies in forest development planning and operations. British Columbia, Forest Science Program.

Wood, C.C. 1987a. Predation of Juvenile Pacific Salmon by the Common Merganser (Mergus merganser) on Eastern Vancouver Island. I: Predation during the Seaward Migration. Can. J. Fish. Aquat. Sci 44: 941–949. doi:10.1139.

Wood, C.C. 1987b. Predation of Juvenile Pacific Salmon by the Common Merganser (Mergus merganser) on Eastern Vancouver Island. II: Predation of Stream-Resident Juvenile Salmon by Meganser Broods. Can. J. Fish. Aquat. Sci. 44(5): 950–959. doi:https://doi.org/10.1139/f87-113.

Woods, A.J., Heppner, D., Kope, H.H., Burleigh, J., and Maclauchlan, L. 2010. Forest health and climate change: A British Columbia perspective. For. Chron. 86(4): 412–422. doi:10.5558/tfc86412-4.

Young, K., and Galbraith, M. 2018. Zooplankton Status and Trends in the Central Strait of Georgia, 2017. *In* State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2017. Canadian Technical Report of Fisheries and Aquatic Sciences 3266.

Zeug, S.C., Sellheim, K., Watry, C., Wikert, J.D., and Merz, J. 2014. Response of juvenile Chinook salmon to managed flow: Lessons learned from a population at the southern extent of their range in North America. Fish. Manag. Ecol. 21(2): 155–168. doi:10.1111/fme.12063.

APPENDIX A. LIST OF SPAWNING STREAMS BY DU

Table A1. List of all known spawning streams for FRC DUs covered in RPA.

DU	DU Name	Stream Name(s)
DU2	Lower Fraser River Ocean Fall	Harrison R
DU4	Lower Fraser River Stream Summer-Upper Pitt	Pitt R (Upper)
DU5	Lower Fraser River Stream Summer	Big Silver Cr
DU7	Middle Fraser River Stream (Nahatlach)	Nahatlatch R
DU8	Middle Fraser River Stream Fall (Portage)	Portage Cr
DU9	Middle Fraser River Stream Spring	Ahbau Cr Baezaeko R Baker Cr Bridge R Cariboo R (upper) Chilako R Chilcotin R (upper) Chilcotin R (lower) Churn Cr Coglistiko R Cottonwood R (lower) Driftwood R Endako R Euchiniko R Horsefly R Lightning Cr McKinley Cr Nadina R Narcosli Cr Naver Cr Nazko R Shovel Cr Stein R Swift R West Road (Blackwater)

DU	DU Name	Stream Name(s)
		Yalakom
DU10	Middle Fraser River Stream Summer	Cariboo R (lower) Cayoosh Cr Chilko R Elkin Cr Kazchek Cr Kuzkwa R Middle R Mitchell R Nachacko R Ormond Cr Pinchi Cr Quesnel R Seton R Stellako R Stuart R Tachie R Taseko R
DU11	Upper Fraser River Stream Spring	Antler Cr Bowron R Captain Cr Dome Cr Driscoll Cr East Twin Cr Fontoniko Cr Forgetmenot Cr Fraser R above Tete Juane Goat R Haggen Cr Herrick Cr Holliday Cr Holmes R

DU	DU Name	Stream Name(s)
		Horsey Cr Humbug Cr Ice Cr Indianpoint Cr Kenneth Cr James Cr McGregor R McKale R Morkill R Nevin Cr Otter Cr Ptarmigan Cr Robson R Salmon R Seebach Cr Slim Cr Small Cr Snowshoe Cr Spakwaniko Cr Sus Cr Swift Cr Torpy R Walker Cr Wansa Cr West Twin Cr Willow R
DU14	South Thompson Stream Summer (Bessette)	Bessette Cr Creighton Cr Duteau Cr Harris Cr
DU16	North Thompson Stream Spring	Albreda R Blue R

DU	DU Name	Stream Name(s)
		Finn Cr Lyon Cr Mad R Mud Cr Thunder R
DU17	North Thompson Stream Summer	Barriere R Clearwater R Lemieux Cr Mahood R Mann Cr N. Thompson R Raft R

APPENDIX B. QUALITY PLOTS

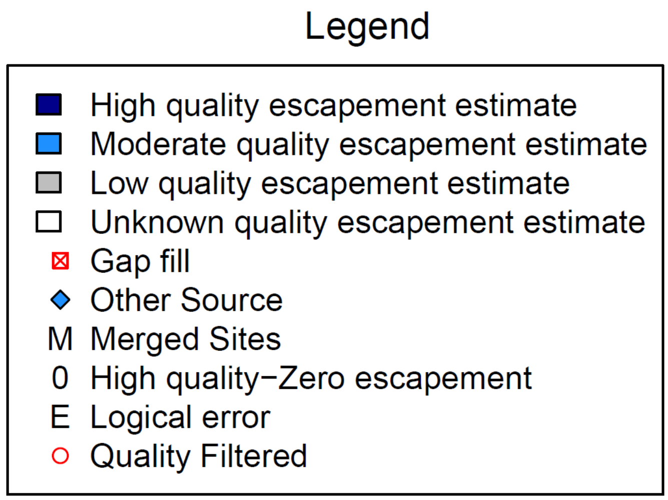


Figure B1. Legend for Escapement Data Quality Plots.

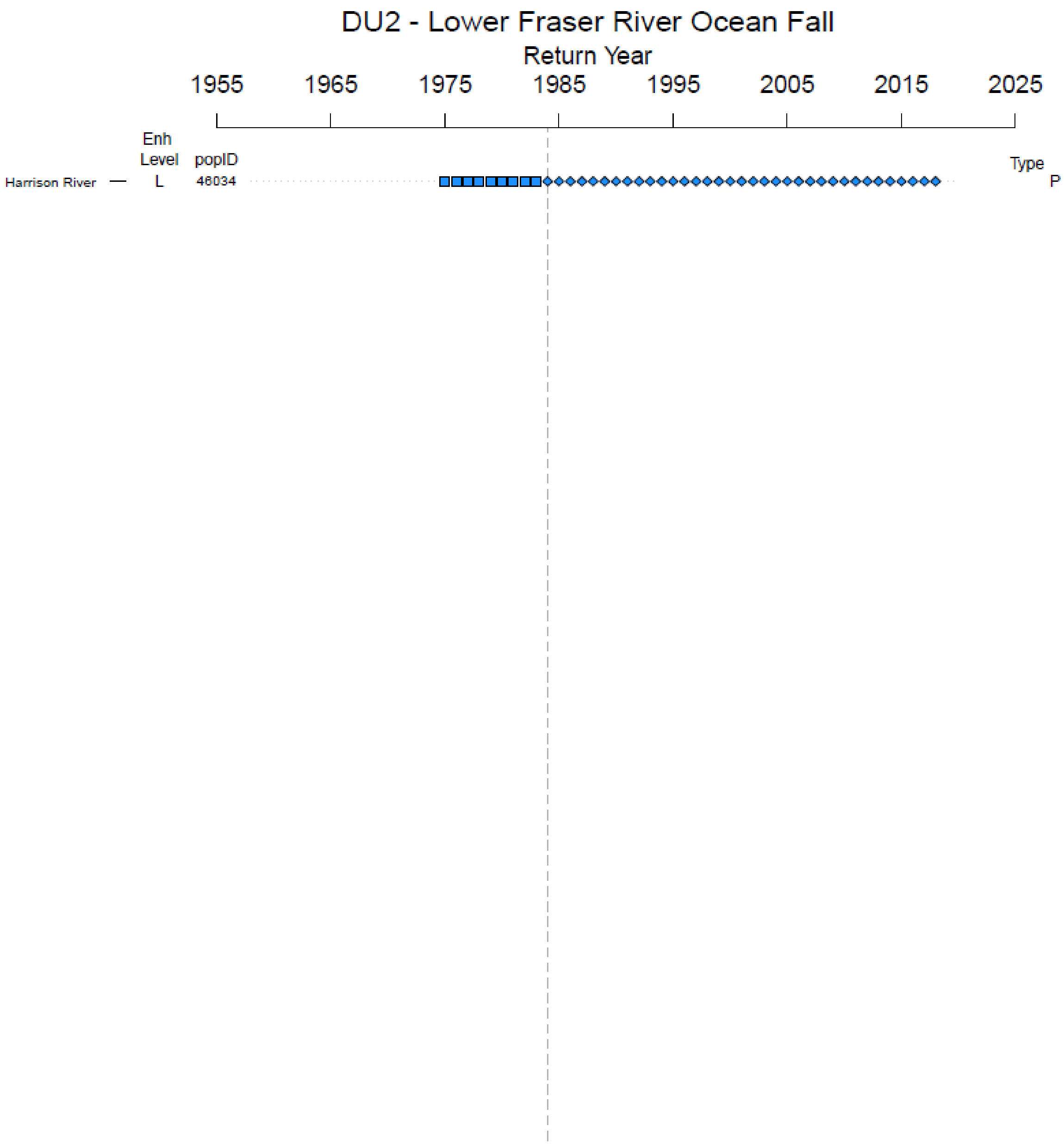


Figure B2. Escapement data quality plot for DU2 Lower Fraser Ocean Fall (Harrison), showing the years where moderate to high quality data is available (refer to Figure B1 for Legend). The grey dashed line indicates the start of the time series; all data from beyond this point are considered to be high quality due to the coded-wired tag program at Harrison. There is a single persistent sampling site in the Harrison River for DU2, indicated by Type = "P".

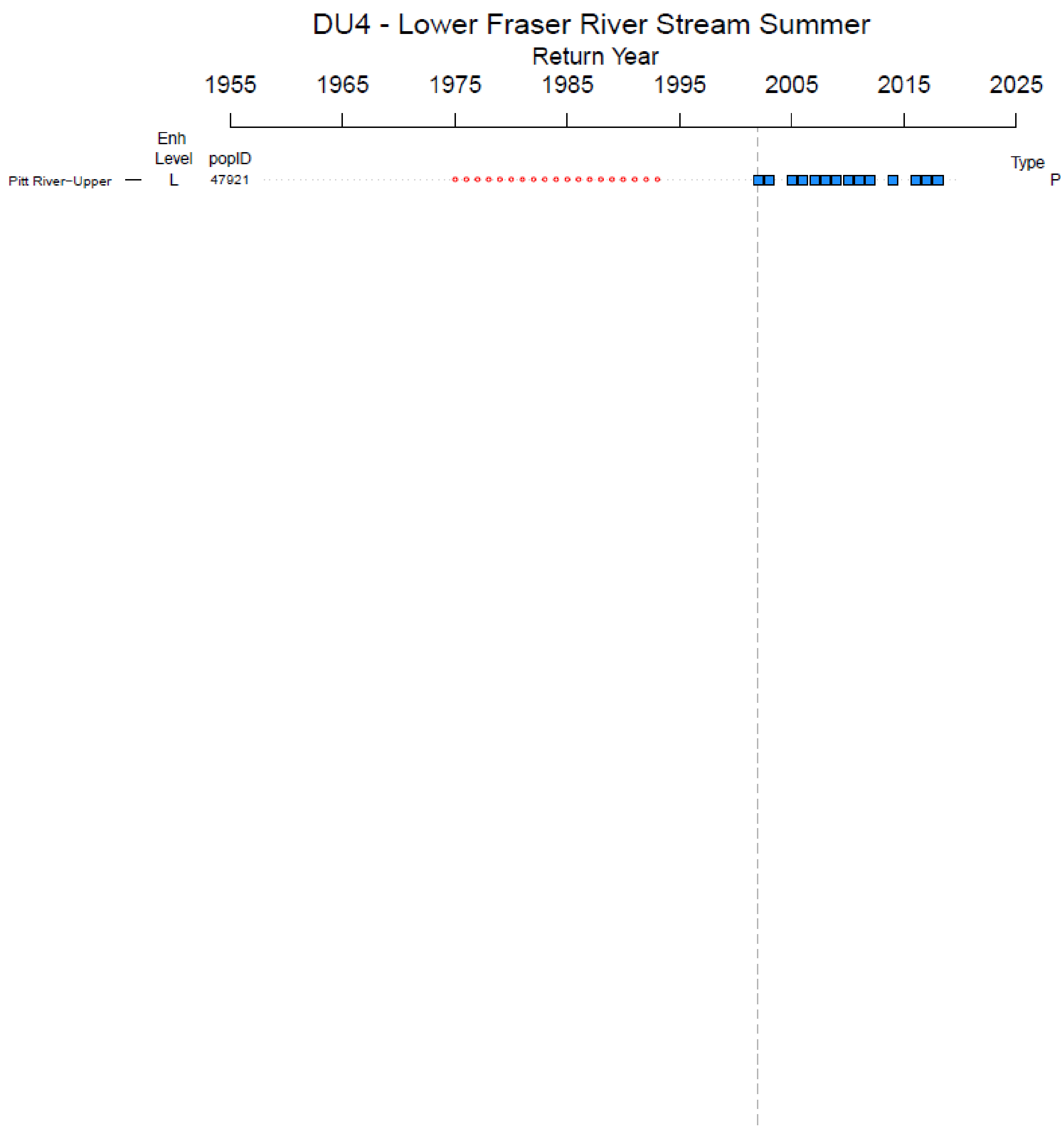


Figure B3. Escapement data quality plot for DU4 Lower Fraser Stream Summer (Upper Pitt), showing the years where moderate quality data is available (refer to Figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There is a single persistent sampling site in the Upper Pitt River for DU4, indicated by Type = "P".

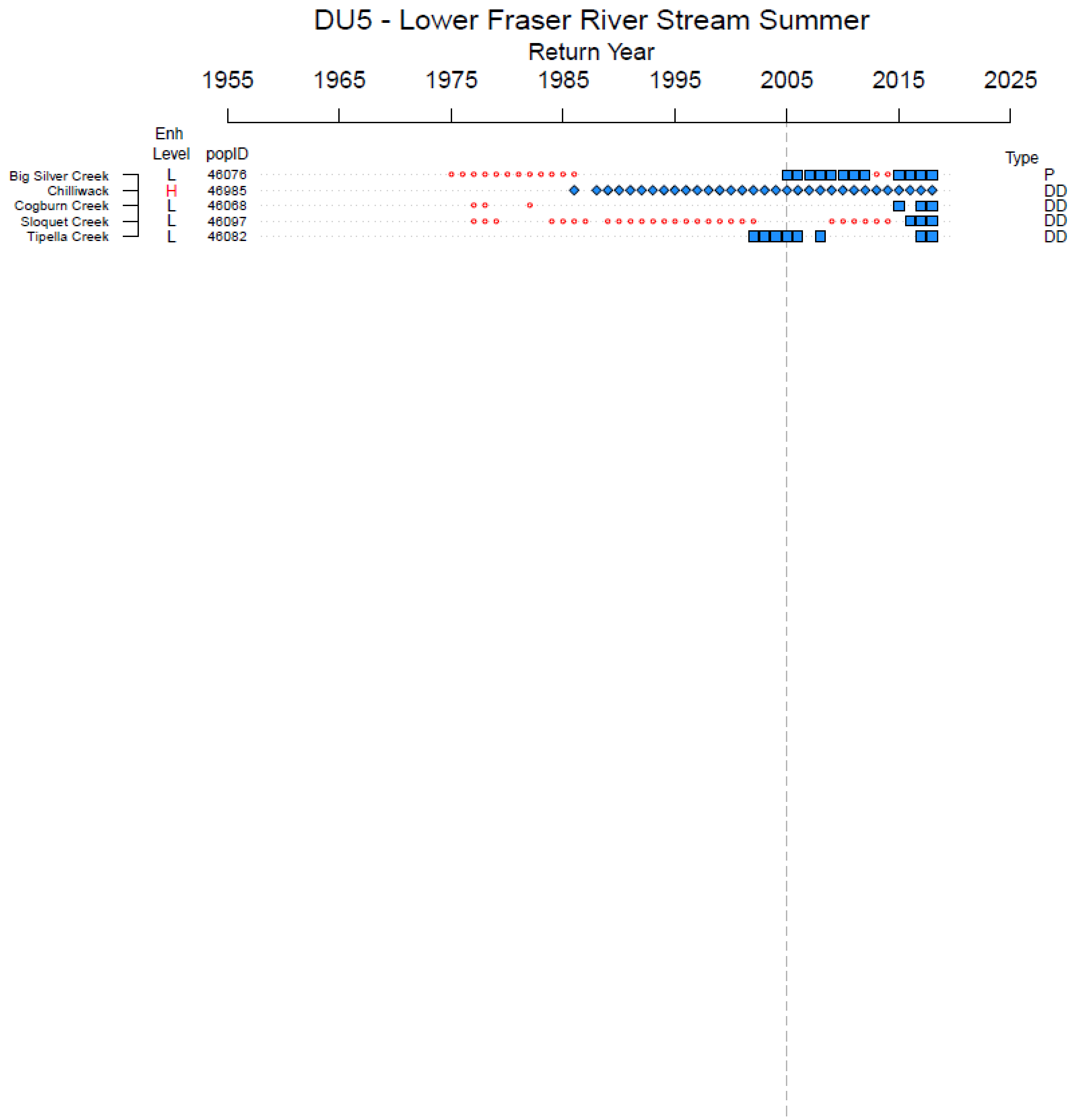


Figure B4. Escapement data quality plot for DU5 Lower Fraser Stream Summer, showing the years where moderate to high quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. Big Silver Creek is the only persistent sampling site for DU5, indicated by Type = "P". Note the Chilliwack River was not included in this RPA due to the high level of hatchery enhancement (assessed in a separate RPA process).

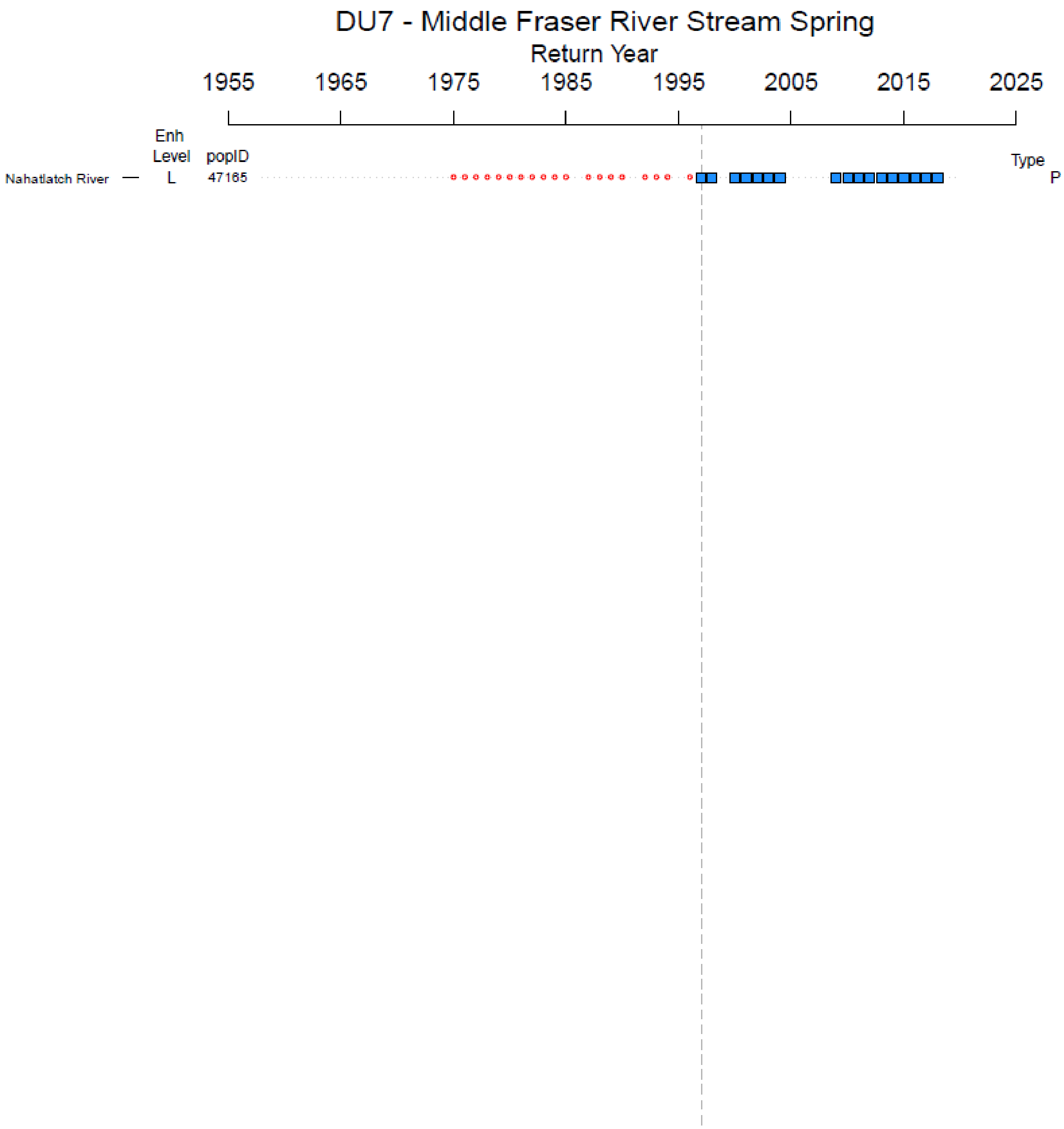


Figure B5. Escapement data quality plot for DU7 Middle Fraser Stream Spring (Nahatlatch), showing the years where moderate to high quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There is a single persistent sampling site in the Nahatlatch River for DU7, indicated by Type = "P".

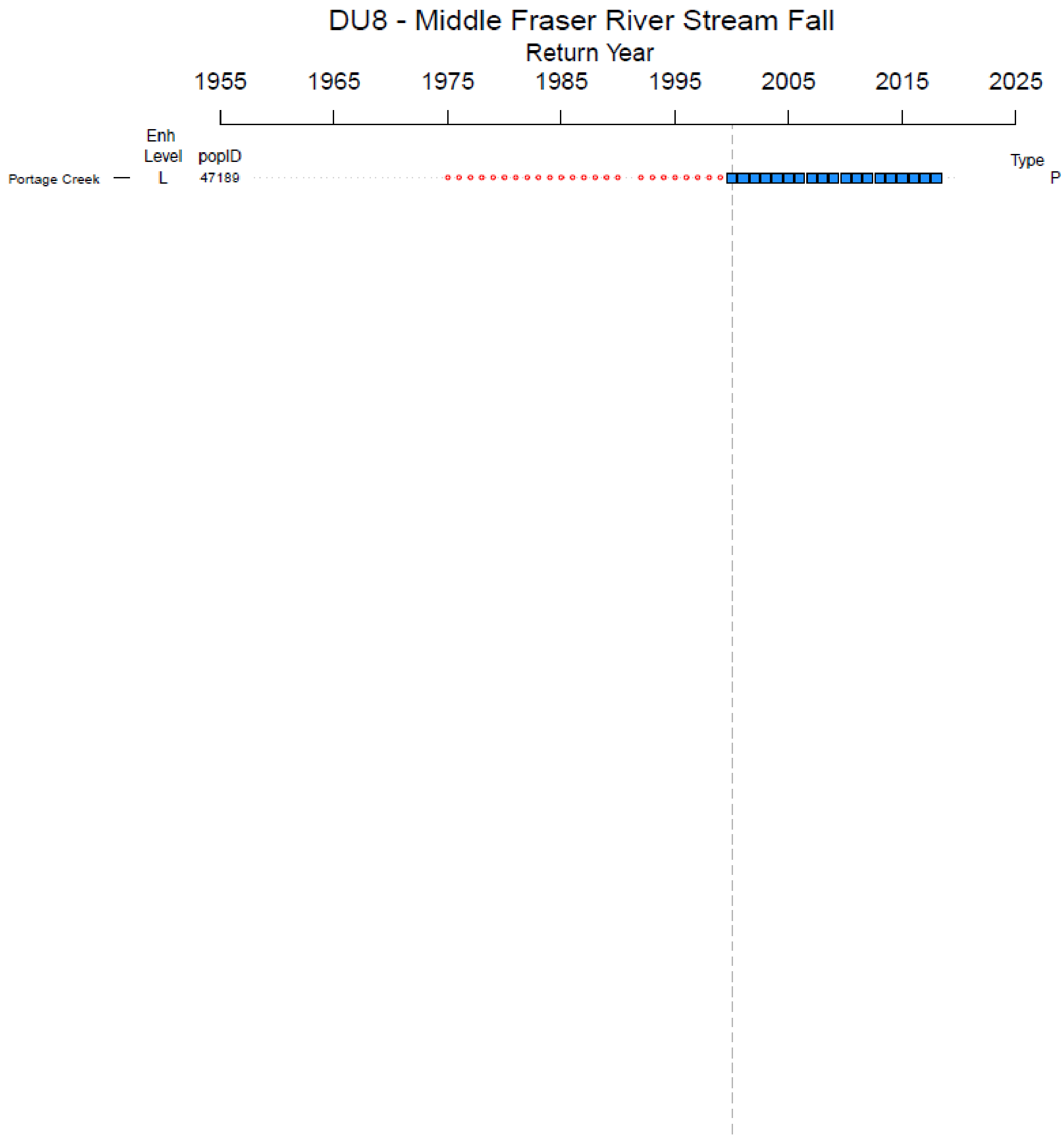


Figure B6. Escapement data quality plot for DU8 Middle Fraser Stream Fall (Portage), showing the years where moderate quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There is a single persistent sampling site in Portage Creek for DU8, indicated by Type = "P".

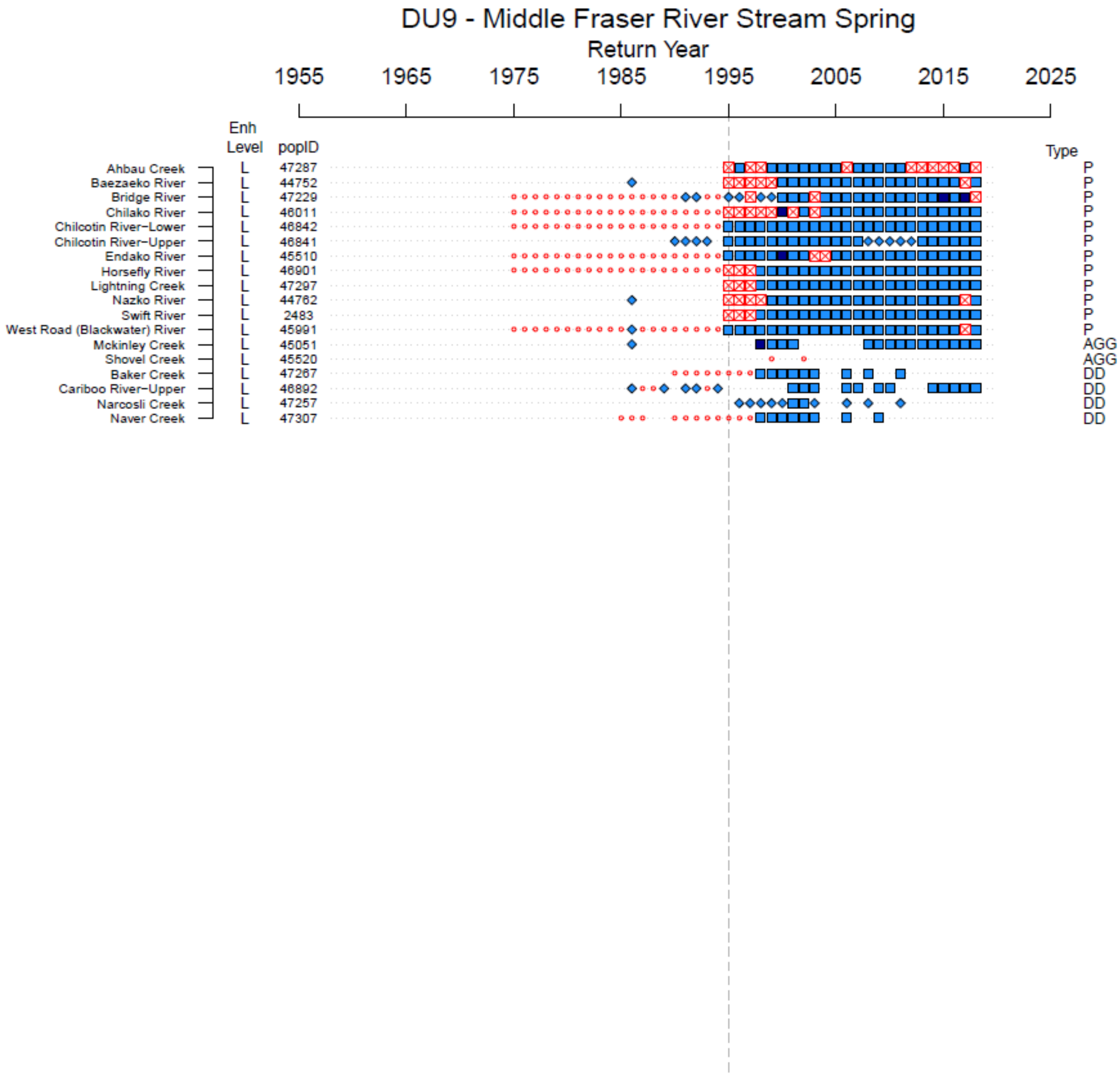


Figure B7. Escapement data quality plot for DU9 Middle Fraser Stream Spring, showing the years where moderate to high quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There are multiple persistent sampling sites within DU9, indicated by Type = "P". These include: Ahbau Creek; Baezaeko River; Bridge River; Chilako River; Chilcotin River (Upper & Lower); Endako River; Horsefly River; Lightning Creek; Nazko River; Swift River; West Road (Blackwater) River.

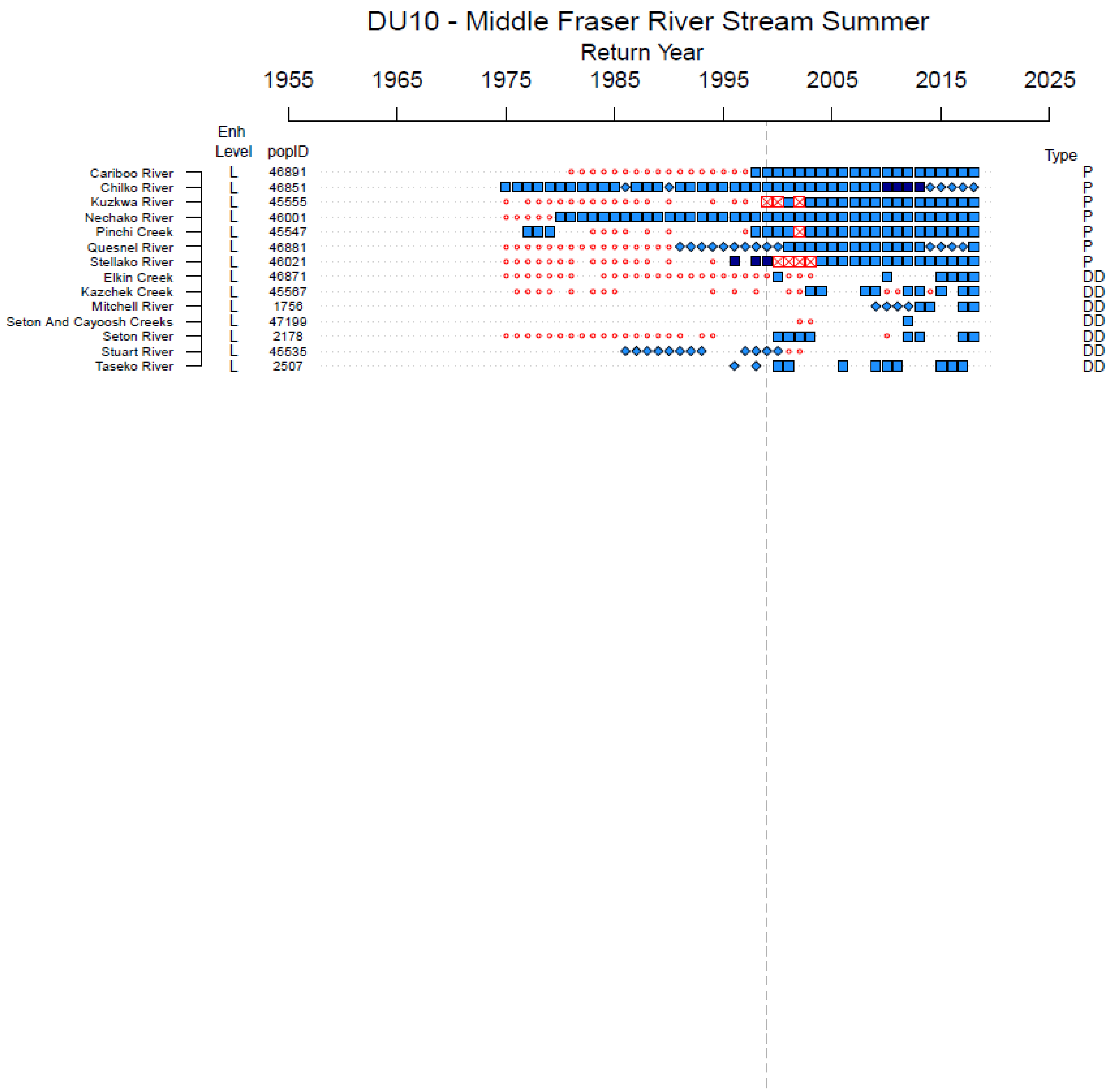


Figure B8. Escapement data quality plot for DU10 Middle Fraser Stream Summer, showing the years where moderate to high quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There are multiple persistent sampling sites within DU10, indicated by Type = "P". These include: Cariboo River; Chilko River; Kuzkwa River; Nechako River; Pinchi Creek; Quesnel River; Stellako River.

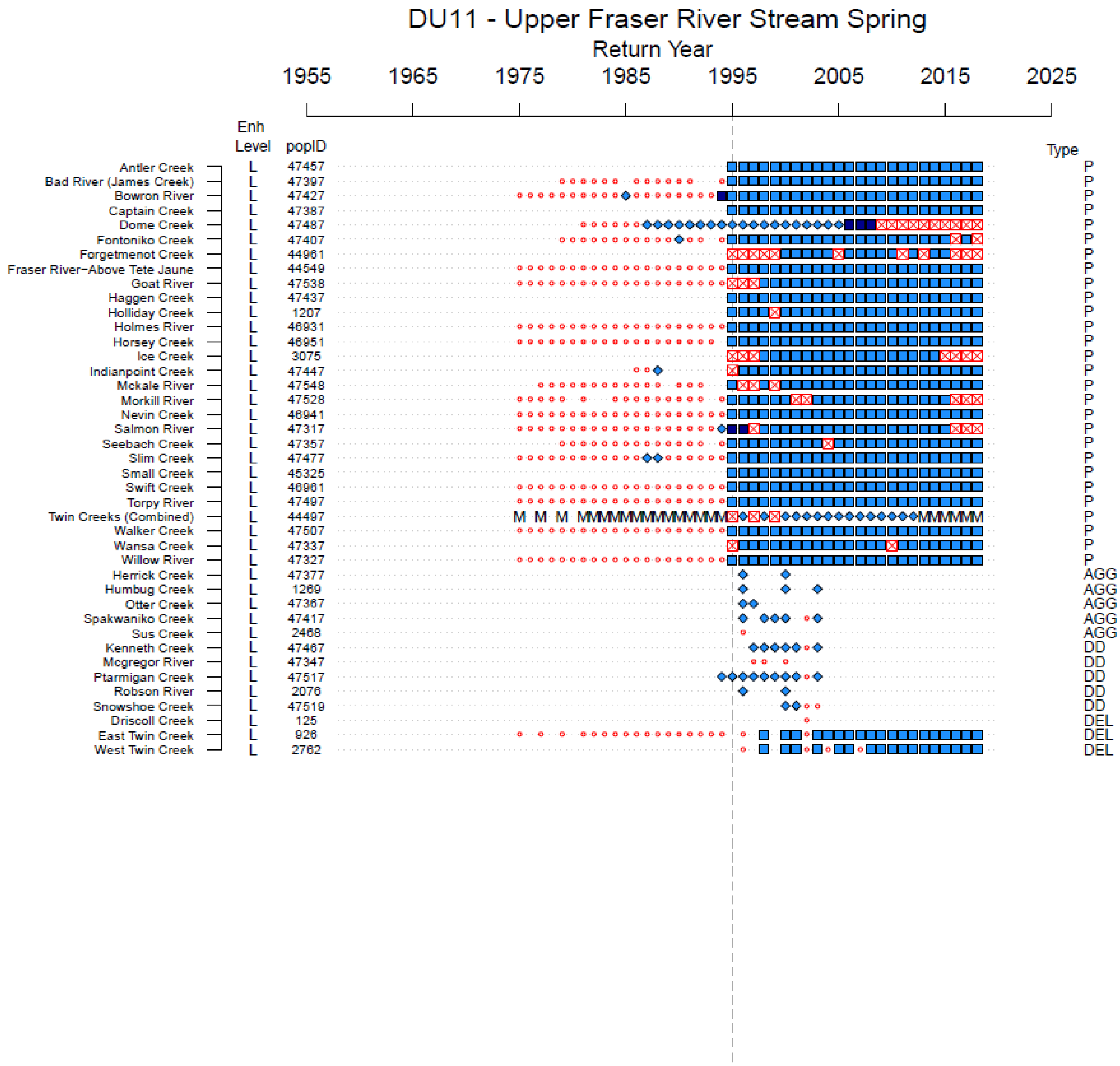


Figure B9. Escapement data quality plot for DU11 Upper Fraser Stream Spring, showing the years where moderate to high quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There are multiple persistent sampling sites within DU11, indicated by Type = "P". These include: Antler Creek; Bad River (James Creek); Bowron River; Captain Creek; Dome Creek; Fontoniko Creek; Forgetmenot Creek; Fraser River (above Tete Jaune); Goat River; Haggen Creek; Holliday Creek; Holmes River; Horsey Creek; Ice Creek; Indianpoint Creek; McKale River; Morkill River; Nevin Creek; Salmon River; Seebach Creek; Slim Creek; Small Creek; Swift Creek; Torpy River; Twin Creeks (East & West); Walker Creek; Wansa Creek; Willow River.

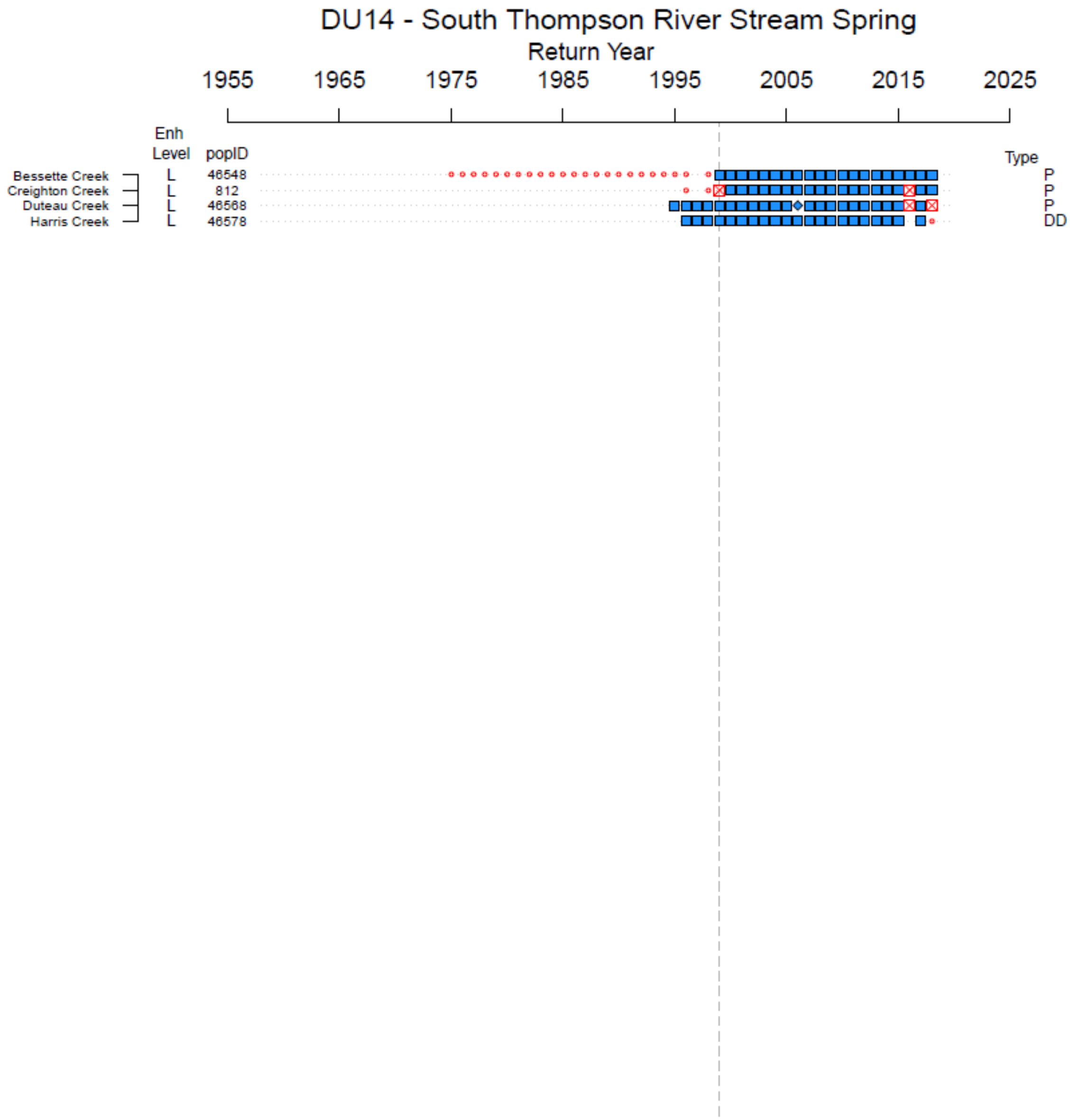


Figure B10. Escapement data quality plot for DU14 South Thompson River Stream Spring, showing the years where moderate quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There are multiple persistent sampling sites within DU14, indicated by Type = "P". These include: Bessette Creek; Creighton Creek; Duteau Creek.

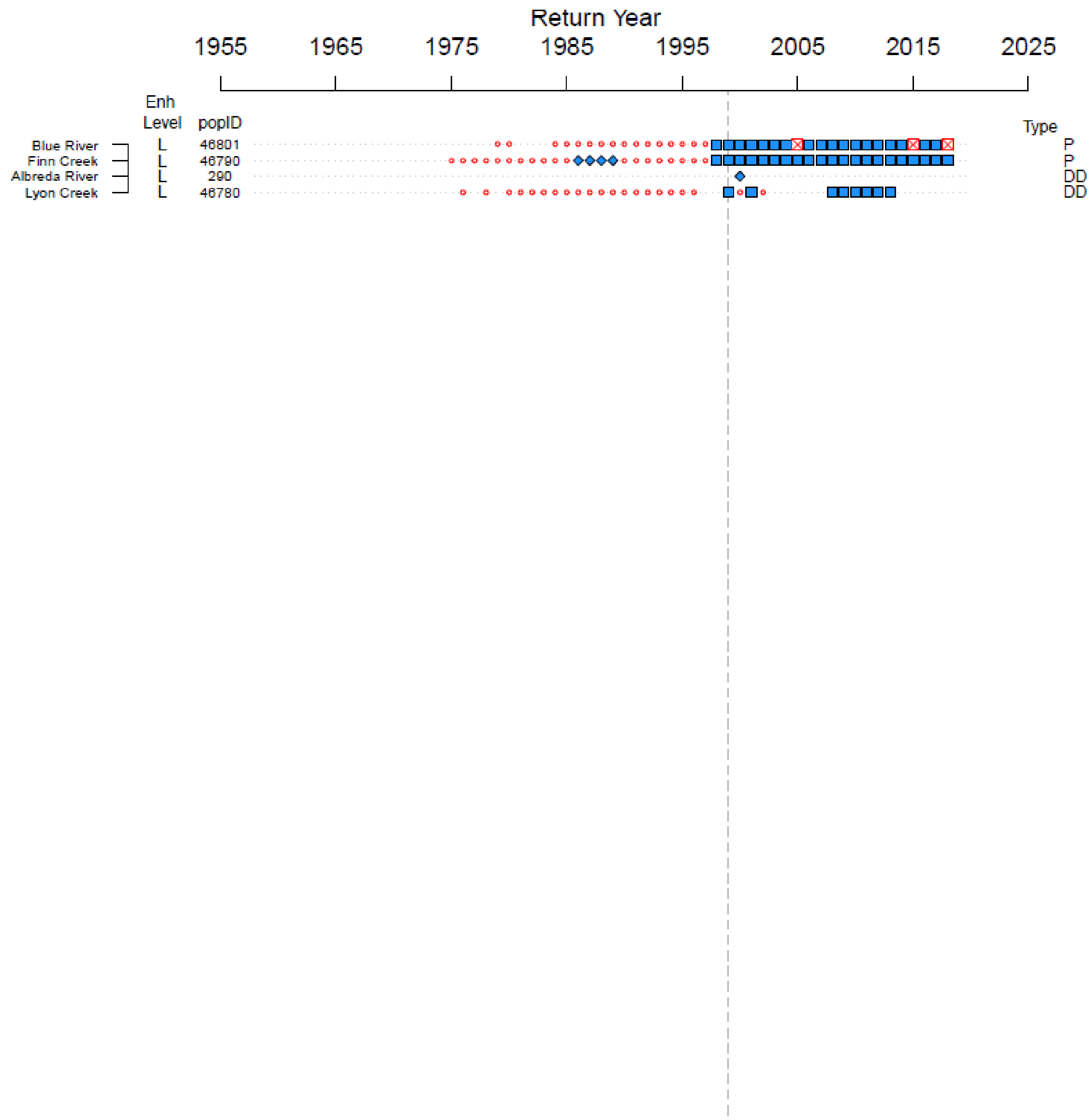


Figure B11. Escapement data quality plot for DU16 North Thompson Stream Spring, showing the years where moderate quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There are two persistent sampling sites within DU16, indicated by Type = "P". These include: Blue River; Finn Creek

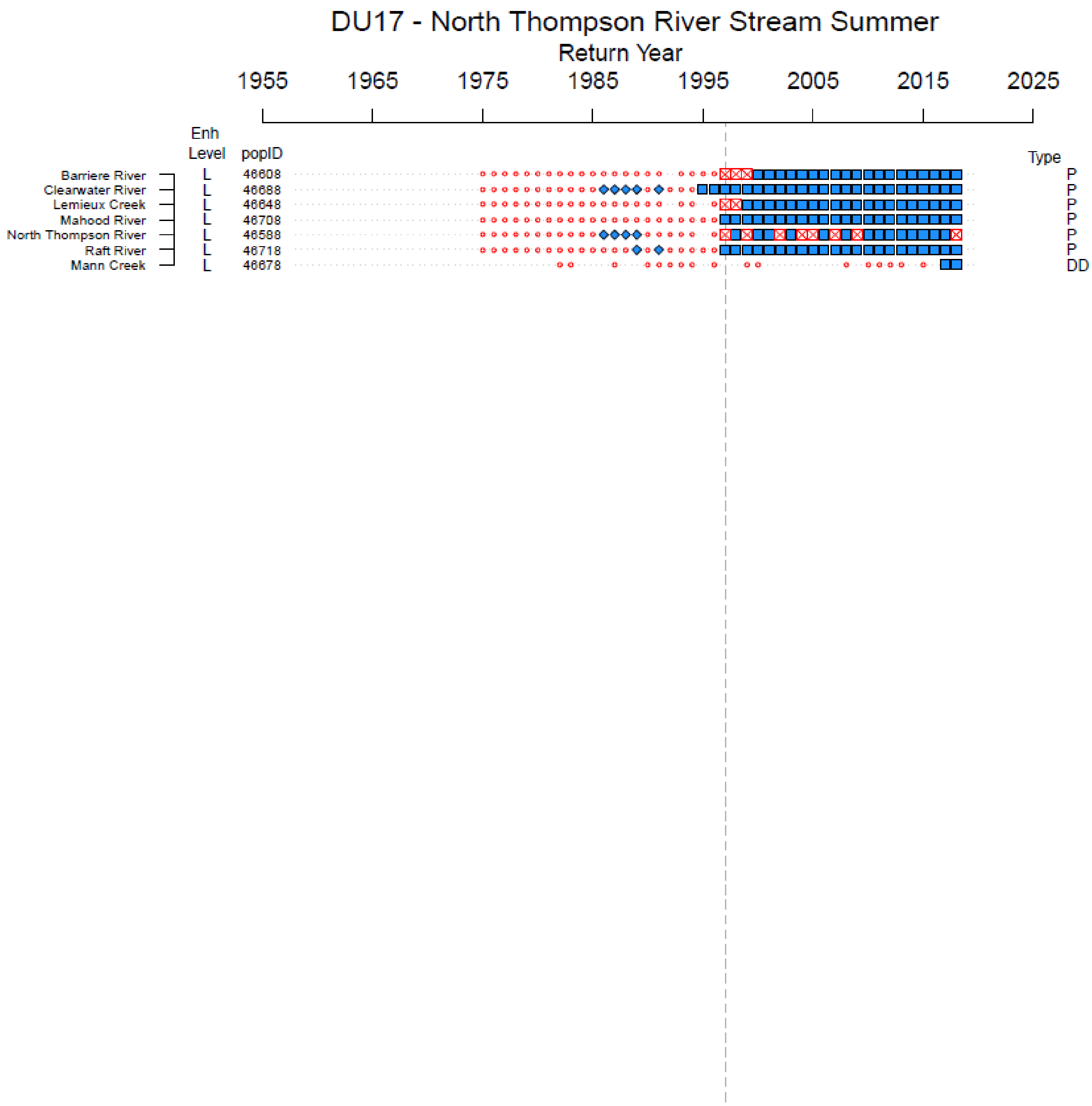


Figure B12. Escapement data quality plot for DU17 North Thompson Stream Summer, showing the years where moderate quality data is available (refer to figure B1 for Legend). The grey dashed line indicates the start of the time series; data from before this point was not included due to inconsistent and uncertain data collection methods. There are multiple sampling sites within DU17, indicated by Type = "P". These include: Barriere River; Clearwater River; Lemieux River; Mahood River; North Thompson River; Raft River.

APPENDIX C. DETAILS ON INFILLING INFLUENCE IN DU9

Middle Fraser Stream Spring (DU9) Infilling Comparison

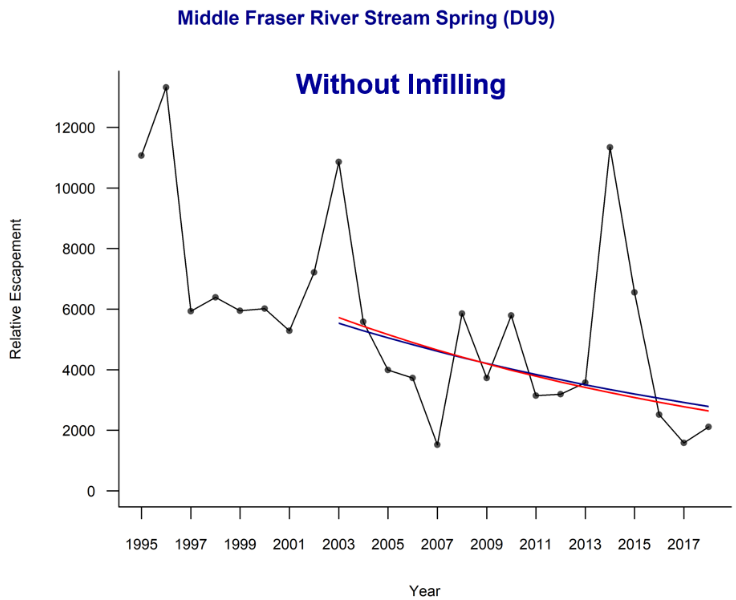


Figure C1. Time series of relative escapement without infilling in 1995 and 1997 from 1995 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

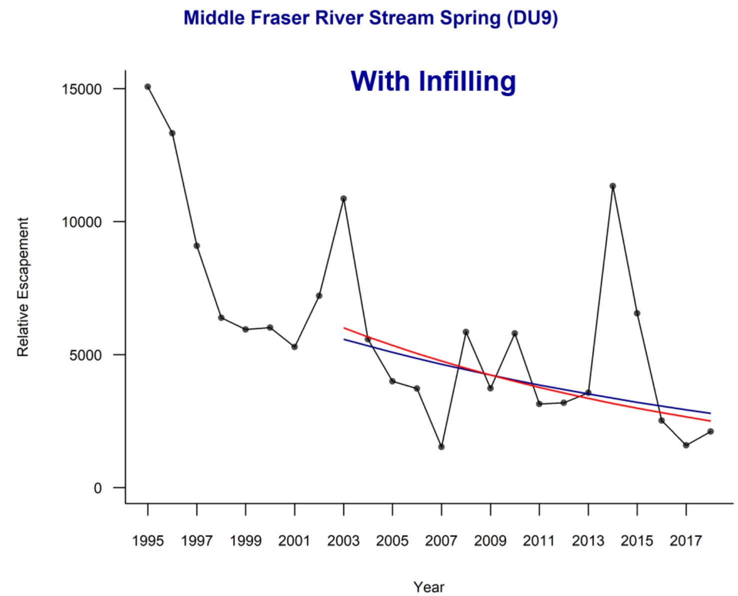


Figure C2. Time series of relative escapement with infilling in 1995 and 1997 from 1995 to 2018 with two estimates of the rate of change in logged escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (blue) (2) rate of change over the last three generations based on all available data (red).

Table C1. Summary of estimated rate of change in spawner abundance and probability of decline over the last three generations (>30%, >50%, >70%) with and without infilling in 1995 and 1997. Rates of change over the last three generations are provided based on analysis of the entire time series.

DU	DU Name Short	Time Series Length	Infilling	Years	Median % Change	95% CI	Probability of Decline		
							>30%	>50%	>70%
DU9	MFR-Springs	All Years	Without Infilling	1995-2018	-52	-69,-28	0.96	0.61	0.02
			With Infilling	1995-2018	-57	-72,-32	0.98	0.76	0.06

APPENDIX D. TREND COMPARISON PLOT ACROSS DUS

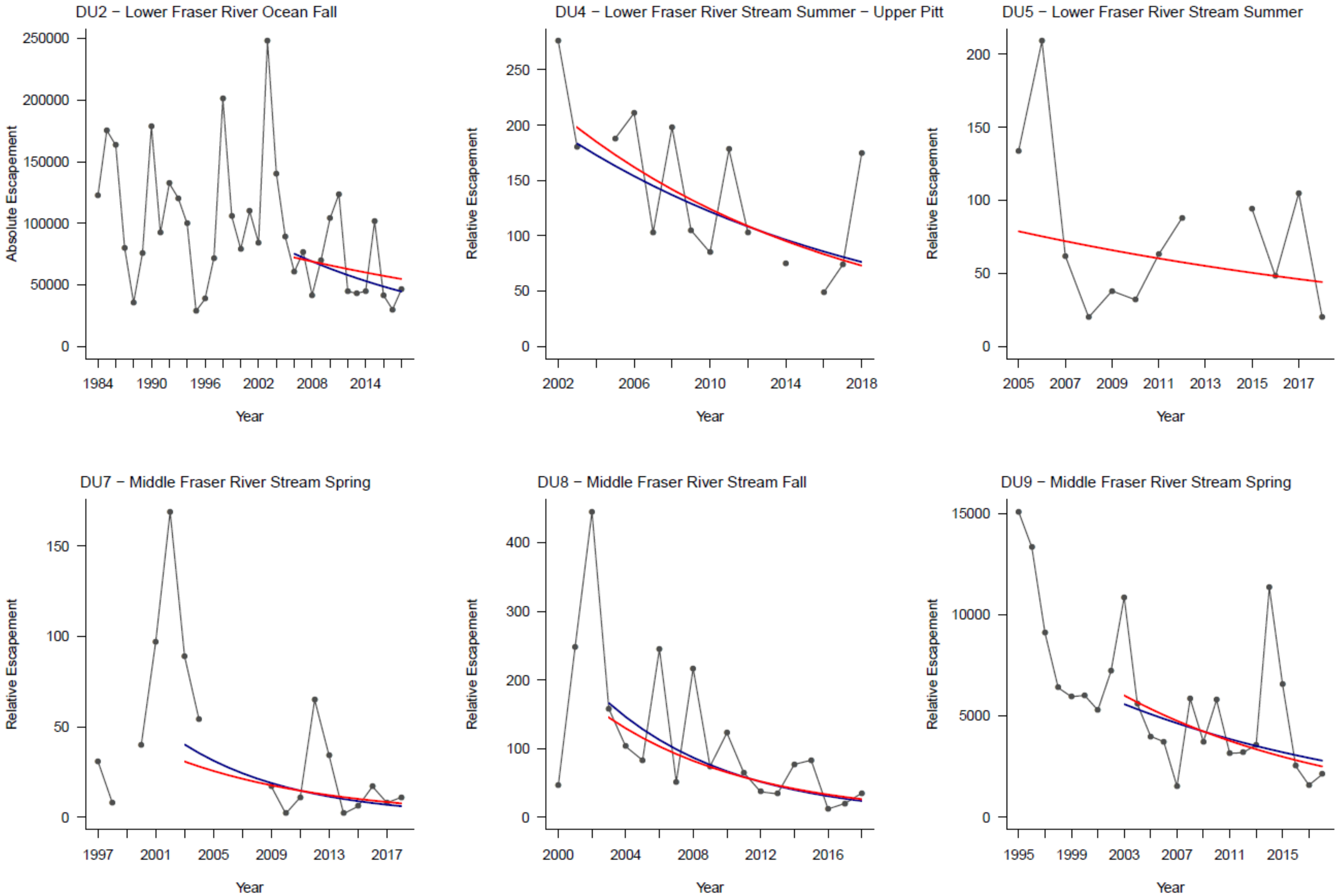


Figure D1. Time series in absolute (DU2 only) and relative escapement estimates with two estimates of the rate of change in log-escapement through time: (blue) rate of change over the last three generations based only on the last three generations of data, and (red) rate of change over the last three generations based on all available data.

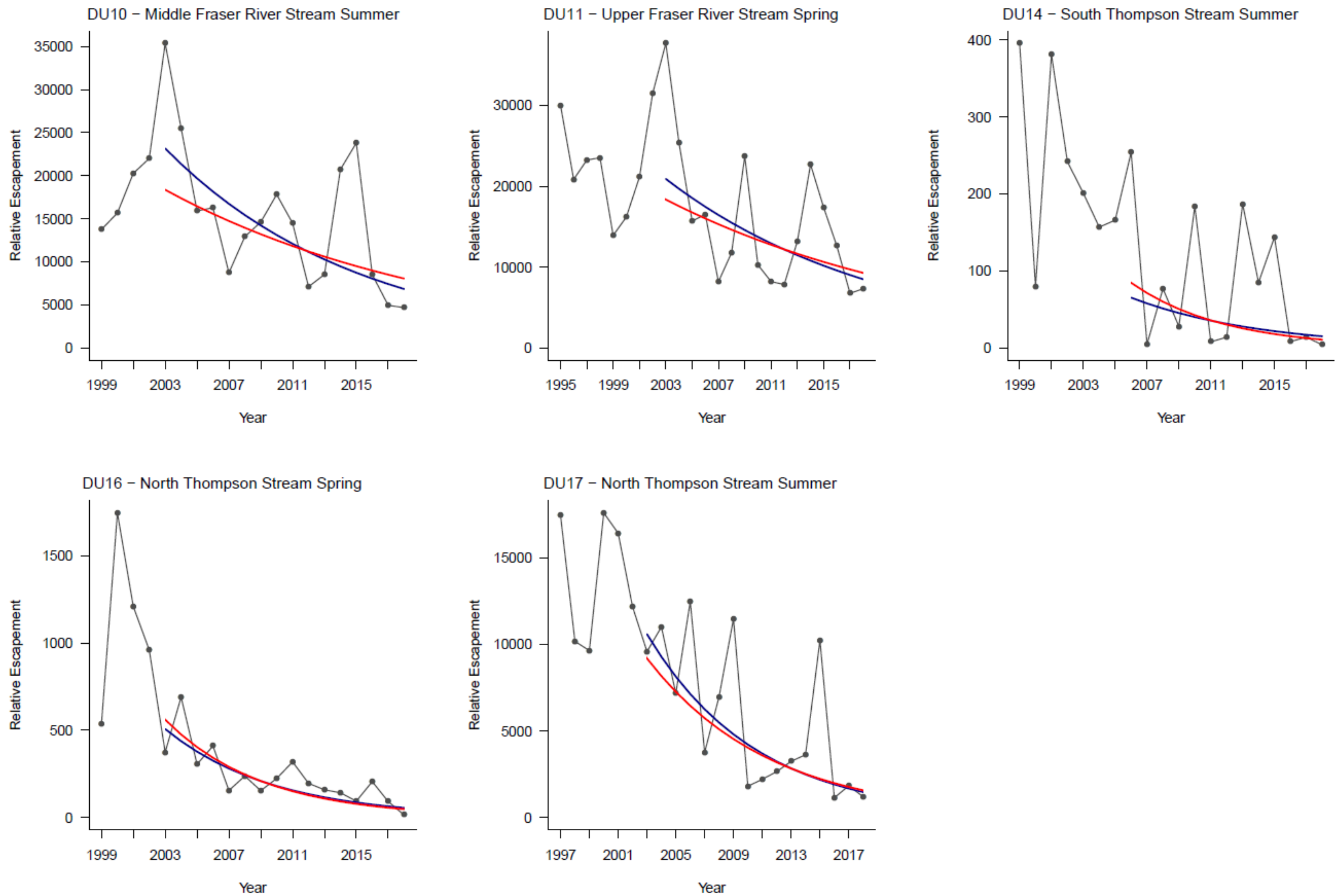


Figure D2. Time series of relative escapement estimates with two estimates of the rate of change in log-escapement through time: (blue) rate of change over the last three generations based only on over the last three generations of data, and (red) rate of change over the last three generations based on all available data.

APPENDIX E. HISTOGRAMS OF PERCENT CHANGE DISTRIBUTIONS

DU2 - Lower Fraser River Ocean Fall (Harrison)

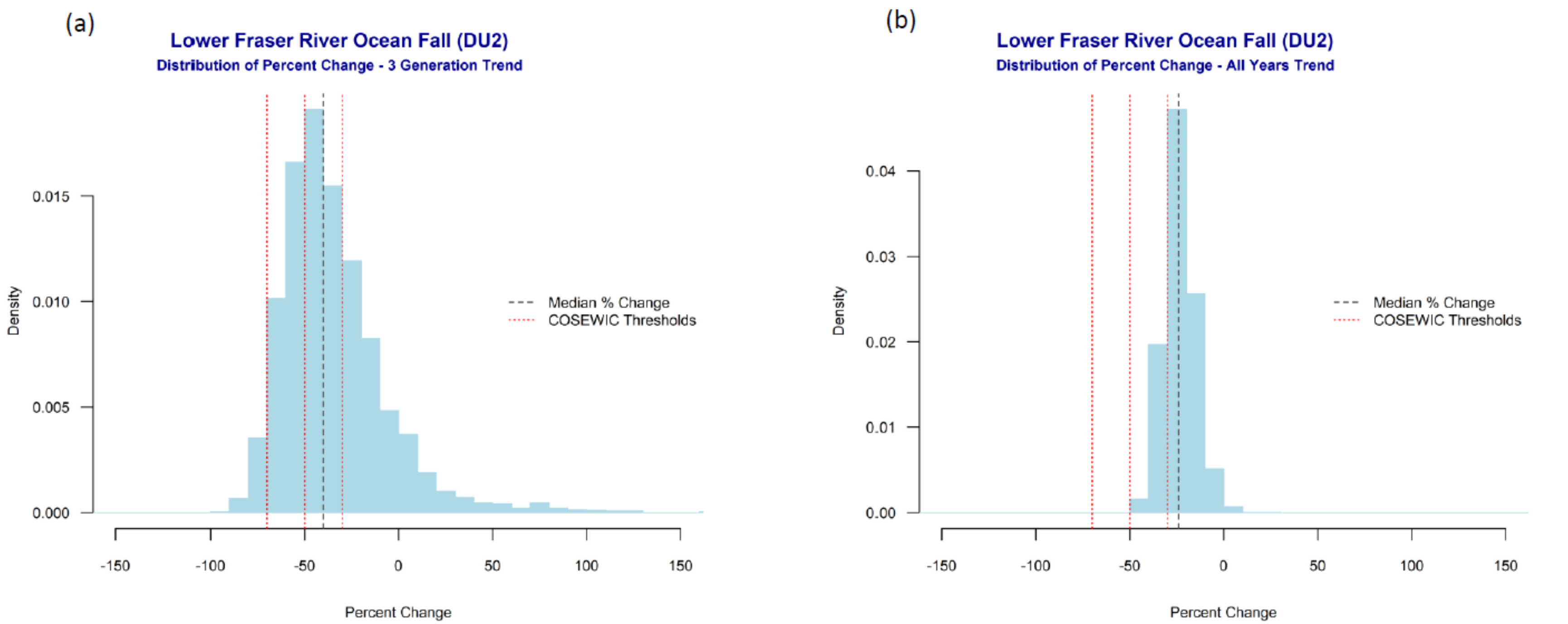


Figure E1. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference

DU4 - Lower Fraser River Stream Summer (Upper Pitt)

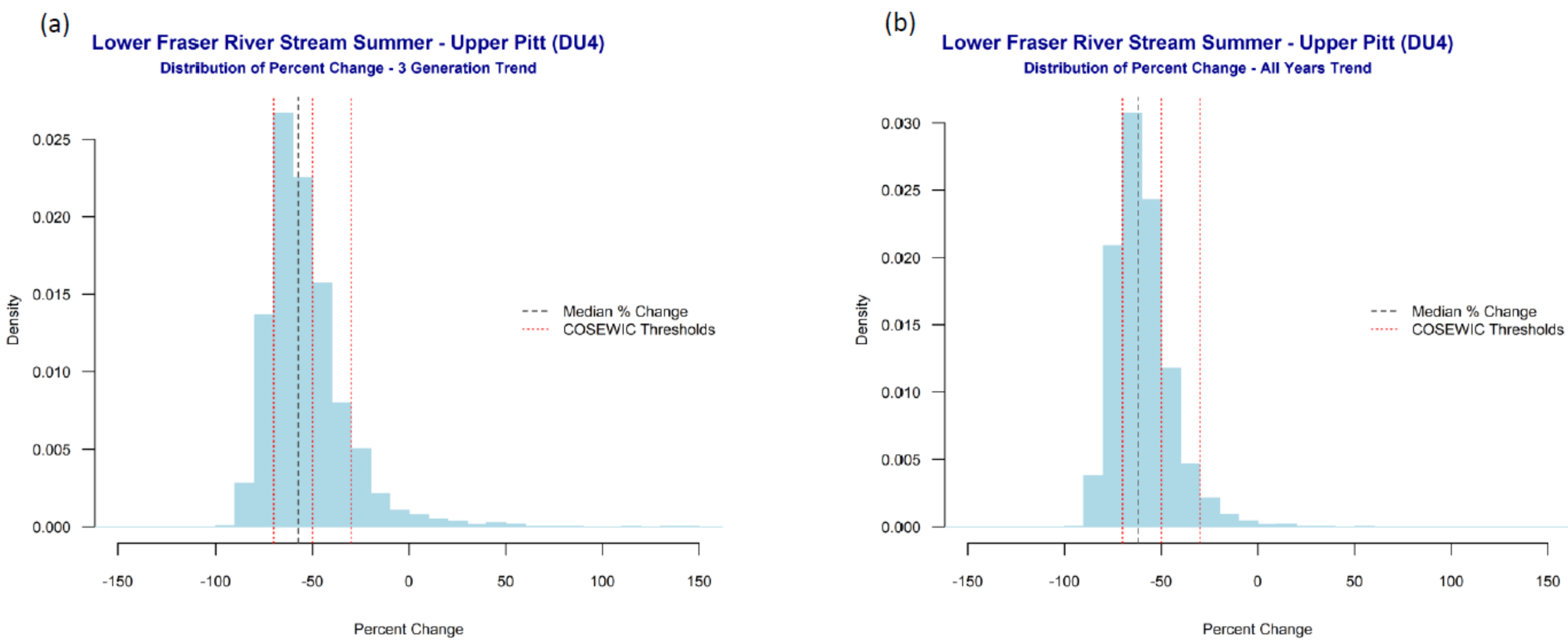


Figure E2. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference

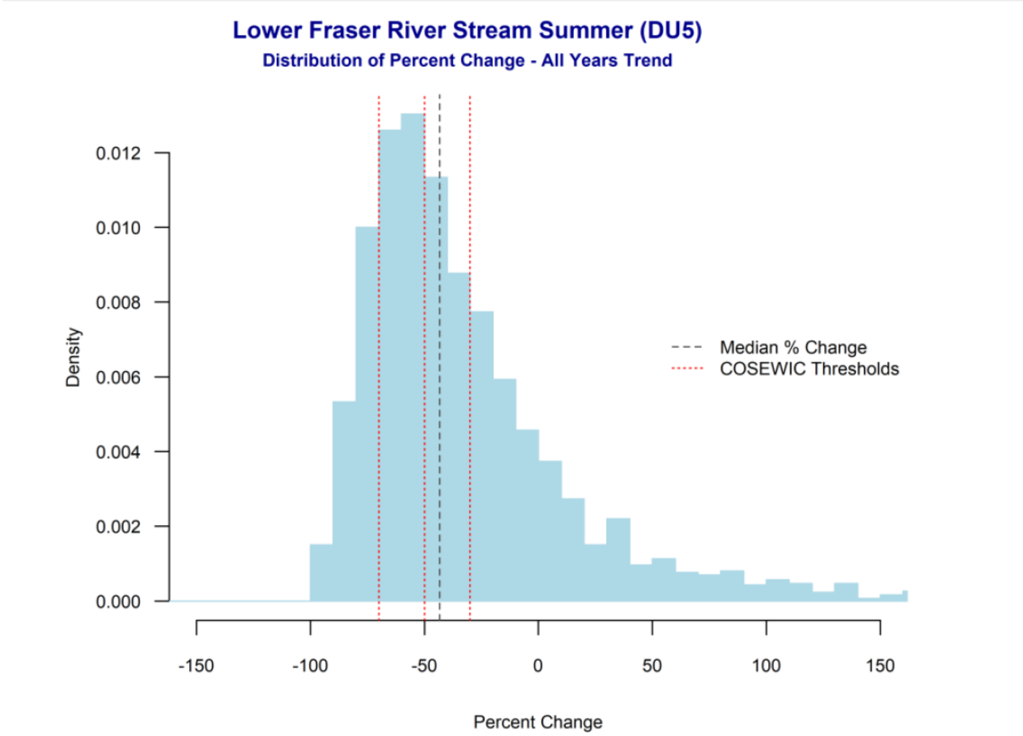
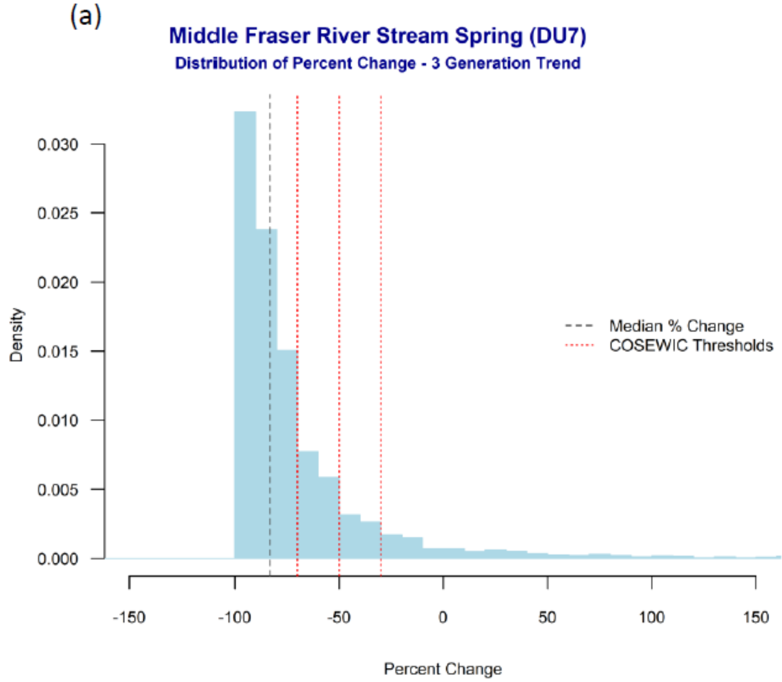


Figure E3. Histogram of the percent change distribution from the trend over the last three generations using the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

DU7 - Middle Fraser River Stream Spring (Nahatlatch)

(a)



(b)

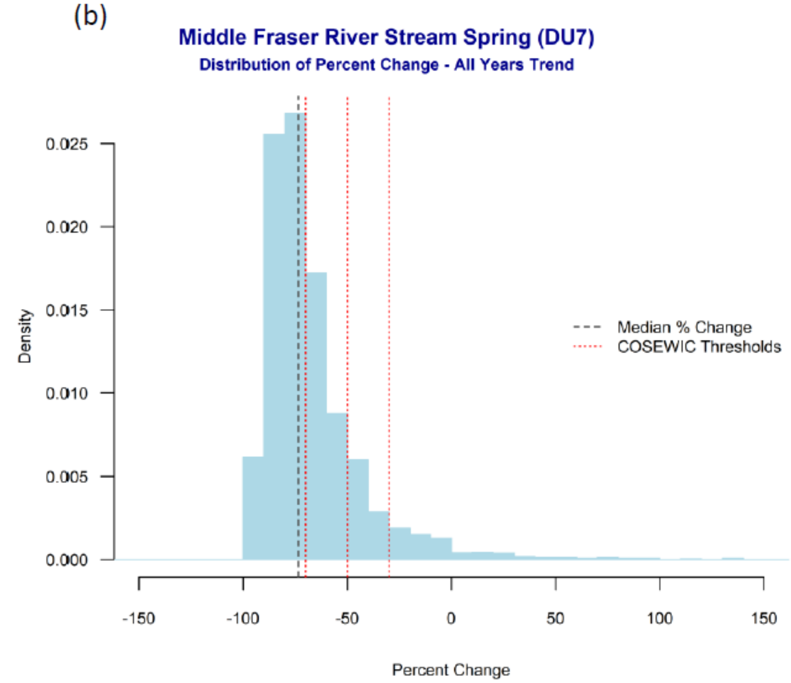


Figure E4. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

DU8 - Middle Fraser River Stream Fall (Portage)

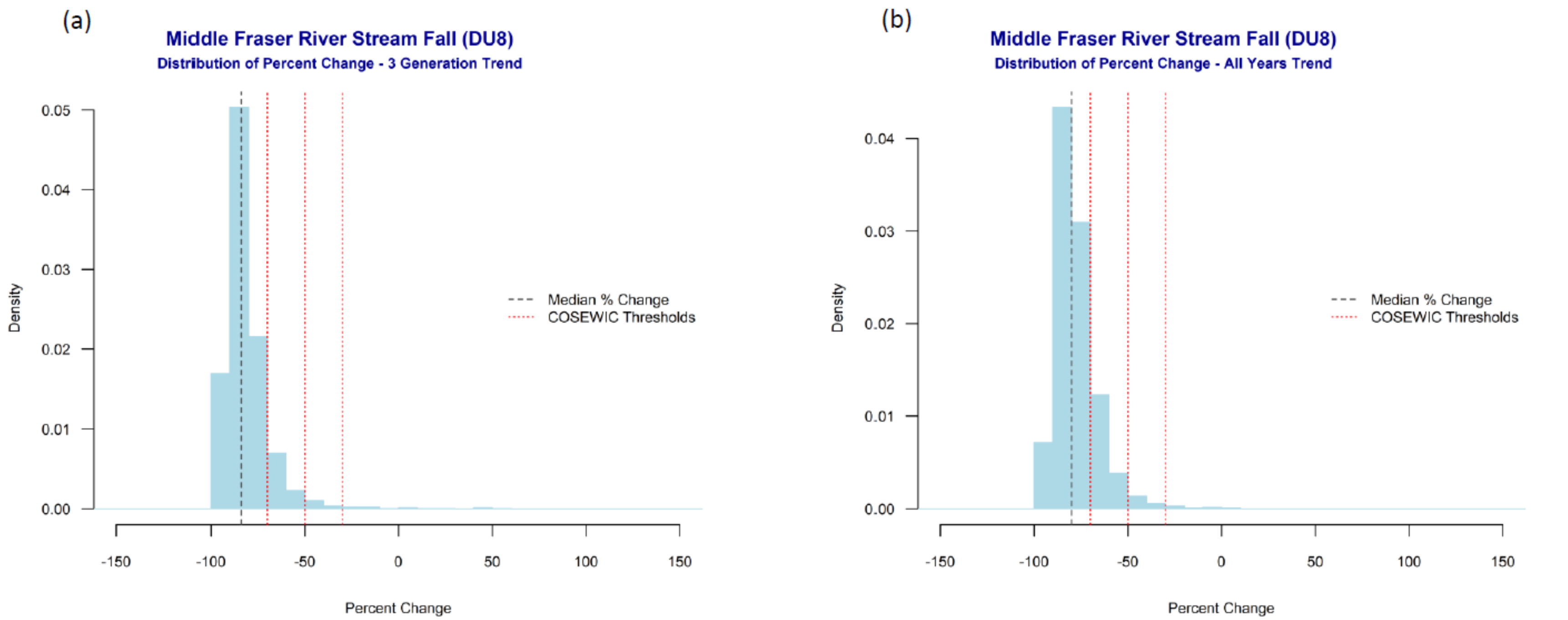


Figure E5. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

DU9 - Middle Fraser River Stream Spring

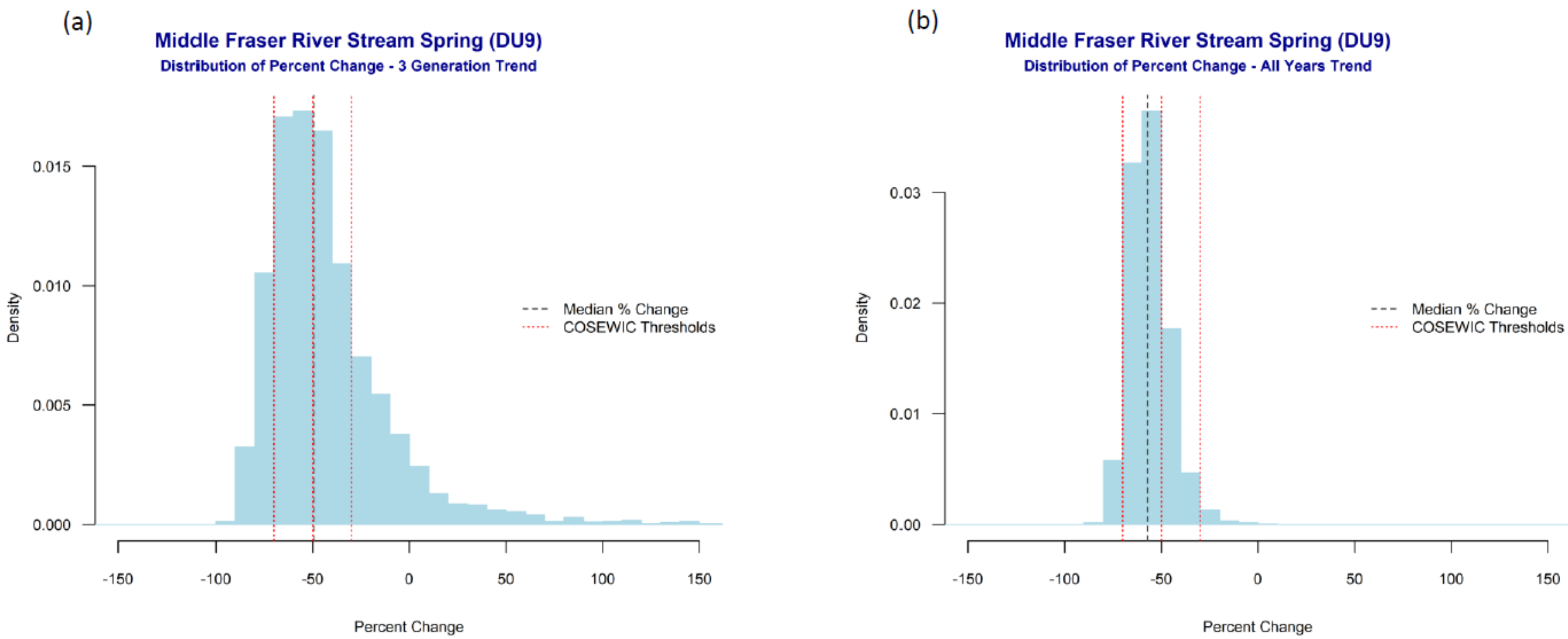


Figure E6. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

DU10 - Middle Fraser River Stream Summer

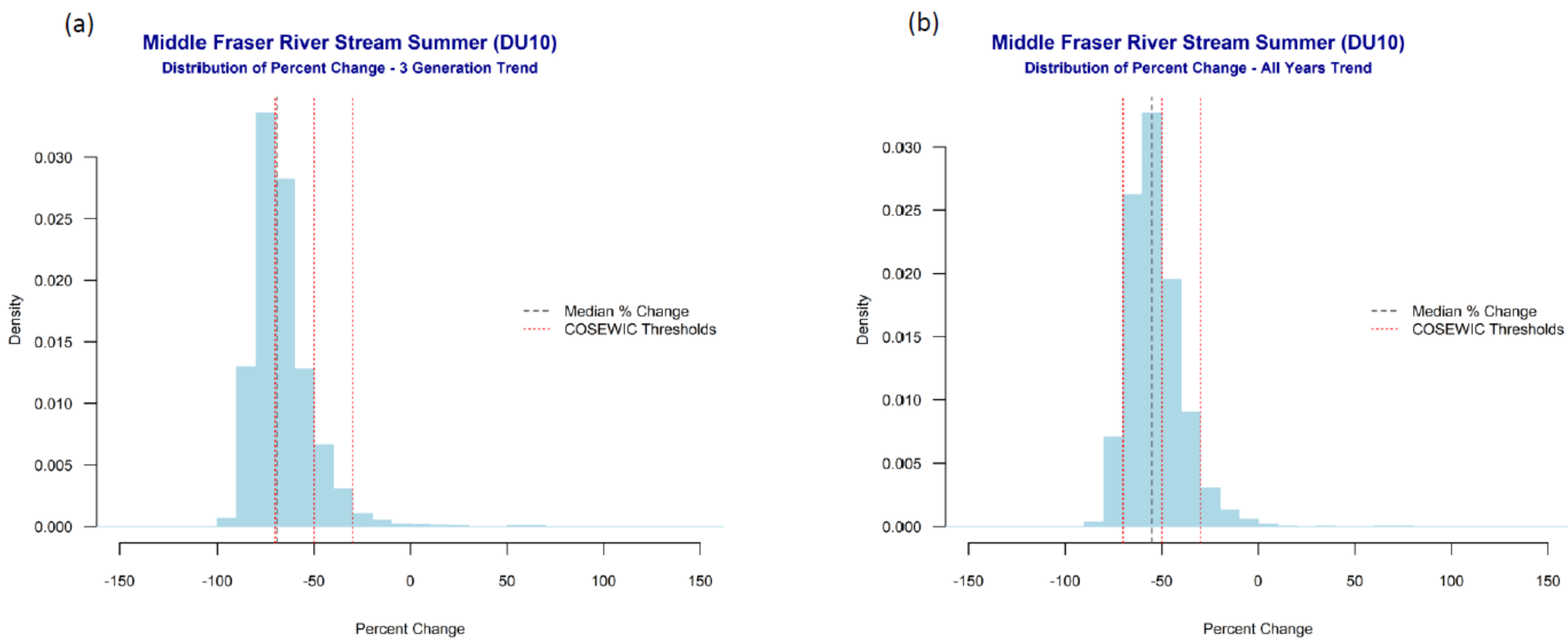


Figure E7. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

DU11 - Upper Fraser River Stream Spring

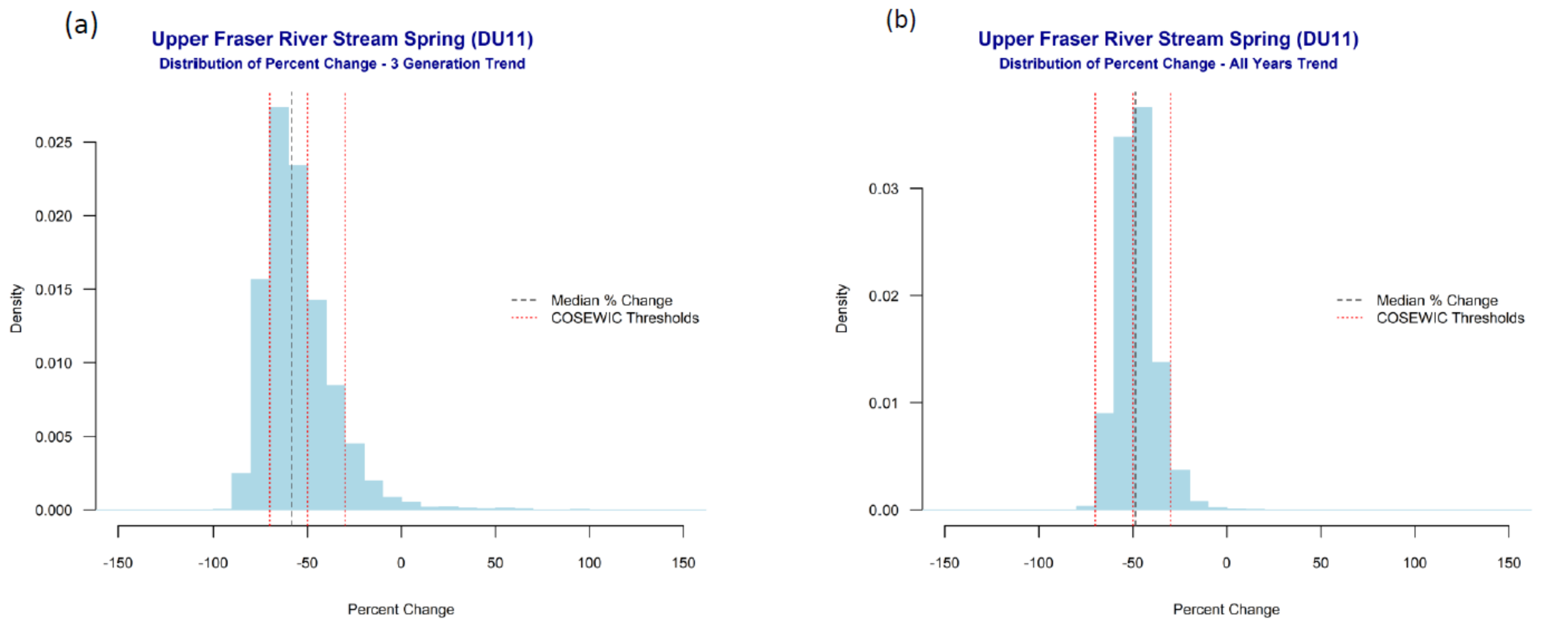


Figure E8. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

DU14 – South Thompson Stream Summer (Bessette)

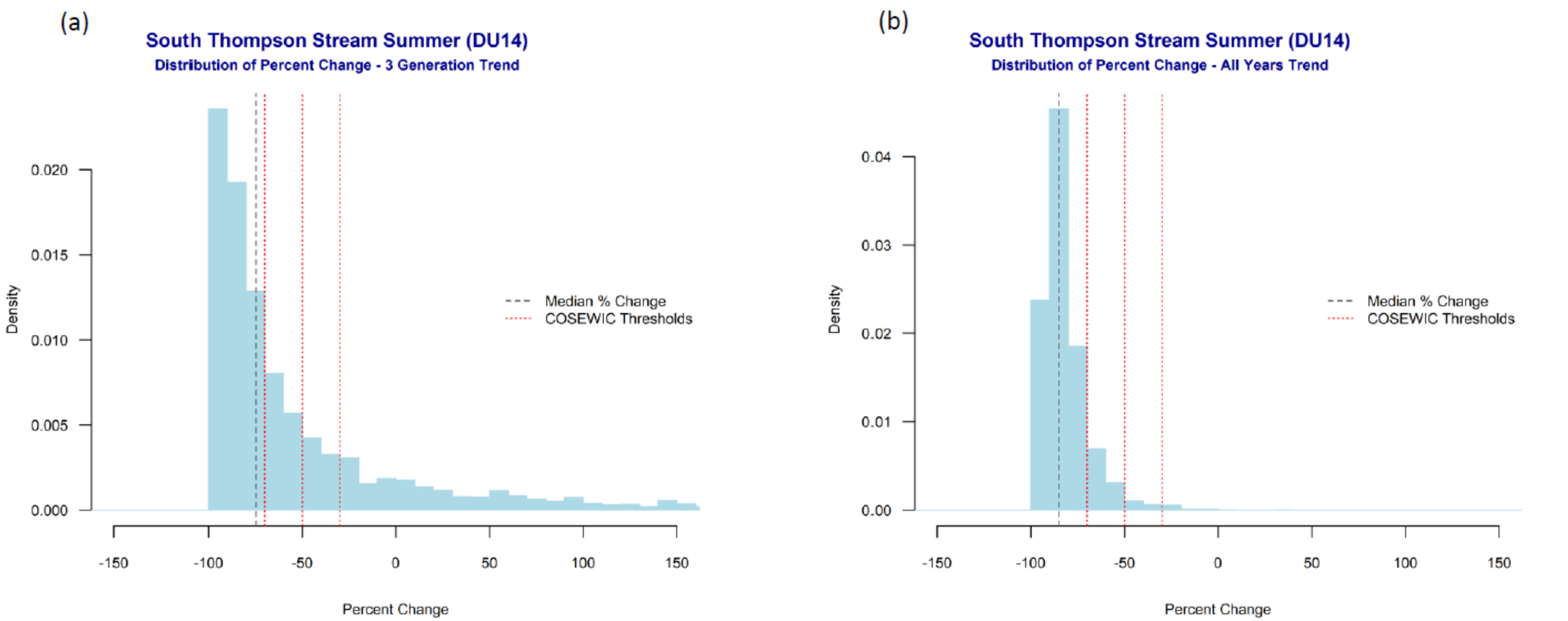
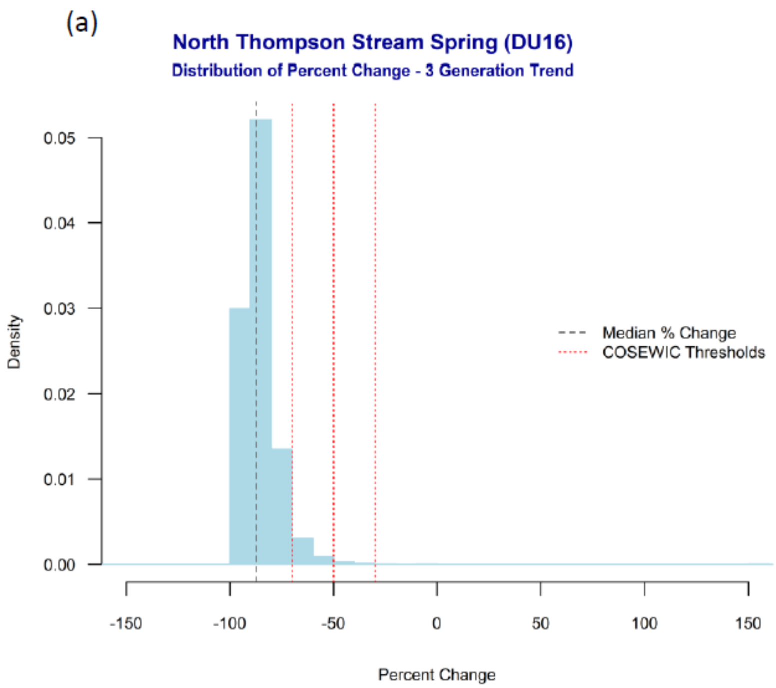


Figure E9. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

DU16 – North Thompson Stream Spring



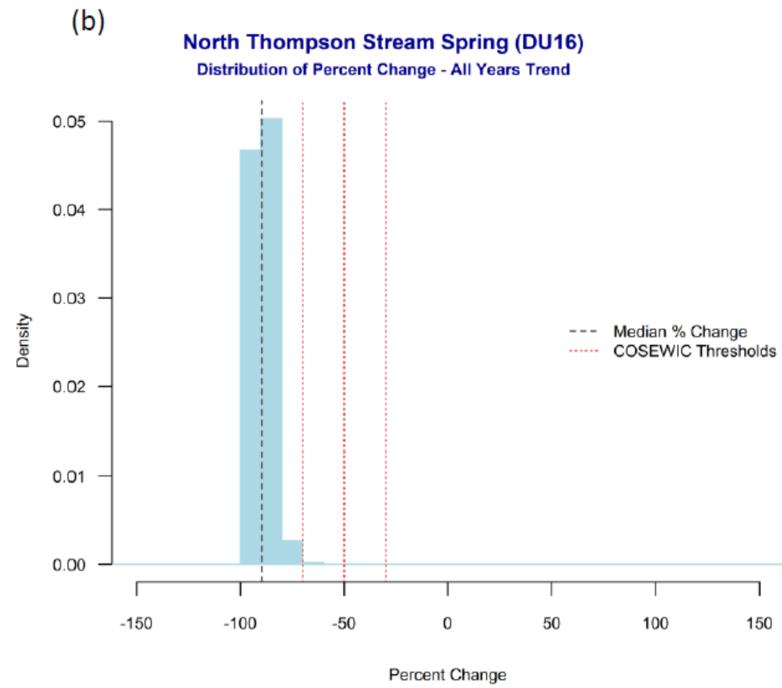
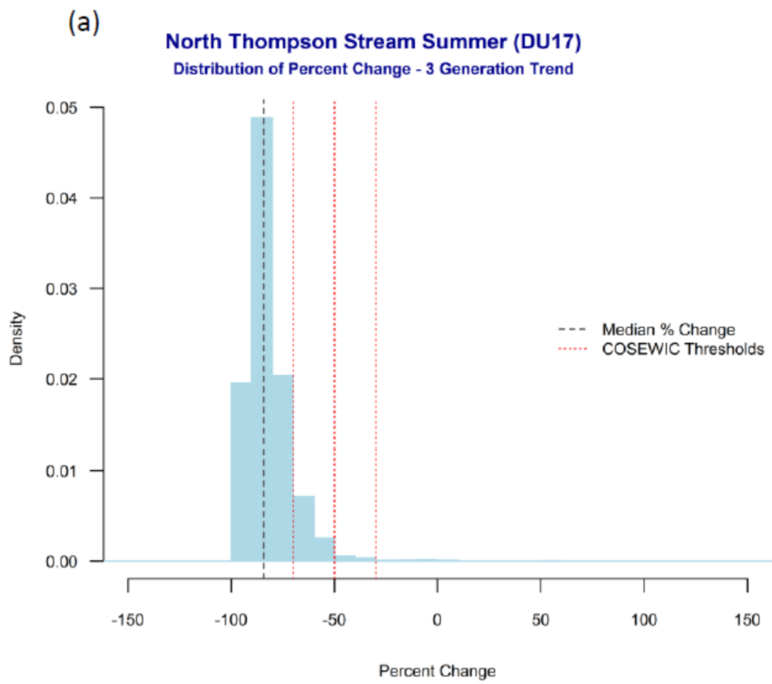


Figure E10. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.



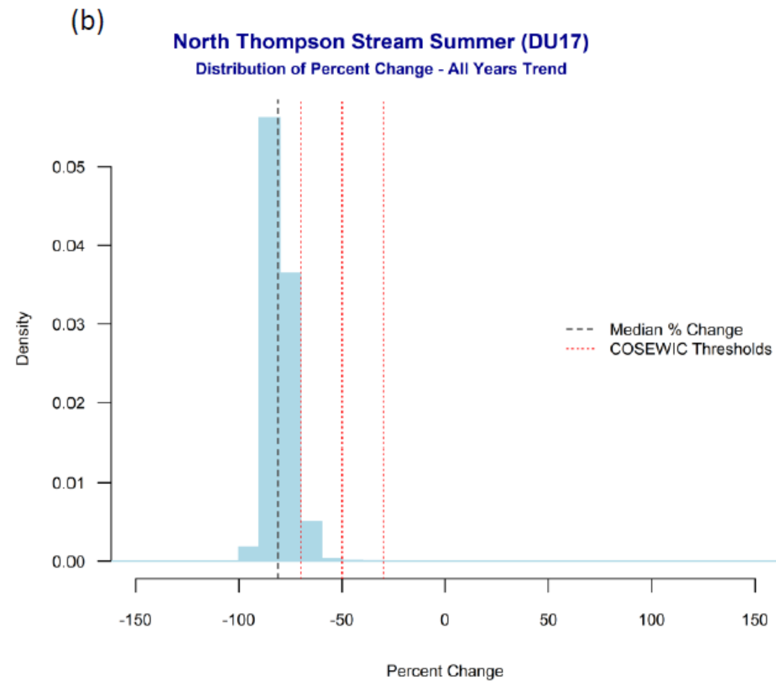


Figure E11. Histograms of the percent change distribution from the trend over the last three generations using (a) only the last three generations of data and (b) over the whole time series. The median percent change and the three COSEWIC thresholds (30%, 50%, 70%) are provided for reference.

APPENDIX F. COSEWIC THREATS TABLES

Table F1. Threats Calculator Results for DU2 - Lower Fraser Ocean Fall (Harrison)

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	0	0
B	High	2	0
C	Medium	5	2
D	Low	1	6
Calculated Overall Threat Impact:		Very High	High

Assigned Overall Impact: **AB = Very High - High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High to B = High was assigned. It was agreed that 100% reduction might not be reasonable, but that the possibility of having a loss of over 70% was. This rating was predominantly based on competition with hatchery fish, climate change, harvest rates and future marine survival. This conservation unit is particularly sensitive to the loss of wetlands in the estuary, predation by seals, and pollution compared to the other DUs. The stock has been harvested recently at ~20% exploitation rate, which is still over the suggested sustainable rate of 16%.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Urban development is considered to be negligible in the land-based area of this DU (0.61%) (Porter et al. 2013). This urbanization is expected to continue at a low rate of timing because the DU area is surrounded by mountain ridges. However, downstream in the Lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already.				

Threat	Impact Calculated	Scope	Severity	Timing
1.2 Commercial and industrial areas	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Habitat for this DU is more prone to industrial development than housing. The number of industrial developments are vast and encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. There is likely at least a slight decline due to industrial development over the whole habitat area for the DU. Note that these threats are only the direct results from new footprints of industrial activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary).				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
There are lots of marinas and boat launches throughout the lower Fraser and on the Chehalis Indian reserve next to the spawning grounds (expansion is expected in the next 10 years). Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments.				
2 Agriculture & aquaculture	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
There are blueberry farms, and intensification of agricultural land through increasing use of greenhouses, but most of the agricultural area is behind dikes already. The conversion of Herrling Island to farm land should not be an impact to this DU as it is upstream of Harrison. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching				
There is cattle ranching and dairy farms in the lower Fraser, however this does not directly impact DU2. The spawning grounds are too deep for cows to cross or encounter redds, thus there will not be any direct impact from the livestock.				
2.4 Marine & freshwater aquaculture	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Fish Farms: There are fish farms and the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. As soon as Chilliwack hatchery started, the abundance of Harrison chinook went down in the 80s. There is some new unpublished information that the age 2 survival of chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Cowichan hatchery has also seen reduced survival with increased hatchery releases. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. It was not felt that there was a 70% decline, but it could be upwards of 30% (based on a recent analysis and documented reduced survival with increased hatchery releases at other locations). This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Medium - Low**	**Pervasive (71-100%)**	**Moderate – Slight (1-30%)**	**High (Continuing)**
3.1 Oil & gas drilling				
None.				
3.2 Mining & quarrying	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity makes the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. Harrison migrate downstream as fry, and would be sensitive to the loss of these shallow water habitats. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is high uncertainty and there will be inter-annual variation, but the severity should be greater than 1%.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use. There is geothermal production upstream at Meager Creek, but it is too far upstream to be considered an impact.				
4 Transportation & service corridors	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**High (Continuing)**
4.1 Roads & railroads				
Pollution, such as road run-off, is dealt with in a different category. Harrison Chinook move out in the Fraser River and down into the estuary quickly, and should not be impacted by road crossings.				
4.2 Utility & service lines				
Not expected to be a threat.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Dredging for shipping lanes is included here. This has the potential to impact Harrison juveniles (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding, particularly as Harrison juveniles occupy the near shore. It is unknown what the population impact is, but stranding does occur.				
4.4 Flight paths				
Not likely a threat.				

Threat	Impact Calculated	Scope	Severity	Timing
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting				
It is not expected that there are any direct impacts from logging and wood harvesting in this DU. Physical log boom impacts are scored under shipping (4.3) and sedimentation is scored under pollution (9.3).				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Based on current exploitation rates and the anticipated 25% reduction of the total exploitation (or more), it was estimated that harvest rates have been approximately 11-14% over the target (assuming the target is sustainable). Years when overexploitation occurred harvest rates were around 30%, while sustainable levels are around 16%.				
6 Human intrusions & disturbance	**Negligible**	**Negligible (<1%)**	**Serious (31-70%)**	**High (Continuing)**
6.1 Recreational activities	*Negligible*	*Negligible (<1%)*	*Serious (31-70%)*	*High (Continuing)*
Jet boat use in the Fraser above Kilby has increased significantly. This threat is scored based on the potential for jet boats to suck up fish or strand fish due to their wakes. The proportion of the population exposed to this is small, but a serious effect when they are. There are no issues with ATVs due to the depth of Harrison.				
6.2 War, civil unrest & military exercises	*Unknown*	*Unknown*	*Unknown*	*High - Low*
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
There are stock assessment activities in the watershed that are in direct contact with fish. In addition, there could be other unknown activities that occur in the watershed, but it is unlikely there should be any significant impact or be pervasive in scope.				

Threat	Impact Calculated	Scope	Severity	Timing
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression				
The fire risk in this DU is low and any bucketing activity would be from Harrison Lake and unlikely to encounter Chinook. Effects from retardants go in pollution (9.3).				
7.2 Dams & water management/use	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015).				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate – Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. The severity is uncertain, but is likely within the 1-30% range. This ranking was identified as better than unknown, as it is known the effect is negative, but the severity if uncertain.				
8 Invasive & other problematic species & genes	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. Currently, it was identified that there is a slight effect.				
8.2 Problematic native species	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook in the lower Fraser. As the Harrison population is at low levels and has reduced resiliency, this predation is now considered a threat. Cryptobia is present in Harrison and could be problematic if temperatures increase. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material	*Negligible*	*Negligible (<1%)*	*Slight (1-10%)*	*High (Continuing)*
There is ongoing very low levels of enhancement for CWT tags. Previously, there was an invasion of some red Chinook and 5-10% of Harrison chinook are now red, when they all used to be white. Additionally, there have been Cowichan Chinook and net pen fish present in Harrison DU.				

Threat	Impact Calculated	Scope	Severity	Timing
9 Pollution	**Medium**	**Pervasive (71-100%)**	**Moderate (11-30%)**	**High (Continuing)**
From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below): *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
High enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019).				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment and pesticide runoff from agriculture.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**Unknown**
10.1 Volcanoes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*Unknown*

Threat	Impact Calculated	Scope	Severity	Timing
Geologically active area, with volcanos, but impossible to predict when it would become active again. This risk is not zero and if it occurred it would be pervasive in scope.				
10.2 Earthquakes/tsunamis	*Unknown*	*Unknown*	*Unknown*	*Unknown*
10.3 Avalanches/landslides	*Negligible*	*Negligible (<1%)*	*Serious (31-70%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
Meager Creek landslide likely had a large impact on the Harrison River turbidity for three years and similar events may occur in the future as the mountain is still unstable. Negligible was selected for the scope, because it is unlikely that there would be a landslide that would completely block Harrison River, so only a portion of the DU would be effected. Note that sedimentation as a direct result of these natural activities are scored here, otherwise all other sedimentation through anthropogenic activities are scored under pollution.				
11 Climate change & severe weather	**High - Low**	**Pervasive (71-100%)**	**Serious - Slight (1-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Low*	*Pervasive (71-100%)*	*Serious - Slight (1-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. Decline could be as low as 1% or as high as 70% over the next 3 generations. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive).				
11.2 Droughts	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
Harrison is a very wet watershed and it is unlikely that droughts will be an issue for this DU.				
11.3 Temperature extremes	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
Temperature extremes in Harrison in the fall are not a threat, given the deep water, and it is unlikely that Harrison Lake would get warm enough to impact juveniles. Furthermore, this DU spends minimal time in freshwater thus upper river DUs are more vulnerable. Marine temperature extremes are recorded and scored under 11.1.				
11.4 Storms & flooding	*Not Calculated (outside assessment timeframe)*	*Small (1-10%)*	*Slight (1-10%)*	*Low (Possibly in the long term, >10 yrs/3 gen)*
Harrison Lake stabilizes the flows, but when there are very high flows in the Harrison, spawners will sometimes spawn in gravel areas that are only inundated during the high flows, and the eggs will desiccate when flows recede.				

Table F2. Threats Calculator Results for DU4 – Lower Fraser River Stream Summer – Upper Pitt

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	0	0
B	High	1	0
C	Medium	5	2
D	Low	2	6
Calculated Overall Threat Impact:		Very High	High

Assigned Overall Impact: **AB = Very High - High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High to B = High was assigned. It was agreed that 100% reduction might not be reasonable, but that the possibility of having a loss of over 70% was . This rating was predominantly based on climate change conditions, logging, the amount of recreation in the area and flood events. It is important to note, that there is data for only one tributary to the Upper Pitt River and that there is Chinook spawning likely in the mainstem and other tributaries, but it is not known what is occurring in those areas. The trend observed in Blue River could be the same across the DU, or it could differ.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already.				
1.2 Commercial and industrial areas	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. There is likely at least a slight decline due to industrial development over the whole habitat area for the DU. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary).				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops				
There should not be any agricultural increases for this DU. The Fraser River below the Pitt River is very developed and there are limited opportunities for agriculture. It would likely be behind dikes already if there were increases.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching				
Not expected to be a threat.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north towards Alaska, where if there is competition it would likely be from Alaskan hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				
3 Energy production & mining				
3.1 Oil & gas drilling				
None.				

Threat	Impact Calculated	Scope	Severity	Timing
3.2 Mining & quarrying				
There are mining quarries right next to the river, encroaching on the bank. However, the resulting pollution is a larger concern (section 9). Dredging in the Pitt and lower Fraser goes under shipping.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**High (Continuing)**
4.1 Roads & railroads	*Unknown*	*Restricted (11-30%)*	*Unknown*	*High (Continuing)*
There are very few roads around Pitt Lake, have to take a barge up. There are forestry roads in the area and there may be some new roads in the future, but there is limited valley bottom, so it is likely there would be road upgrades instead of new roads. This area was logged heavily in the 90s and recently upstream of the lake. However since it is a narrower valley, the roads will often be close to the river and may encounter a restricted portion of the population.				
4.2 Utility & service lines				
Not expected to be a threat.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes in the lower Fraser has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. Unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: There are log booms in Pitt Lake and all down the river with lots of wood debris at the top end of the lake. The main impact from the booms is sediment. There is dredging in the Pitt and Fraser Rivers, but they shouldn't be rearing in the areas where the dredging occurs as they prefer littoral areas.				
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				

Threat	Impact Calculated	Scope	Severity	Timing
Not likely a threat.				
5.3 Logging & wood harvesting	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
Physical activity of dumping the logs into the habitat scours the area and removes vegetation which would impact the habitat and make it less usable. This occurs at the log dump right at the mouth of the Pitt River, at the top end of the lake.				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no indicator of this stock or anyway currently of calculating the optimal harvest rate. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Medium**	**Restricted (11-30%)**	**Serious (31-70%)**	**High (Continuing)**
6.1 Recreational activities	*Medium*	*Restricted (11-30%)*	*Serious (31-70%)*	*High (Continuing)*
There is heavy jet boat use in Pitt Lake and River and it is visited regularly by many fishermen. Additionally, it is also likely ATVs are in there. Jet boats are going over spawning grounds and potentially sucking up fish. This activity goes on throughout the calendar year. Washing fry up could also be an issue with the heavy boat traffic. A 3-21% overall population decline was not considered to be unreasonable.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
Given the proximity to the Lower Mainland, there could be other research activities in the area (UBC/SFU/BCIT).				
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression				
If there was a fire they would bucket from Pitt Lake.				
7.2 Dams & water management/use	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. There is very limited floodplain habitat left for these overwintering juveniles, and many of the sloughs have also been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: Diking and dams in the Pitt Polder can cut off habitat. Not as many flood boxes and tides gates in this area, so there is less of an impact and most of the area has already been cut off. These juveniles would mostly just be moving by these areas and have historical impacts from cut off habitat.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). Lower Fraser Impacts: As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. Additional Impacts to this DU: There are many modifications to the landscape downstream of the DU and there has been lots of forestry activity in the Upper Pitt watershed, which has likely modified the catchment area.				
8 Invasive & other problematic species & genes	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect. A variety of invasive species are becoming established in the area. Currently it is uncertain what the impact is as there is a lack information about the residency of the juveniles. It is uncertain about their behavior and habitat use in the area. A lot of the rearing habitat below Pitt Lake is clear water where spiny fish could effectively predate on juvenile Chinook. The impact was evaluated as slight, but the general consensus was it is at the top end of the slight category and could even be over, particularly in the future.				
8.2 Problematic native species	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat (similar predation rates to Harrison). Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
Unlikely to be a threat.				

Threat	Impact Calculated	Scope	Severity	Timing
9 Pollution	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below): *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019).				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are log booms and lots of debris at the top end of Pitt Lake that are impacting the estuary up there. There is a substantial amount of booming from the natal stream to the estuary. Can't quantify this impact enough to adjust the score from the general Lower Mainland. There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from agriculture in the Lower Pitt.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				

Threat	Impact Calculated	Scope	Severity	Timing
10 Geological events	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**Unknown**
10.1 Volcanoes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*Unknown*
Geologically active area, with volcanos, but impossible to predict when it would become active again. This risk is not zero and if it occurred it would be pervasive in scope.				
10.2 Earthquakes/tsunamis	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Not likely to be a threat, except potential to cause a landslide which goes under section 10.3.				
10.3 Avalanches/landslides	*Negligible*	*Negligible (<1%)*	*Serious – Moderate (11-70%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
There is a potential to have landslides upstream, and it has probably happened in the past, but it is not known. The Upper Pitt River is very braided, so the river should work its way around any slide, and hence would not be pervasive or serious. Note that sedimentation as a direct result of these natural activities is scored here, otherwise all other sedimentation through anthropogenic activities are scored under pollution.				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				
11.2 Droughts	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
Not expected to be in issue in this DU in the short term.				
11.3 Temperature extremes	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
This is a cold system with a large snow pack, and as such is not expected to have an impact from temperature extremes in the short term. This DU also have such a short migration through tidal habitat that it is unexpected to be affected by high temperatures in the short term.				
11.4 Storms & flooding	*Medium*	*Pervasive (71-100%)*	*Moderate (11-30%)*	*High (Continuing)*
Likely that there are storms and flooding regularly throughout this DU (rain on snow events). In the gravel all fish could be exposed to these and it could have significant impacts (egg mortality).				

Table F3. Threats Calculator Results for DU5 – Lower Fraser River Stream Summer

Threat Impact		Level 1 Threat Impact Counts: High Range	Level 1 Threat Impact Counts: Low Range
A	Very High	0	0
B	High	1	0
C	Medium	4	1
D	Low	3	7
Calculated Overall Threat Impact:		Very High	High

Assigned Overall Impact: **AB = Very High - High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High to B = High was assigned. Change in ocean productivity will significantly affect this DU and they could be rearing in the Lower Mainland, which is severely impacted. This DU may be a little buffered because there is some rearing habitat in areas that are not highly developed. There is a lot of uncertainty associated with this DU, because Big Silver is the only system there is data for. There is a spawning population in the Lillooet River, it is uncertain what is happening with them, it could be the same as Big Silver or different. It is likely the good spawning habitat in the Lillooet has been dredged and impacted by sediment inputs from the Meager Creek slide. Climate change is the driver for the very high, as the blob would have a big impact. It is possible that it is at the lower end of the assigned range. Since there are such low numbers already, it was determined to be reasonable to have extinction within the next three generations.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as the juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: No additional impacts anticipated.				
1.2 Commercial and industrial areas	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. There is likely at least a slight decline due to industrial development over the whole habitat area for the DU. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary).				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: There is uncertainty towards where this DU rears, but there should not be additional impacts beyond that for Harrison.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching				
Not expected to be a threat.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north towards Alaska, where if there is competition it would likely be from Alaskan hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
None.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser River Gravel Extraction: This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: There use to be more activity in this DU, but in the future no additional mining impacts are anticipated.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**High (Continuing)**
4.1 Roads & railroads	*Unknown*	*Small (1-10%)*	*Unknown*	*High (Continuing)*
Pollution is dealt with in a different category. It is uncertain where Chinook spend time, but most of the roads around Harrison are older and the culverts will likely be replaced. Hence it is unknown as it could be a positive effect.				
4.2 Utility & service lines				
Not expected to be a threat.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes in the lower Fraser has the potential to impact Chinook (depending on when it is done), but there shouldn’t be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. Unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: There are log booms in Harrison Lake near Tipella and right below the mouth of Big Silver at times. Additionally there is lots of wood debris at the top end of the lake. It is uncertain how much of that foreshore is used by DU5 fish, but potentially as early fry habitat.				

Threat	Impact Calculated	Scope	Severity	Timing
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
Physical activity of dumping logs scours the area and removes vegetation which would impact the habitat and make it less usable. This occurs at the log dump right at the mouth of Tipella.				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no indicator of this stock or anyway currently of calculating the optimal harvest rate. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Negligible**	**Negligible (<1%)**	**Negligible (<1%)**	**High (Continuing)**
6.1 Recreational activities				
Not expected that there would be impacts from ATVs or jet boats. The creeks have lots of trees on either side which would make access by quads difficult.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Monitoring for the hydro projects in the area could encounter juvenile Chinook, but are not normally lethal. There could be other unknown activities that occur in the watershed, but unlikely there should be any significant impact or be pervasive in scope.				
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression				
If there was a fire they would bucket from Harrison Lake.				
7.2 Dams & water management/use	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. There is very limited floodplain habitat left for these overwintering juveniles, and many of the sloughs have also been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: There is a run of river upstream on Big Silver, the power house is approximately 8 km upstream. There could be some impact from stranding due to ramping events, but it tends to only have significant impacts on the periods when fry are present. There is a slight impact as there is less of chance they will meet pumps migrating out and they don't spend as much time in the estuary as Harrison Chinook.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). Lower Fraser Impacts: As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. Additional Impacts to this DU: There are many modifications to the landscape downstream of the DU, but we are uncertain where the juveniles in this DU spend time rearing. No additional impacts anticipated.				
8 Invasive & other problematic species & genes	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect. There are more invasive species in and near Harrison Lake. Confirmed invasives include Large and Smallmouth Bass. Bass are visual predators and as Chinook would have to migrate through the lake the impact is probably slight. The future impact is difficult to predict as it could get worse. However, as Harrison Lake is oligotrophic, it isn’t suitable for Bass and therefore the population might not explode.				
8.2 Problematic native species	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat (similar predation rates to Harrison). Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
Unlikely to be a threat.				
9 Pollution	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below): *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019).				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are log booms and lots of debris in the estuary at the top end of Harrison Lake that are impacting the estuary up there. There is a substantial amount of booming from the natal stream to the estuary. Can't quantify this impact enough to adjust the score from the general Lower Mainland. There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**Unknown**
10.1 Volcanoes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*Unknown*
Not likely a threat.				
10.2 Earthquakes/tsunamis	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Negligible*	*Negligible (<1%)*	*Serious (31-70%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
Meager Creek landslide likely had a large impact on the Harrison and the Lillooet River. Similar events may occur in the future as this mountain is still unstable. Note that sedimentation as a direct result of these natural activities is scored here, otherwise all other sedimentation through anthropogenic activities are scored under pollution.				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				
11.2 Droughts	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
This DU is located within a very wet watershed and is unlikely to experience a drought in the short term.				
11.3 Temperature extremes	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*

Threat	Impact Calculated	Scope	Severity	Timing
Not expected to be in issue in this DU in the short term.				
11.4 Storms & flooding	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
Big Silver has blown out before and surveys haven't been able to be done because of this (2013).				

Table F4. Threats Calculator Results for DU7 – Middle Fraser River Stream (Nahatlatch)

Threat Impact		Level 1 Threat Impact Counts: High Range	Level 1 Threat Impact Counts: Low Range
A	Very High	0	0
B	High	1	0
C	Medium	3	1
D	Low	3	6
Calculated Overall Threat Impact:		Very High	High

Assigned Overall Impact: **AB = Very High - High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High to B = High was assigned. It was agreed that 100% reduction might not be reasonable, but that the possibility of having a loss of over 70% was. This is a single site DU, so there is less resilience if the habitat shifts or becomes degraded. There have been years where less than 10 fish have been counted in the system. Snow pack failures or early melts could become more common and would significantly impact this DU. This rating was predominantly based on ecosystem modifications, climate change, harvest rates, and future marine survival.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very small impact as they spend less time in the area than DU2. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: Impacts to this DU are anticipated to be lower than the Harrison DU as they spend less time in the habitat and are mostly migrating through; thus, a negligible severity was chosen.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching				
None.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
None.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. However, DU7 in particular may use the gravel in this area, as there is limited rearing habitat at the mouth of Nahatlatch. Additional impacts to this DU: No additional mining impacts are anticipated.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**High (Continuing)**
4.1 Roads & railroads				
There are logging roads on either side of Nahatlatch and near two tributaries. There is a free span bridge over the spawning areas, but it isn't in the river and is not expected to be an impact. Culverts may be perched in the area, but they wouldn't be cutting off any important habitat for Chinook. There are siltation and sediment effects from the roads, but they will be dealt with in section 9 (pollution).				
4.2 Utility & service lines				
Not expected to be a threat.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated.				
4.4 Flight paths				

Threat	Impact Calculated	Scope	Severity	Timing
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting				
It is not expected that there are any direct impacts from logging and wood harvesting in this DU. Physical log boom impacts are scored under shipping (4.3) and sedimentation is scored under pollution (9.3).				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, as early spring Chinook are very desirable for their fat content, but it is uncertain how much it is. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. For example, in summer 2019 there was no legal fishing until July 15, and by then they should be passed the major fishing areas. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no perfect control as there is management error and illegal fishing. It was felt 10% severity was too low, and that 30% was too high, so the moderate to slight category was selected. Additionally, there are no harvest rates for this stock and it is uncertain what the optimal harvest rate should be. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Negligible**	**Negligible (<1%)**	**Negligible (<1%)**	**High (Continuing)**
6.1 Recreational activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
There are limited impacts in the Nahatlatch due to its size and location. Jet boats from DFO are occasional but paddle rafting is regular (rafting is unexpected to have impacts).				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
There could be other unknown activities that occur in the watershed, but it is unlikely there should be any significant impact or be pervasive in scope.				
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression	*Negligible*	*Negligible (<1%)*	*Unknown*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
There will likely be a fire in this DU in the next 3 generations, the effects are unknown, but not anticipated to impact many of the fish in the DU. Effects from retardants go in pollution.				
7.2 Dams & water management/use	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: No additional impacts anticipated.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. The severity is uncertain, but within 1-30% as the range. This was identified as better than unknown, as it is known the effect is negative, but uncertain of the extent. There have been fires and logging in the area, which could impact the hydrology of the system, which would lead to higher impacts than DU2, but they are very uncertain.				
8 Invasive & other problematic species & genes	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect.				
8.2 Problematic native species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				

Threat	Impact Calculated	Scope	Severity	Timing
8.3 Introduced genetic material				
Other Chinook DUs are unlikely to stray into Nahatlatch.				
9 Pollution	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below): *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019).				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment and pesticide runoff from agriculture. All the logging roads and forestry activity in this DU will add sediment into the Nahatlatch.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				

Threat	Impact Calculated	Scope	Severity	Timing
10 Geological events	**Not Calculated (outside assessment timeframe)**	**Pervasive (71-100%)**	**Serious (31-70%)**	**Low (Possibly in the long term, >10 yrs/3 gen)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Serious (31-70%)*	*Low (Possibly in the long term, >10 yrs/3 gen)*
There is potential to have a landslide that could send a pulse of water into Chinook habitat below the lake and there is some evidence this has occurred before. Landslides also occur in the Fraser Canyon (Hell's gate). Given the extent of logging, there is a chance a landslide could impact spawning habitat. As Nahatlatch is a more stable area than Meager (DU2), a low timing instead of a moderate was chosen. Note that sedimentation as a direct result of these natural activities is scored here, otherwise all other sedimentation through anthropogenic activities are scored under pollution.				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. Decline could be as low as 1% or as high as 70% over the next 3 generations. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change. This would impact this DU, as the groundwater is what provides stability to this system.				
11.2 Droughts	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
There could be a drought in the future and a potential impact would be more restricted spawning habitat at lower flows. However, there should be some buffering from groundwater flows. This is highly variable, and the frequency of these events will change with climate change, but it is hard to predict the impacts.				
11.3 Temperature extremes	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
Mostly ground water, cold system above the lake, this is where most of the spawning occurs. Below the lake there is a possibility that there could get warmer water.				

Threat	Impact Calculated	Scope	Severity	Timing
11.4 Storms & flooding	*Low*	*Small (1-10%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Flooding occurs regularly in Nahatlatch and it is not a stable system. Even small rain on snow events can shift LWD and gravel in the stream, which can scour redds and cause egg mortality. Ice break ups in this system can also scour and cause egg mortality. Impacts from storms will be more significant for spring Chinook who do not spawn below lakes. This is highly variable, and the frequency of these events will change with climate change, but it is hard to predict the impacts.				

Table F5. Threats Calculator Results for DU8 – Middle Fraser Stream Fall (Portage)

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	0	0
B	High	2	1
C	Medium	3	2
D	Low	3	5
Calculated Overall Threat Impact:		Very High	Very High

Assigned Overall Impact: **A = Very High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High was assigned. In addition to the impact from the hydro dam, there has been a recent landslide that has significantly impacted the ability of the population to successfully spawn. Furthermore, they return late and can get harvested during the Middle Shuswap fishery.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: There should be no residential development in the DU itself, this is scored based on the lower Fraser.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. There is likely at least a slight				

Threat	Impact Calculated	Scope	Severity	Timing
decline due to industrial development over the whole habitat area for the DU. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching				
None.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known and is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
None.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: No additional mining impacts are anticipated.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**High (Continuing)**
4.1 Roads & railroads				
There are logging roads in the area, but they are not expected to be an issue.				
4.2 Utility & service lines				
Not expected to be a threat.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated.				
4.4 Flight paths				
Not likely a threat.				

Threat	Impact Calculated	Scope	Severity	Timing
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting				
It is not expected that there are any direct impacts from logging and wood harvesting in this DU. Physical log boom impacts are scored under shipping (4.3) and sedimentation is scored under pollution (9.3).				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, as early spring Chinook are very desirable for their fat content, but it is uncertain how much it is. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. However, this DU is the latest returning yearling stock, and mostly return in September. Unfortunately this means that they tend to have the same timing as Middle Shuswap and get harvested in the fishery if there is an opening for the Shuswap stock. They can also get harvested in the Pink fishery. Efforts to back calculate for them in the run reconstruction, but don't get as many hits in the genetic test fishery. There is no indicator for this stock and broodstock attempts have not been successful. Additionally, there is very limited data for this DU. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
6.1 Recreational activities				
There are limited impacts in the area due to the dams. There is some rafting, but that is unlikely to have an impact.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				
6.3 Work & other activities	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
A substantial amount of research in the area from UBC and BC Hydro looking at passage and entrainment has been conducted. A previous study blocked passage with a weir that would have affected all species. This can be particularly detrimental to Chinook as they tend to be unwilling to pass through weirs on a descending hydrograph.				
7 Natural system modifications	**Medium**	**Pervasive (71-100%)**	**Moderate (11-30%)**	**High (Continuing)**
7.1 Fire & fire suppression				
If there was a fire they would bucket from the lake.				
7.2 Dams & water management/use	*Medium*	*Pervasive (71-100%)*	*Moderate (11-30%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: Mortality is at least 10 to 15 % through entrainment (i.e. total recruitment reduction annually) as the whole population has to migrate over Seton dam. Gas bubbles and attraction flows would also have impacts. There is potential for additional mitigation for some of these impacts, but it is unlikely to happen due to trade offs for energy production.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. Additional impacts to this DU: No additional impacts are anticipated.				
8 Invasive & other problematic species & genes	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect.				
8.2 Problematic native species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation				

Threat	Impact Calculated	Scope	Severity	Timing
is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
Unlikely to be a threat.				
9 Pollution	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below): *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019).				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment and pesticide runoff from agriculture.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*

Threat	Impact Calculated	Scope	Severity	Timing
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**High**	**Pervasive (71-100%)**	**Serious (31-70%)**	**High (Continuing)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*High*	*Pervasive (71-100%)*	*Serious (31-70%)*	*High (Continuing)*
Recently there were landslides that moved significant amounts of material downstream. This changed the spawning habitat due to flow backup from additional gravel. It is suspected that material will continue to move down. It is no longer ideal spawning habitat, but it is gradually improving. After this event there were talks to attempt brood capture, but attempts so far have been unsuccessful. Currently there is too much fine sediment in the spawning gravels and not enough fish to clean it out. There will be a continuing impact on the spawning grounds and there are no alternative spawning sites. Landslides do also occur in the Fraser Canyon (Hell's Gate & Big Bar).				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				
11.2 Droughts				
Not a threat because of the upstream dam release. (There is no dam upstream of this spawning population)				
11.3 Temperature extremes				
Not expected to be a threat because of their run timing and the upstream dam. (There is no dam upstream of this spawning population)				
11.4 Storms & flooding				
Storms and flooding are a major issue, because they could cause another landslide which is captured above in 10.3.				

Table F6. Threats Calculator Results for DU9 – Middle Fraser River Stream Spring

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	1	1
B	High	2	0
C	Medium	3	4
D	Low	3	4
Calculated Overall Threat Impact:		Very High	Very High

Assigned Overall Impact: **A = Very High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High was assigned. The stock was determined to be in serious trouble and that if the Big Bar slide is not fixed, it would be unlikely to persist. Fish passage observed over the summer will not maintain these populations in perpetuity. In addition, there are serious threats from natural systems modification from changes in catchment surfaces from forestry and fires, as well as the additional impact from climate change. Due to the high disturbance in the watersheds of this DU, it is particularly sensitive to climate change impacts.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: There is urban development within this DU, but it not encroaching the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very small impact as they spend less time in the area than DU2. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: Impacts to this DU are anticipated to be lower than the Harrison DU as they spend less time in the habitat and are mostly migrating through; thus, a negligible severity was chosen.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: There is no encroachment of agricultural land on the rivers, however there are sloughing and sediment issues that will be dealt with in section 9. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Despite regulations that are not enforced, cattle are regularly in streams in DU9. It is pervasive in certain streams of the DU, and irregular in others (12 of the streams in the DU are extensively impacted by cattle, but only 3 have cattle directly in spawning grounds. Additionally, there have been increases in cattle on the landscape. The threat here is direct trampling of redds and egg mortality.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high				

Threat	Impact Calculated	Scope	Severity	Timing
so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				
3 Energy production & mining	**Medium**	**Pervasive (71-100%)**	**Moderate (11-30%)**	**High (Continuing)**
3.1 Oil & gas drilling				
No oil and gas drilling in the area.				
3.2 Mining & quarrying	*Medium*	*Pervasive (71-100%)*	*Moderate (11-30%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: DU9 is subject to placer mining and some illegal hydro mining. Placer mining pulls substrate out of the river, removes riparian and has sediment and pollution impacts. Additionally there has been a great amount of historical mining and it continues today (there are people mining daily in August). Historical impacts still cause leaching, but scored in Section 9.2. It is pervasive in scope in DU9.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use. Some wind tenures in DU9, but they will not be in salmon habitat.				
4 Transportation & service corridors	**Negligible**	**Small (1-10%)**	**Negligible (<1%)**	**Moderate (Possibly in the short term, < 10 yrs/3 gen)**
4.1 Roads & railroads	*Unknown*	*Restricted (11-30%)*	*Unknown*	*High (Continuing)*
There are very high road densities in the area, and most of them are logging roads. Many logging roads are supposed to be decommissioned, but this often doesn't happen. It is unlikely that there will be many more roads built in DU9. There will be road construction to fix culverts, bridges and roads in the next few years in DU9, particularly in the Chilcotin. This is because these systems have blown out do to culvert plugging and flooding. There are siltation and sediment effects from the roads, but they will be dealt with in Section 9 pollution. Due to new regulations these replacements should result in better culverts that are properly sized and could potentially be a benefit.				
4.2 Utility & service lines	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
There is proposed twinning of natural gas and bitumen pipelines in the area, but the footprint is unlikely to have a large impact in DU9. As only certain streams and certain sections of streams will have pipeline crossings the scope is small. As old material used to patch the pipeline is now considered hazardous due to a failure in Shelly, there is a need to replace the natural gas pipeline. Oil spills will be dealt with in Section 9. Construction should be negligible because of mitigation and timing.				

Threat	Impact Calculated	Scope	Severity	Timing
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated as logs are moved by trucks and no longer in the river.				
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Log booms are scored under shipping (4.3). Lots of logging has already occurred in this DU. There have been significant fires in this DU and after the fires much of the areas have been or will be salvage logged. As the burnt riparian area is determined not to have value, there are no riparian requirements, and there is potential for logging to occur to the water edge. It is likely that there would be some intrusions into the river bed by machines or felled trees, but ideally this would be minimal.				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, as early spring Chinook are very desirable for their fat content, but it is uncertain how much it is. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. For example, in summer 2019 there was no legal fishing until July 15, and by then they should be passed the major fishing areas. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no perfect control as there is management error and illegal fishing. It was felt 10% severity was too low, and that 30% was too high, so the moderate to slight category was selected. Additionally, there are no harvest rates for this stock and it is uncertain what the optimal harvest rate should be. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Low**	**Restricted (11-30%)**	**Slight (1-10%)**	**High (Continuing)**
6.1 Recreational activities	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
There is high ATV use in DU9 which can be problematic. Individuals drive their ATVs through many of the streams in the DU, which would likely expose about 30% of the DU to this activity. They do run through the spawning grounds because the spawning ground tend to be where the easiest crossings are. Additionally, jet boats can also be in the rivers.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
There could be other unknown activities that occur in the watershed, but it is unlikely there should be any significant impact or be pervasive in scope.				
7 Natural system modifications	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
7.1 Fire & fire suppression	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
The interior DUs have burned significantly in the recent past and the amount in DU9 is particularly high. Bucketing in DU9 would be more impactful, as there are shallower streams, which could pick up fish, and other areas are dug out to create deep enough sections for bucketing. In the summer, adults can move into these pools and get bucketed up. Unlikely it would impact many individuals and it should be a low impact overall.				
7.2 Dams & water management/use	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: In this DU, the impacts towards fish in the Bridge River are significant. There are many water withdrawals that should be screened but frequently are not. Currently Bridge River flows are higher than usual as they are drawing down the upstream reservoir for repairs and upgrades. This released water is warmer and is causing early emergence in December. The impact in the Bridge River is very serious and affects all the fish there, but the same impact is not seen elsewhere in the DU. If this threat calculator was completed solely for the Bridge River, there would be a much higher scoring. However, as it is a small proportion of the DU, the severity overall is moderate to slight.				
7.3 Other ecosystem modifications	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. There are significant impacts from the changes to hydrological regime due to forest cover removal through logging, fires, and pine beetle. Some changes have already occurred, but there will be more to come. There will be ground water and aquifer changes in the future and an overall destabilization of the systems. Loss of riffle pool habitat, gravel additions, increase in shallow gravel bars, general destabilization and decrease in complexity. Not thought to be a 70% decline, but it will not be a slight impact. The full long term impacts are unknown (Carnation Creek is only starting to recover after 50 years).				

Threat	Impact Calculated	Scope	Severity	Timing
8 Invasive & other problematic species & genes	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect. There are some additional invasive species in DU9, but currently these are not expected to have any additional impact.				
8.2 Problematic native species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material	*Negligible*	*Negligible (<1%)*	*Unknown*	*High (Continuing)*
Spruce City Wildlife in Prince George have been doing some hatchery activities but these impacts are unknown. They recently used 20 year old sperm from Endako with the current female brood. They could have re-introduced genes that were selected out in the last 20 years. The high pre-spawn mortality in the early 2000s would have been a strong selective pressure.				
9 Pollution	**Medium**	**Pervasive (71-100%)**	**Moderate (11-30%)**	**High (Continuing)**
Due to high industrial and forestry effluent the score is rounded up to a moderate. **From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below):** *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019). Particular to this DU: Acid rock runoff from an old mine in Cottonwood and Quesnel Rivers, which is not pervasive across the DU, but is not a slight impact. Pulp mill effluents in DU9 are higher than other DUs and are likely having an impact. There is also Gibraltar Mine, which has a dead zone below the output.				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment accumulation through pesticide runoff from agriculture, logging roads, and forestry activity in this area.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Very High**	**Pervasive (71-100%)**	**Extreme (71-100%)**	**High (Continuing)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Very High*	*Pervasive (71-100%)*	*Extreme (71-100%)*	*High (Continuing)*
There is a high potential for landslides in DU9, likely due to forest removal. Every system in DU 9 has slopes that are at risk of failing. Big Bar is a huge risk and it is not known if this is a multi-year impact or not, but it is likely to remain an impediment for the near future. The slope still remains unstable and could fail again. If this is removed, it would not be an extreme severity but could still take generations for the populations to recover. It is likely that without the slide removal this stock will go extinct. Note that sedimentation as a direct result of these natural activities is scored here, otherwise all other sedimentation through anthropogenic activities are scored under pollution.				

Threat	Impact Calculated	Scope	Severity	Timing
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				
11.2 Droughts	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There could be a drought in the future and a potential impact would be more restricted spawning habitat at lower flows. However, there should be some buffering from groundwater flows. This is highly variable, and the frequency of these events will change with climate change, but it is hard to predict the impacts. There have been drastic floods in the spring followed by a drought in DU9. Have evidence in the Nicola that there was a huge freshwater juvenile die off in 2015, this is likely applicable to DU9. The dunes where spawning occurs are the first to dry out.				
11.3 Temperature extremes	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
It is known that temperature refuge is important to juveniles. DU9 will have temperature impacts likely because of all the loss of riparian habitat. Extreme temperatures would be severe. Drought and temperature tend to act together and could have cumulative impacts.				
11.4 Storms & flooding	*Medium - Low*	*Large (31-70%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Flooding occurs regularly in DU9 now and many of these systems are unstable. It likely impacts about 50% of the population in this DU. Highly variable, and the frequency of these events will change with climate change, but it is hard to predict the impacts.				

Table F7. Threats Calculator Results for DU10 – Middle Fraser River Stream Summer

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	1	1
B	High	1	0
C	Medium	3	1
D	Low	3	6
Calculated Overall Threat Impact:		Very High	Very High

Assigned Overall Impact: **A = Very High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High was assigned. The stock was determined to be in serious trouble and that if the slide is not fixed, it would be unlikely to persist. Fish passage observed over the summer will not maintain these populations in perpetuity. In addition, the anticipated impacts from climate change along with the slide is driving this to be Very High. It is in a slightly less dire situation than DU9 due to the large lakes that provide a buffer from the modification of catchment surfaces.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: There is urban development within this DU, but it not encroaching the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very small impact as they spend less time in the area than DU2. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this				

Threat	Impact Calculated	Scope	Severity	Timing
threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: Impacts to this DU are anticipated to be lower than the Harrison DU as they spend less time in the habitat and are mostly migrating through; thus, a negligible severity was chosen.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: There is no encroachment of agricultural land on the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
DU10 has fewer issues then DU9 with cattle as there are bigger rivers in DU10 that cows can't cross. Elkin, Nechako and Cariboo have cattle, but they are not always in the spawning areas. There are steep banks and fast water so it won't be as severe if they are near the spawning grounds.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under Section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
No oil and gas drilling in the area.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: DU10 has less placer mining then DU9 as there are less opportunities due to the size of the rivers (Quesnel and Cariboo Rivers are the main areas). As a result, the severity is less than DU9 because it does not create as much of a footprint. The pervasive scope is due to the impacts of gravel extraction in the lower Fraser.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use. Some wind tenures in DU10, but they will not be in salmon habitat.				
4 Transportation & service corridors	**Negligible**	**Small (1-10%)**	**Negligible (<1%)**	**Moderate (Possibly in the short term, < 10 yrs/3 gen)**
4.1 Roads & railroads	*Unknown*	*Small (1-10%)*	*Unknown*	*High (Continuing)*
There are a lot of logging roads in DU10 with more potential for them to be built than DU9, since there are more logging opportunities left. Many bridges and crossings are already in place. There is a possibility for a mine to open up in DU10 that would potentially increase road construction.				
4.2 Utility & service lines	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
There is proposed twinning of natural gas and bitumen pipelines in the area, but the footprint is unlikely to have a large impact in DU10. As only certain streams and certain sections of streams will have pipeline crossings the scope is small. As old material used to patch the pipeline is now considered hazardous due to a failure in Shelly, there is a need to replace the natural gas pipeline. Oil spills will be dealt with in Section 9. Construction should be negligible because of mitigation and timing.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can				

Threat	Impact Calculated	Scope	Severity	Timing
lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated as logs are moved by trucks and no longer in the river.				
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
DU10 has been logged less than DU9 and contains larger river systems that would be less impacted. Historically, much of DU10 has been impacted, and is unlikely to be logged again in the next ten years. Log booms are scored under shipping (Section 4.3).				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, as early spring Chinook are very desirable for their fat content, but it is uncertain how much it is. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no perfect control as there is management error and illegal fishing. It was felt 10% severity was too low, and that 30% was too high, so the moderate to slight category was selected. Additionally, there are no harvest rates for this stock and it is uncertain what the optimal harvest rate should be. There are plans for this stock to have an indicator in the future. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Negligible**	**Negligible (<1%)**	**Negligible (<1%)**	**High (Continuing)**
6.1 Recreational activities				
Unlike DU9, DU10 does not have the same scope of ATV use, as the rivers in this DU are too often large to cross. There is a potential to have boating activity in the system that could have impacts.				
6.2 War, civil unrest & military exercises				

Threat	Impact Calculated	Scope	Severity	Timing
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
There could be other unknown activities that occur in the watershed, but it is unlikely there should be any significant impact or be pervasive in scope.				
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression				
DU10 has burned significantly, but because of the larger river systems and lakes in the area bucketing should not have an impact.				
7.2 Dams & water management/use	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: In years with large Nechako flows there is good production. However, the dam above Nechako has ongoing flow impacts and Rio Tinto owns the water rights to Nechako. There is still an impact, but it is limited to Nechako and the impact is not as severe as Bridge River in DU9.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate – Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. There are significant impacts from the changes to hydrological regime due to forest cover removal through logging, fires, and pine beetle. Some changes have already occurred, but there will be more to come. However, DU10 will not be as impacted because there are such large stabilizing lakes above these systems that will prevent extreme impacts. There are still unlogged areas at the inflow areas of the large lakes which can provide additional stability. It is possible these areas will be logged in the future particularly since there will likely be more pressure with potential mill closures. There are continuing issues with bark beetles in DU 10 that could increase these impacts.				
8 Invasive & other problematic species & genes	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for				

Threat	Impact Calculated	Scope	Severity	Timing
this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect. There are some additional invasive species in DU10, but currently these are not expected to have any additional impact.				
8.2 Problematic native species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
Not likely a threat.				
9 Pollution	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below): *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019). Particular to this DU: Pulp mill effluents.				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment accumulation through pesticide runoff from agriculture, logging roads, and forestry activity in this area. However, it is less of an issue in this DU than DU9.				

Threat	Impact Calculated	Scope	Severity	Timing
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Very High**	**Pervasive (71-100%)**	**Extreme (71-100%)**	**High (Continuing)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Very High*	*Pervasive (71-100%)*	*Extreme (71-100%)*	*High (Continuing)*
There is a high potential for landslides in DU10, likely due to forest removal. Every system in DU10 has slopes that are at risk of failing. Big Bar is a huge risk and it is not known if this is a multi-year impact or not, but it is likely to remain an impediment for the near future. The slope still remains unstable and could fail again. If this is removed, it would not be an extreme severity but could still take generations for the populations to recover. It is likely that without the slide removal this stock will go extinct. Note that sedimentation as a direct result of these natural activities is scored here, otherwise all other sedimentation through anthropogenic activities are scored under pollution.				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				

Threat	Impact Calculated	Scope	Severity	Timing
11.2 Droughts	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
The timing for a drought is moderate because of the large lakes it isn't likely to occur and shouldn't have a large impact. Nechako is the only system that could have impacts, because Rio Tinto has been releasing more than the minimum flow. In extreme drought years this could be an issue.				
11.3 Temperature extremes	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
Due to the large lakes, temperatures extremes shouldn't occur in the near future. However the adults do have to migrate up through the Fraser in the summer and could experience warmer temperatures.				
11.4 Storms & flooding	*Low*	*Restricted – Small (1-30%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
The systems in DU10 are much more stable than DU9, with the exception of Nechako. However, when Nechako floods it tends to be a positive because it flushes some of the sediment out of the gravels. Elkin might have a flood event in the future but there are not many Chinook in this system. Depending on which system flooded there could be different scope of the population effected hence the small to restricted scope.				

Table F8. Threats Calculator Results for DU11 – Upper Fraser River Stream Spring

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	1	1
B	High	1	0
C	Medium	3	1
D	Low	4	7
Calculated Overall Threat Impact:		Very High	Very High

Assigned Overall Impact: **A = Very High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High was assigned. The stock was determined to be in serious trouble and that if the Big Bar slide is not fixed, it would be unlikely to persist. Fish passage observed over the summer will not maintain these populations in perpetuity. This DU is in a less dire situation than DU9 and 10, because of the cooler, wetter climate and comparatively less disturbance in the watersheds overall. Without the Big Bar slide this DU would be closer to a High threat impact.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: There is urban development within this DU, but it not encroaching the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very small impact as they spend less time in the area than DU2. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this				

Threat	Impact Calculated	Scope	Severity	Timing
threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: Impacts to this DU are anticipated to be lower than the Harrison DU as they spend less time in the habitat and are mostly migrating through; thus, a negligible severity was chosen.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: There is no encroachment of agricultural land on the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
There are cattle in this DU, but fewer than DU9.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under Section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
No oil and gas drilling in the area.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: There is some mining that occurs in this DU, but not nearly as prevalent as DU 9 or 10, as there is less gold. Score is for gravel extraction, no additional impacts expected.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Negligible**	**Small (1-10%)**	**Negligible (<1%)**	**High (Continuing)**
4.1 Roads & railroads	*Unknown*	*Restricted (11-30%)*	*Unknown*	*High (Continuing)*
There are very high rail densities in the area, but this is unlikely to change. There are lots of logging roads as well, but less than DU 9 and 10. However, there is a higher potential for more roads to be built in this DU, as spruce beetle has been impacting the forests in the watershed and could trigger salvage logging.				
4.2 Utility & service lines	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Sections of the pipeline need to be replaced, but it is uncertain where. The replacement shouldn't be impactful, particularly if mitigation is followed. There will be a twinning of the Trans Mountain Pipeline at the northern extent of the DU, but it will be limited to a few crossings. Additionally, this should also have a low impact unless there is a spill (oil spills dealt with in Section 9). Construction should be negligible because of mitigation and timing.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated.				

Threat	Impact Calculated	Scope	Severity	Timing
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
Lots of logging has already occurred in this DU, but there will be salvage logging as a result of spruce beetle. Log booms are scored under shipping (4.3).				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, as early spring Chinook are very desirable for their fat content, but it is uncertain how much it is. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. For example, in summer 2019 there was no legal fishing until July 15, and by then they should be passed the major fishing areas. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no perfect control as there is management error and illegal fishing. It was felt 10% severity was too low, and that 30% was too high, so the moderate to slight category was selected. Additionally, there are no harvest rates for this stock and it is uncertain what the optimal harvest rate should be. This DU previously had an indicator (Dome Creek), but that ended in the early 2000's. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Low**	**Restricted (11-30%)**	**Slight (1-10%)**	**High (Continuing)**
6.1 Recreational activities	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
There is a lot of ATV use in DU11 from hunters and anglers.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				

Threat	Impact Calculated	Scope	Severity	Timing
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
Not aware of any activities that would be an issue, but it is possible there are some scientific activities in the area.				
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
DU11 is similar to DU9 in that there would be impacts from bucketing, as there are shallower streams, which could pick up fish, and other areas are dug out to create deep enough sections for bucketing. In the summer, adults can move into these pools and get bucketed up. Unlikely it would impact many individuals and it should be a low impact overall.				
7.2 Dams & water management/use	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: There are many water withdrawals in this DU, which are not always screened, and leads to the pervasive designation, but it is less than DU9. There are also lots of run-of-river hydro dams upstream on tributaries, but they would likely not impact the stocks significantly. The only potential for harm would be stranding from ramping events but all the facilities should have ramping rates that are protective of fish. If there was a ramping event outside those rates, it is only at the fry stage that they would be susceptible to stranding.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate – Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. There are significant impacts from the changes to hydrological regime due to forest cover removal through logging, fires, and pine beetle. Some changes have already occurred, but there will be more to come.				
8 Invasive & other problematic species & genes	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect.				
8.2 Problematic native species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
Not likely a threat.				
9 Pollution	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below): *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019). DU11 wouldn't be exposed to the pulp mill effluents until after Prince George as these juveniles tend to stay closer to their natal streams due to better rearing habitat.				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment accumulation through pesticide runoff from agriculture, logging roads, and forestry activity in this area.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*

Threat	Impact Calculated	Scope	Severity	Timing
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Very High**	**Pervasive (71-100%)**	**Extreme (71-100%)**	**High (Continuing)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Very High*	*Pervasive (71-100%)*	*Extreme (71-100%)*	*High (Continuing)*
There is a high potential for landslides in DU11, likely due to forest removal. Big Bar is a huge risk and it is not known if this is a multi-year impact or not, but it is likely to remain an impediment for the near future. The slope still remains unstable and could fail again. If this is removed, it would not be an extreme severity but could still take generations for the populations to recover. It is likely that without the slide removal this stock will go extinct. Note that sedimentation as a direct result of these natural activities is scored here, otherwise all other sedimentation through anthropogenic activities are scored under pollution.				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. Decline could be as low as 1% or as high as 70% over the next 3 generations. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change. DU11 is not lake stabilized, however it is a colder system than DU9 and will likely feel impacts closer to those of DU10.				
11.2 Droughts	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
Compared to DUs 9 and 10, there will be less chance of drought conditions as this DU is in the interior wet belt.				

Threat	Impact Calculated	Scope	Severity	Timing
11.3 Temperature extremes	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
DU11 is similar to DU9 because the stocks migrate up the Fraser at the same time.				
11.4 Storms & flooding	*Low*	*Restricted – Small (1-30%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
These systems are much more stable than DU9. Depending on which system flooded there could be different proportion of the population effected hence the small to restricted scope.				

Table F9. Threats Calculator Results for DU14 – South Thompson Stream Summer (Bessette)

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	1	0
B	High	1	1
C	Medium	4	2
D	Low	2	5
Calculated Overall Threat Impact:		Very High	Very High

Assigned Overall Impact: **A = Very High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: DU14 was assigned an overall threat rating of Very High. It was agreed that this was reasonable and that there could be the extirpation of this DU in the next ten years. This rating is based on water use, climate change, agriculture impacts, and pollution. This DUs' smaller systems are temperature and drought sensitive and these additional threats have severely impacted it and are unlikely to diminish in the future.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: There is unlikely to be additional impacts into the stream in this DU.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very small impact as they spend less time in the area than DU2. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this				

Threat	Impact Calculated	Scope	Severity	Timing
threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts. The systems in this DU are too small for marinas.				
2 Agriculture & aquaculture	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: There is intensive agriculture occurring with minimal area left for expansion. Zero riparian habitat left next to these farms despite many stewardship efforts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This DU has the greatest trampling impact of all DUs in the RPA due to the density of cows in the area. Since the streams are small, cows can enter in many different places and it is possible for them to enter when and where there are redds. This is especially specific to the Duteau and Harris systems.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under Section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
No oil and gas drilling in the area.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: There are placer mining tenures in Harris Creek, but it is uncertain if these are currently active. Consequently this is not included in score and further investigation would be required to bump up the severity. However, it is evident that mining was done historically.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Unknown**	**Pervasive (71-100%)**	**Unknown**	**High (Continuing)**
4.1 Roads & railroads	*Unknown*	*Restricted (11-30%)*	*Unknown*	*High (Continuing)*
DU14 has a railway to Lavington (upper part of Duteau). As there is already a high density of roads and crossings, there shouldn't additional road building. Furthermore, as the Bessette complex isn't steep, culvert and crossings shouldn't be cutting off habitat. There are many stream crossings that are added in by farmers and there will be ongoing culvert and bridge replacements.				
4.2 Utility & service lines				
No utility lines in the area.				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated as systems are too small for shipping.				

Threat	Impact Calculated	Scope	Severity	Timing
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting				
There is some logging in the upper parts of the watershed. However, as most of this DU has been logged it is unlikely that there will be additional impacts because there should be the buffers since it isn't salvage logging.				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, but it is uncertain how much it is. There is likely less of an impact on Thompson DUs then the middle and upper Fraser DUs. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. For example, in summer 2019 there was no legal fishing until July 15, and by then they should be passed the major fishing areas. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no perfect control as there is management error and illegal fishing. It was felt 10% severity was too low, and that 30% was too high, so the moderate to slight category was selected. Additionally, there are no harvest rates for this stock and it is uncertain what the optimal harvest rate should be. When populations are declining at this rate, it is unlikely that there is a sustainable harvest rate. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Low**	**Small (1-10%)**	**Slight (1-10%)**	**High (Continuing)**
6.1 Recreational activities	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
Some ATV access in the Bessette complex.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				

Threat	Impact Calculated	Scope	Severity	Timing
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
Not likely a threat.				
7 Natural system modifications	**Very High - High**	**Pervasive (71-100%)**	**Extreme - Serious (31-100%)**	**High (Continuing)**
7.1 Fire & fire suppression	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
If there was bucketing they would have to dig holes in the stream to make it deep enough, thus it is likely they would go to nearby lakes to scoop water.				
7.2 Dams & water management/use	*Very High - High*	*Pervasive (71-100%)*	*Extreme - Serious (31-100%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: DU14 is a very drought sensitive system and water withdrawals have been heavily oversubscribed. There is low water already, and agriculture is drawing more water. High agricultural water use creates summer low flows in some years and there have been fish kills at times. Low flows also create stream temperatures that are too high for fish survival affecting both juveniles and adults. There is efforts for water conservation by the province in the headwaters, but water use practices have all but extirpated the species. There has been extensive diking in the area as well. Lumby is a growing town and is extracting ground water, which will also affect the ground water availability for the stream. Lots of subsurface flows at low water due to gravel aggradation. It is known that there are documented fish kills, high temperatures and that it is oversubscribed.				
7.3 Other ecosystem modifications	*Very High - High*	*Pervasive (71-100%)*	*Extreme - Serious (31-100%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. There has be lots of riprapping all around the farms along streams to protect land from floods. In terms of total change to the ecosystem there is a lot of impervious surfaces, relative to the past, and this is likely to continue.				
8 Invasive & other problematic species & genes	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect. At this point in time, all recorded observations of invasives are downstream, but it is likely they would thrive if they were to establish in the complex.				

Threat	Impact Calculated	Scope	Severity	Timing
8.2 Problematic native species	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. Otters could be having an impact as there are limited pools and numbers of fish in the system. Therefore, since abundance is so low in the DU, predation from Otters can be a significant impact. Juveniles also lack deep water refuges and are more subject to predation. As well, they have to migrate through Mable lake, which have native Rainbow and Bull Trout that would prey on them. Initially, predation would be focused only on DU14, because the Shuswap fish migrate down later. Mable lake is very oligotrophic and unproductive as a result, and so the predators could focus on emergent and migrating Chinook. However, this is speculative which results in the severity rating of 1 to 30%. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
There have been past hatchery practices that caused interbreeding between the Bessette and Shuswap stocks, but this shouldn't be ongoing because of the timing of brood stock collection. There may be some ongoing impacts from previous interbreeding, but current broodstock practices are stringent in attempting to get solely wild fish so the impacts should be minimal in the near future. There might be a new hatchery manager soon, and it is unknown if the period for broodstock collection will change. Furthermore, it is not possible to genetically ID Bessette fish as they are too genetically similar to Shuswap fish due to past practices 20-30 years ago (took 150 fish out of Bessette in the 1980's for Shuswap broodstock).				
9 Pollution	**Medium**	**Pervasive (71-100%)**	**Moderate (11-30%)**	**High (Continuing)**
In addition to the impacts in the lower Fraser, it is felt that this threat is closer to the upper end of moderate severity with potential for it to slightly exceed 30%, but it is uncertain. The impact from temperature, water withdrawal, and pollution will interact. **From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below):** *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
DU 14 has a golf course right next to the river so any pesticides would runoff, as well as two waste water discharges in the area. Sewage could potentially be a large addition at times compared to the level of the water in the river. This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There is a new junk yard in the DU right next to the river with no riparian buffer. Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019).				

Threat	Impact Calculated	Scope	Severity	Timing
9.3 Agriculture & forestry effluents	*Medium*	*Pervasive (71-100%)*	*Moderate (11-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment accumulation through pesticide runoff from agriculture, sloughing banks, logging roads, and forestry activity in this area with no riparian buffer to catch any runoff. There is high impact from dairy farming effluent and a saw mill with a sawdust pile right on the bank of the river. These runoff effluents would be even more concentrated due to the low flows. The Province has indicated that the benthic invertebrate composition suggests the system is stressed.				
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Not Calculated (outside assessment timeframe)**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**Low (Possibly in the long term, >10 yrs/3 gen)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*Low (Possibly in the long term, >10 yrs/3 gen)*
Not likely to be a threat in the DU, but there is a possible threat of landslides in the Fraser canyon.				

Threat	Impact Calculated	Scope	Severity	Timing
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. Decline could be as low as 1% or as high as 70% over the next 3 generations. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				
11.2 Droughts	*Medium*	*Pervasive (71-100%)*	*Moderate (11-30%)*	*High (Continuing)*
Duteau is a drought sensitive stream and regularly has drought impacts. Drought reduces the wetted width of the stream. It is difficult to identify the differences between the temperature, drought, and pollution.				
11.3 Temperature extremes	*Medium*	*Pervasive (71-100%)*	*Moderate (11-30%)*	*High (Continuing)*
Temperature refuge is important to juveniles, but there isn't much ground water input in this stream. In these streams there have been die offs from the high temperatures. Extreme weather in the summer can heat the stream water above 20 Celsius. Fish may be able to move out, but sometimes they get trapped by subsurface flows.				
11.4 Storms & flooding	*Low*	*Restricted – Small (1-30%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Recent flood events has resulted in riprapping for flood control, but this wouldn't affect all of the DU at a time. The recent events were when flooding was rampant across the province because of a large snow pack and a quick melt. It is likely this will happen in the future.				

Table F10. Threats Calculator Results for DU16 – North Thompson Stream Spring

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	0	0
B	High	1	0
C	Medium	4	2
D	Low	5	8
Calculated Overall Threat Impact:		Very High	High

Assigned Overall Impact: **AB = Very High - High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High to B = High was assigned. There was discussion about ranking this DU as high, instead of Very High - High, but given the uncertainty of spill events in the future along with the threat of climate change and fisheries harvest it was felt that this was an appropriate ranking.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: There is urban development within this DU, but it not encroaching the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very small impact as they spend less time in the area than DU2. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this				

Threat	Impact Calculated	Scope	Severity	Timing
threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very minimal impact. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: There is no encroachment of agricultural land on the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching				
Should not be an issue in this DU.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under Section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
No oil and gas drilling in the area.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: No additional mining impacts are anticipated.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
4.1 Roads & railroads	*Unknown*	*Restricted (11-30%)*	*Unknown*	*High (Continuing)*
There is a high density of roads in the area, and most of them are logging roads. In certain places the road footprint encroaches on the river and there are many planned bridge replacements. Additionally, the highway is being widened, and while it is currently not right next to the river, it could be in the future.				
4.2 Utility & service lines	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
It is likely they will be twinning the Trans Mountain Pipeline in the next 10 years, resulting in construction, maintenance, and an increase in the footprint size. However, construction should be drilling below the streams with limited to no instream work and if done properly there should not be an impact. There are three crossing on the Albreda River, and quite a number of the fish in this DU would encounter the crossings, but there should be a negligible impact. If the old pipeline is not recovered and left empty, there could be impacts from runoff, but runoff from this goes in pollution (Section 9).				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn't be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated.				

Threat	Impact Calculated	Scope	Severity	Timing
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
There has been salvage logging in the past resulting from large fires in the area and there are likely still ongoing sediment issues. Furthermore, salvage logging is still likely occurring in the area. Physical log boom impacts are scored under shipping (4.3) and sedimentation is scored under pollution (9.3).				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, as early spring Chinook are very desirable for their fat content, but it is uncertain how much it is. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. For example, in summer 2019 there was no legal fishing until July 15, and by then they should be passed the major fishing areas. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no perfect control as there is management error and illegal fishing. It was felt 10% severity was too low, and that 30% was too high, so the moderate to slight category was selected. Additionally, there are no harvest rates for this stock and it is uncertain what the optimal harvest rate should be. When populations are declining at this rate, it is unlikely that there is a sustainable harvest rate. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Low**	**Small (1-10%)**	**Slight (1-10%)**	**High (Continuing)**
6.1 Recreational activities	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
There are limited impacts due to recreational activities. It was uncertain if there are any regular ATV crossings in the DU. There is however some jet boat use in the North Thompson and they can get into the spawning areas.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				

Threat	Impact Calculated	Scope	Severity	Timing
There might be additional impacts from protests if the pipeline begins construction but this impact is unknown. Equipment sabotage could lead to spills. Protests could attract people for across North America so there is a potential for ecoterrorism.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
There could be other unknown activities that occur in the watershed, but it is unlikely there should be any significant impact or be pervasive in scope.				
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
It is a wetter climate in this area than the middle Fraser and hence will have less of an impact. It is expected there will be a negligible impact from direct fire and fire suppression activities. Effects from retardants go in pollution.				
7.2 Dams & water management/use	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: No additional impacts anticipated. There are run or river facilities in DU16, however almost all of these are above Chinook rearing habitat and are not expected to have a significant effect.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate – Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. There have been fires and logging in the area, which could impact the hydrology of the system, but the impacts are very uncertain. DU16 has yet to see any noticeable effect in the main stem from hydrology changes in the tributaries. The basin is very steep and there are limited opportunities for additional logging.				
8 Invasive & other problematic species & genes	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect. There are Brook Trout in the DU area, but not yet overlapping with Chinook habitat, and is not expected to have a large impact.				

Threat	Impact Calculated	Scope	Severity	Timing
8.2 Problematic native species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. There is potential issues with River Otter predation as well in the North Thompson tributaries. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
Not likely a threat.				
9 Pollution	**Medium**	**Pervasive (71-100%)**	**Moderate (11-30%)**	**High (Continuing)**
Rolled up to moderate due to the higher risk of spills in this DU. **From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below):** *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles. In the North Thompson, the road runs along the valley bottom near the river and it is possible there is slightly more impact from runoff in these DUs.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019). The total risk of a large pollution event is high in DUs 16 and 17. There is a concentration of service corridors along the mainstem and because it is a U shaped valley with concentrated fish presence, any large spill would impact all the fish in both DUs. The Trans Mountain Pipeline runs along the valley in the ground water, and a large spill could have a significant impact. There have been pipeline spills, railcar spills and transport trucks that have entered the stream in the past. As well, it is known that the pipeline leaks in some spots as it is about 50 years old. This may get better with the twinning, if the old pipe is fully recovered, but if left in the ground it could get worse. Coal dust has also been raised as a concern in the area.				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment accumulation through pesticide runoff from agriculture, logging roads, and forestry activity in this area.				

Threat	Impact Calculated	Scope	Severity	Timing
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**Moderate (Possibly in the short term, < 10 yrs/3 gen)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
There is a potential for landslides in this DU as there are steep banks that could cutoff habitat. Recently, there was action taken by pumping ground water from a cliff to prevent failure. There hasn't been a large landslide in the DU in the recently, but there is a possibility in the Fraser canyon. Little Hell's Gate near Avola and Kettle Rapids in the Clearwater River are also potential migration barriers. Severity depends on the location of where it occurs so the ranking overall is moderate to slight.				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				

Threat	Impact Calculated	Scope	Severity	Timing
11.2 Droughts	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
The vast majority of the systems will likely not have a problem, but there are specific areas that could have drought conditions, hence an unknown impact.				
11.3 Temperature extremes	*Not Calculated (outside assessment timeframe)*	*Pervasive (71-100%)*	*Unknown*	*Low (Possibly in the long term, >10 yrs/3 gen)*
The North Thompson DU is in a wet belt and in an area that still has a lot of glaciation, therefore it shouldn't see a temperature impact in the near future.				
11.4 Storms & flooding	*Low*	*Restricted – Small (1-30%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are rain on snow events in the North Thompson but wouldn't affect the whole DU at the same time.				

Table F11. Threats Calculator Results for DU17 – North Thompson Stream Summer

		Level 1 Threat Impact Counts	
Threat Impact		High Range	Low Range
A	Very High	0	0
B	High	1	0
C	Medium	4	2
D	Low	5	8
Calculated Overall Threat Impact:		Very High	High

Assigned Overall Impact: **AB = Very High - High**

Impact Adjustment Reasons: No adjustment

Overall Threat Comments: An overall impact rating of A = Very High to B = High was assigned. There was discussion about ranking this DU as high, instead of Very High - High, but given the uncertainty of spill events in the future along with the threat of climate change and fisheries harvest it was felt that this was an appropriate ranking.

Threat	Impact Calculated	Scope	Severity	Timing
1 Residential	**Negligible**	**Pervasive (71-100%)**	**Negligible (<1%)**	**High (Continuing)**
1.1 Housing	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: In the lower Fraser, there has been significant development and the severity of urbanization on Chinook salmon is unknown. There are some house boats in the Fraser River, but it is unknown whether more homes will be added to the river. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments. The impact from this future development is unknown. Note that these threats are only the direct results from new footprints of housing and development activities. Previous development is not included in this threat, but the lower Fraser has been intensively developed and diked already. Additional impacts to this DU: There is urban development within this DU, but it not encroaching the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.2 Commercial and industrial areas	*Negligible*	*Pervasive (71-100%)*	*Negligible (<1%)*	*High (Continuing)*
Lower Fraser Impacts: The lower Fraser River is more prone to industrial development than housing. The number of industrial developments are vast and are encroaching on the foreshore which is critical for Chinook. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very small impact as they spend less time in the area than DU2. Note that these threats are only the direct results from new footprint of industrial activities. Previous development is not included in this				

Threat	Impact Calculated	Scope	Severity	Timing
threat, but the lower Fraser has been intensively developed and diked already (loss of 80% of the lower Fraser estuary). Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
1.3 Tourism and recreation areas	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: There are lots of marinas and boat launches throughout the lower Fraser. Pervasive was selected because as juveniles and adults migrate through the lower Fraser, it is likely they will encounter any new developments, but it should be a very minimal impact. Additional impacts to this DU: No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2 Agriculture & aquaculture	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
2.1 Annual & perennial non-timber crops	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
Lower Fraser Impacts: There are blueberry farms and intensification of agricultural land through increasing use of greenhouses in the area. The conversion of Herrling Island to farm land could impact the overwintering of juvenile Chinook from this DU. In particular, this is the encroachment of agricultural areas into sides channels and back waters that upriver Chinook would be overwintering in. There is limited riparian area in the lower Fraser for Chinook to overwinter, so future losses could create crowding in those areas. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses, but this should be farther back from the river. However, it can still have significant impacts on stream areas through reductions in riparian areas. It is difficult to determine the difference between what has happened and what will happen. As well, it is difficult to predict what the future development will look like and exactly what the impact would be. However, it is anticipated there would be at least a slight impact. Many of the occurrences reported to DFO are riparian removals, and particularly in the lower Fraser. Additional impacts to this DU: There is no encroachment of agricultural land on the rivers. No additional impacts anticipated for this DU other than the Lower Mainland impacts.				
2.2 Wood & pulp plantations				
None.				
2.3 Livestock farming & ranching				
There are some cows in the Raft River, they should not have an impact in this DU.				
2.4 Marine & freshwater aquaculture	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Fish Farms: There are fish farms, but the impact of the footprint itself is not known, but is not expected to be high. Fish will encounter the farms but threats from disease, sea lice, and introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery fish are scored here. There is some new unpublished information that the age 2 survival of Chinook is associated with their early marine growth rate and so any competition from conspecifics will impact their survival. Hatchery fish comprise approximately 40% of salmon in the ocean (Ruggerone and Irvine 2018), and could present significant competition. The Chinook for this DU migrate north out into the open ocean, where if there is competition it would likely be from Asian hatchery production, but that impact is unknown. Currently there is no marine survival data set to examine the impacts of survival with hatchery releases. This DU would have less competition than DU2, where many hatchery Chinook with a similar life history are released. Additionally, there are not any known plans to increase production. Negligible is not representative enough, and 30% was determined to be to high so slight was chosen. This included effects from all hatchery fish, not just hatchery fish from the same DU. There was some discussion about whether impacts from hatchery fish from other DUs should be considered under Section 8.2. Ultimately it was decided that the impact is from hatchery fish in general, and that it would be difficult to tease apart the impacts from different hatchery releases based on whether they are from the same DU or not.				

Threat	Impact Calculated	Scope	Severity	Timing
3 Energy production & mining	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
3.1 Oil & gas drilling				
No oil and gas drilling in the area.				
3.2 Mining & quarrying	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
This category pertains mainly to the direct impact to aquatic habitat. Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser. It should occur in the dry, but it can change the depth and velocity of the habitat. This change in depth and velocity make the habitat unsuitable for juvenile chinook. However, the system is very dynamic and would continuously change after the extraction until the area stabilizes again. Approximately 10% of the gravel removal area is below Harrison, with the remaining 90% above Harrison and below Hope. However, the reduction of gravel would still impact sediment accumulation downstream. There is a possibility that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if that is not taken into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. It is possible that this could be a bigger threat in the future, with increased demand for gravel and increases in flood protection and dike set back. There is some evidence that overwintering Chinook from upstream would use the gravel bars that are subject to gravel extraction. It is unlikely it would have a large impact as there are other areas of use. Additional impacts to this DU: There is a mine proposal in Barriere (Harper Mine) which would impact the summer Chinook, but unknown if this mine will go through or what the impacts would be. This might result in drilling in the upper headwaters, but it shouldn't impact Chinook, the impact threats are focused on Bull Trout.				
3.3 Renewable energy				
None, as this is solar, wind, or tidal energy only. Hydroelectric is scored under dams and water management use.				
4 Transportation & service corridors	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
4.1 Roads & railroads				
There should be no road issues within this DU. Most of the spawning habitat is in the boundary of Wells Grey Provincial Park, where the roads are away from the river. There are however lots of railroads, which could have spills, but this will be discussed in Section 9.				
4.2 Utility & service lines	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
It is likely they will be twinning the Trans Mountain Pipeline in the next 10 years, resulting in construction, maintenance, and an increase in the footprint size. However, construction should be drilling below the streams with limited to no instream work and if done properly there should not be an impact. There are three crossing on the Albreda River, and quite a number of the fish in this DU would encounter the crossings, but there should be a negligible impact. However, all of the Chinook migrate past so a pervasive scope was identified. If the old pipeline is not recovered and left empty, there could be impacts from runoff, but runoff from this goes in pollution (Section 9).				
4.3 Shipping lanes	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Lower Fraser Impacts: Dredging for shipping lanes is included here. This has the potential to impact Chinook (depending on when it is done), but there shouldn’t be dredging occurring at critical times. This is a very active channel for shipping and log booms. Physical impacts from booms and barges are scored here. There are places where barges are tied up and settle on tide marsh (not supposed to be grounded, but does occur). The proportion of tide marsh habitat that has booms is high and the impact on tide marsh habitats is significant. Wake displacement from vessels can lead to stranding. It is unknown what the population impact is, but stranding does occur. These juveniles will not be spending as much time here as Harrison as they will just be passing through the area and not rearing, but the impacts are still unknown. Additional impacts to this DU: No additional impacts anticipated.				

Threat	Impact Calculated	Scope	Severity	Timing
4.4 Flight paths				
Not likely a threat.				
5 Biological resource use	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
5.1 Hunting & collecting terrestrial animals				
Not likely a threat.				
5.2 Gathering terrestrial plants				
Not likely a threat.				
5.3 Logging & wood harvesting	*Low*	*Restricted (11-30%)*	*Slight (1-10%)*	*High (Continuing)*
The vast majority of the fish inhabit Wells Gray Park, where there has been some salvage logging. As well, there has been a lot of timber activity in the Raft, Barrier and Lemieux systems. Physical log boom impacts are scored under shipping (4.3) and sedimentation is scored under pollution (9.3).				
5.4 Fishing & harvesting aquatic resources	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity is not how many fish are caught but the percent decline in the population, so if there is no decline, there is no impact. Currently, there are no measurements of the fishing rates for this DU. There is an illegal fishery issue in the Fraser canyon, as early spring Chinook are very desirable for their fat content, but it is uncertain how much it is. Freshwater fishing pressure is likely higher then marine fishing, particularly given their marine distribution. In addition, relative abundance data may not be reliable. Harvest rates have been decreasing for these stocks, given the declines that have been seen. For example, in summer 2019 there was no legal fishing until July 15, and by then they should be passed the major fishing areas. It is unlikely that management of these fisheries will change from the last two years in the near future, and so harvest rates should be lower than historical. There is no perfect control as there is management error and illegal fishing. It was felt 10% severity was too low, and that 30% was too high, so the moderate to slight category was selected. Additionally, there are no harvest rates for this stock and it is uncertain what the optimal harvest rate should be. When populations are declining at this rate, it is unlikely that there is a sustainable harvest rate. *Note, currently only salmon fisheries are evaluated and the threat from bycatch fisheries (herring and ground fish fisheries) are not included here. Furthermore there is not enough data to evaluate the impact currently.				
6 Human intrusions & disturbance	**Low**	**Small (1-10%)**	**Slight (1-10%)**	**High (Continuing)**
6.1 Recreational activities	*Low*	*Small (1-10%)*	*Slight (1-10%)*	*High (Continuing)*
There are limited impacts due to recreational activities. It was uncertain if there are any regular ATV crossings in the DU. There is however some jet boat use in the North Thompson and they can get into the spawning areas.				
6.2 War, civil unrest & military exercises				
No DND activities known to occur in freshwater, however Chinook pass near Nanoose in the marine but any impacts or severity is completely unknown. There may be other military exercises that are unknown. There have been protest fisheries in BC before, and with a potential for more fisheries closures this could be a possibility; however, any fish mortality would be considered under 5.4.				

Threat	Impact Calculated	Scope	Severity	Timing
There might be additional impacts from protests if the pipeline begins construction but this impact is unknown. Equipment sabotage could lead to spills. Protests could attract people for across North America so there is a potential for ecoterrorism.				
6.3 Work & other activities	*Negligible*	*Negligible (<1%)*	*Negligible (<1%)*	*High (Continuing)*
There could be other unknown activities that occur in the watershed, but it is unlikely there should be any significant impact or be pervasive in scope.				
7 Natural system modifications	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**High (Continuing)**
7.1 Fire & fire suppression	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
It is a wetter climate in this area than the middle Fraser and hence will have less of an impact. It is expected there will be a negligible impact from direct fire and fire suppression activities. DU17 is a higher fire risk then DU16 because it is farther south in the watershed and has more lightning strikes. Effects from retardants go in pollution.				
7.2 Dams & water management/use	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This section includes water extraction, diking for flood control, and hydroelectric. Chinook fry are using lower Fraser habitat from March to June which is the most critical period for Chinook after emergence. Diking activities have cut them off from many backchannels and sloughs (i.e. loss of Sumas lake in the lower Fraser). Most of these impacts are historical and future dike developments will likely be adjustments to the current dikes. Ephemeral and off-channel habitats have already been cutoff. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral areas and creating undesirable habitat for juvenile Chinook (Gordon et al 2015). In addition, Chinook juveniles could be put through pumps which would cause mortality. These previous impacts may have already eliminated much of the population and may have selected for juveniles that don't use these habitats as much. A 1-10% severity was chosen, based on current population levels and the fact that most of the damage has already occurred. Additional Impacts to this DU: DU17 has lots of water extraction, but as most of the fish are in the park, there is no water extraction so there should be no additional impacts.				
7.3 Other ecosystem modifications	*Medium - Low*	*Pervasive (71-100%)*	*Moderate – Slight (1-30%)*	*High (Continuing)*
Included here are: rip rapping, impacts to food webs and prey of Chinook (i.e., mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This would likely increase river velocity on the edges and reduce cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Canary reed grass can often choke out habitat that would be used by juvenile Chinook. In addition, there has been significant change in catchment surfaces in the Lower Mainland, which would have an unknown impact. There have been fires and logging in the area, which could impact the hydrology of the system, but the impacts are very uncertain. The basin is very steep and there are limited opportunities for additional logging.				
8 Invasive & other problematic species & genes	**Low**	**Pervasive (71-100%)**	**Slight (1-10%)**	**High (Continuing)**
8.1 Invasive non-native/alien species	*Negligible*	*Small (1-10%)*	*Negligible (<1%)*	*High (Continuing)*
Non-native diseases are included here along with predation and competition with spiny rays. There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years (green crabs, zebra and quagga mussels). It cannot be certain if or when they will arrive, but it is a serious potential threat. Green crabs impact eel grass, which is important salmon habitat, and they are very close to establishing in the lower Fraser. Scope and severity will increase over time if new invasive species arrive, but it is hard to predict. However, for this DU, they will not be spending much time in the estuary where the eel grass impacts will be high, so it is unlikely to have a population level effect. There are Brook Trout in the DU area, but not yet overlapping with Chinook habitat, and is not expected to have a large impact.				

Threat	Impact Calculated	Scope	Severity	Timing
8.2 Problematic native species	*Low*	*Pervasive (71-100%)*	*Slight (1-10%)*	*High (Continuing)*
Included here are predation (i.e., pinnipeds etc.) and native disease issues. There are more seals in freshwater now, but they could still be within historical levels. Hatcheries could be attracting more seals farther into freshwater and there is now a year round group of seals that can prey on Chinook there. As Chinook populations are at low levels and have reduced resiliency, this predation is now considered a threat. There should be lower impact for upstream DUs, compared to the lower Fraser DUs. There is potential issues with River Otter predation as well in the North Thompson tributaries. Parasite load increases faster with increasing temperature (however increasing water temperature scored elsewhere).				
8.3 Introduced genetic material				
Not likely a threat.				
9 Pollution	**Medium**	**Pervasive (71-100%)**	**Moderate (11-30%)**	**High (Continuing)**
Rolled up to moderate due to the higher risk of spills in this DU. **From discussion with Tanya Brown (Research Scientist, DFO) (This is applicable to all DUs and Section 9 as a whole, but won't be duplicated in the comment sections below):** *It is hard to pinpoint exactly what the severity would be. There hasn't been a lot of research in BC about the impact to Chinook, but there has been some in Washington. The scope is that all fish pass through the lower Fraser and will be exposed to pollutants, but there is lots of uncertainty about the impacts. Therefore, it is difficult to assign one category, as there isn't the information to support a specific severity. A negative effect is known, therefore a 30% is not too high and moderate to slight is appropriate. A lot of information should be coming on this in the next few years. Currently, there are some intensive studies on a long list of contaminants in the Fraser estuary (household/industrial/historical). With the work that has been done to date, the current scope, severity, and timing is appropriate. It is anticipated that future work will identify what the different pollution effects are and how it changes with the different ocean migration routes. Additionally, studies will also look at micro plastics as much is unknown. It was suggested lumping up to moderate overall for Harrison which spends more time in the Lower Mainland compared to other DUs. Contaminants of greatest concern are PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. It was identified that offshore migrates might have more impacts from mercury.*				
9.1 Household sewage & urban waste water	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. Untreated storm drains can be acute on smaller systems and result in die offs of juveniles. In the North Thompson, the road runs along the valley bottom near the river and it is possible there is slightly more impact from runoff in these DUs.				
9.2 Industrial & military effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Contaminants may be high enough to reduce reproductive success by 10% (Spromberg and Meador 2006). Exposure to some chemicals during early life stages can cause immunosuppression (Milston et al 2003). One study found that there is delayed mortality in juvenile Chinook (in Washington) from pollutants that can limit the ability for stocks to recover (Lundin et al 2019). The total risk of a large pollution event is high in DUs 16 and 17. There is a concentration of service corridors along the mainstem and because it is a U shaped valley with concentrated fish presence, any large spill would impact all the fish in both DUs. The Trans Mountain Pipeline runs along the valley in the ground water, and a large spill could have a significant impact. There have been pipeline spills, railcar spills and transport trucks that have entered the stream in the past. As well, it is known that the pipeline leaks in some spots as it is about 50 years old. This may get better with the twinning, if the old pipe is fully recovered , but if left in the ground it could get worse. Coal dust has also been raised as a concern in the area.				
9.3 Agriculture & forestry effluents	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
There are lots of log booms in the lower Fraser, and bark debris would be prevalent, along with any runoff or sedimentation from mills and log sorts along the lower river. In addition there is sediment accumulation through pesticide runoff from agriculture, logging roads, and forestry activity in this area.				

Threat	Impact Calculated	Scope	Severity	Timing
9.4 Garbage & solid waste	*Unknown*	*Pervasive (71-100%)*	*Unknown*	*High (Continuing)*
Included here are micro plastics and abandoned nets/lost nets. Micro plastic impacts are unknown but pervasive in scope. This is an unknown impact, because it is not known how severely Chinook will be impacted by micro plastics or fishing gear, but there is no doubt that there is an impact and that it is a threat.				
9.5 Air-borne pollutants	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*High (Continuing)*
Ubiquitous contaminant impacts, with an unknown severity, but it was agreed there are population level effects.				
9.6 Excess energy	*Unknown*	*Unknown*	*Unknown*	*Unknown*
Noise impacts are scored here, but may be unknown. Additionally, excess light energy impacts are scored here, but in this case it may not be a threat.				
10 Geological events	**Medium - Low**	**Pervasive (71-100%)**	**Moderate - Slight (1-30%)**	**Moderate (Possibly in the short term, < 10 yrs/3 gen)**
10.1 Volcanoes				
Not likely a threat.				
10.2 Earthquakes/tsunamis				
Not likely to be a threat, except maybe cause a landslide which goes under 10.3.				
10.3 Avalanches/landslides	*Medium - Low*	*Pervasive (71-100%)*	*Moderate - Slight (1-30%)*	*Moderate (Possibly in the short term, < 10 yrs/3 gen)*
There is a potential for landslides in this DU as there are steep banks that could cutoff habitat. Recently, there was action taken by pumping ground water from a cliff to prevent failure. There hasn't been a large landslide in the DU in the recently, but there is a possibility in the Fraser canyon. Little Hell's Gate near Avola and Kettle Rapids in the Clearwater River are also potential migration barriers. Severity depends on the location of where it occurs so the ranking overall is moderate to slight.				
11 Climate change & severe weather	**High - Medium**	**Pervasive (71-100%)**	**Serious - Moderate (11-70%)**	**High (Continuing)**
11.1 Habitat shifting & alteration	*High - Medium*	*Pervasive (71-100%)*	*Serious - Moderate (11-70%)*	*High (Continuing)*
Included here are: sea level rise, the blob 2.0, and ocean acidification. This threat included marine survival and all associated aspects. Marine temperature is included here with the blob. Future ocean conditions are uncertain, and there is a possibility that ocean survival could improve, but the formation of blob 2.0 indicates that it will decline. In a recent report evaluating threats to southern BC Chinook salmon by Riddell et al. (2013), the panel concluded that marine habitat conditions during the first year of marine residency were very likely a key driver in recent trends in survival and productivity. Shifting marine habitat will be experienced by all Chinook salmon in this DU (i.e., scope = pervasive). Snow dominated watersheds will be more subject to the hydrological shifts due to climate change compared to other systems, and in particular, spring Chinook will be more vulnerable than summers which spawn below large lakes in more stable habitat. Predicted changes include the timing of freshet and a change in precipitation from snow to rain. Groundwater regime could change with climate change.				

<table>
<tr><th>Threat</th><th>Impact Calculated</th><th>Scope</th><th>Severity</th><th>Timing</th></tr>
<tr><td>11.2 Droughts</td><td>Unknown</td><td>Pervasive (71-100%)</td><td>Unknown</td><td>Moderate (Possibly in the short term, < 10 yrs/3 gen)</td></tr>
<tr><td colspan="5">The vast majority of the systems will likely not have a problem, but there are specific areas that could have drought conditions, hence an unknown impact. There are less differences between springs and summers in the North Thompson, because the summer are below smaller lakes then in DU10, hence the risk will be the same for DU16 and DU17.</td></tr>
<tr><td>11.3 Temperature extremes</td><td>Not Calculated (outside assessment timeframe)</td><td>Pervasive (71-100%)</td><td>Unknown</td><td>Low (Possibly in the long term, >10 yrs/3 gen)</td></tr>
<tr><td colspan="5">The North Thompson DU is in a wet belt and in an area that still has a lot of glaciation, therefore it shouldn't see a temperature impact in the near future.</td></tr>
<tr><td>11.4 Storms & flooding</td><td>Low</td><td>Restricted – Small (1-30%)</td><td>Moderate - Slight (1-30%)</td><td>High (Continuing)</td></tr>
<tr><td colspan="5">There are rain on snow events in the North Thompson but wouldn't affect the whole DU at the same time.</td></tr>
</table>

APPENDIX G. HARRISON CHINOOK SURVIVAL INVESTIGATION

Examination of Survival Patterns for Harrison Chinook with Lower Fraser Fall Chinook Hatchery Production Levels

Chuck Parken

G.1. BACKGROUND

Hatchery Chinook salmon can interact with wild Chinook in several ways that can threaten the recovery of wild stocks, such as through mixed stock fishing, genetic impacts, competition, predation, parasites and fish health (e.g. denser populations lead to faster spread of parasites or disease; Gardner et al. 2004). Hatchery fish can compete with wild fish for food, by consuming prey that would otherwise be available to wild fish, and for spatial resources, by occupying preferred feeding areas and displacing wild fish to less productive feeding areas. These interactions can negatively affect wild fish when food resources are limited, and carrying capacities occur in freshwater, estuary or discrete ocean habitats, such as the Salish Sea.

Harrison Chinook have a unique natural juvenile life history among the Fraser River DUs (Fraser et al. 1982; DFO 1995). They emigrate from the natal river upon emergence from the gravel in March and April and then migrate downstream to rear in the lower Fraser River, for periods of days to weeks from mid-March to mid-May, before arriving in the tidal marshes of the Fraser River estuary for rearing, from March to June (Levy and Northcote 1982). The migration of fry immediately to rear in estuaries also occurs at other rivers entering the Strait of Georgia (e.g. Cowichan and Nanaimo; Healey 1991), Puget Sound (Duffy et al. 2010), the Columbia River (Roegner et al. 2012) and coastal Oregon (Volk et al. 2010). The small Chinook fry rear and feed in the nearshore environments of the Fraser River estuary where emergent vegetation (e.g. sedges and rushes) and riparian shrubs and trees provide detritus and habitats for Chinook food organisms, such as oligochaetes, chironomid pupae, *Corophium* and fish larvae (Levings et al. 1991). As the fry grow larger, they likely redistribute from nearshore habitats, roughly 2-33 m from shore, to neritic habitats (i.e. those adjacent to shore but too deep to sample with a beach seine, Rice et al. 2011), and then to offshore habitats (>30 m deep) during July—September and their diet changes from mainly insects and gammarid amphipods in nearshore areas to decapods and fish in offshore areas (Duffy et al. 2010). In the Salish Sea, Chinook fry use their local estuary until they redistribute to other nearby river estuaries and inshore islands during July and August, and then to more distant areas within the Salish Sea by the fall (Levings et al. 1986; Rice et al. 2011; Beamish et al. 2012) and to coastal inlets and estuaries (Roegner et al. 2012; Tucker et al. 2011). Many Chinook emigrate from the Strait of Georgia during November, but some remain during the late fall and winter (Neville et al. 2015).

The ability for Chinook to eat prey and grow in the nearshore and offshore estuary habitats has been hypothesized to have a large influence on their early marine survival and cohort abundance, called the critical size and period hypothesis (Beamish and Mahnek 2001). In Puget Sound, the marine survival of Coded Wire Tagged (CWT) Chinook was most strongly related to their average body size in July, and mortality after July was strongly size-dependent (Duffy and Beauchamp 2011). In short, there can be substantial early natural mortality in the marine environment, resulting mostly from predation (e.g. river lampreys, Beamish and Neville 1995), when the juvenile Chinook do not grow large enough to reach a critical minimum size by July (Duffy and Beauchamp 2011) or the end of their first marine summer (Beamish et al. 2011). The abundance of aquatic food resources in nearshore and offshore areas can be influenced by variations in ocean productivity (e.g. nutrients regulating food production) and competition for food (Beamish and Mahnek 2001), and competitive effects may be exacerbated during years of low ocean productivity. For Spring Chinook in the Snake River, a tributary of the Columbia River, a negative relationship was reported between smolt-adult survival and the number of hatchery fish released, particularly in years with poor ocean conditions, which suggested that hatchery programs that produce increasingly higher numbers of fish may hinder the recovery of threatened wild populations (Levin et al. 2001).

Nearly 40 years ago, major salmon enhancement projects were initiated in British Columbia because catches had dropped by approximately 50%, and several studies had indicated that the major mortality factors on salmon populations happened in freshwater, and abundance could be increased if these bottlenecks were circumvented (Peterman 1978). Those enhancement programs aimed to double the salmon production back to the historic levels experienced about 40 years earlier. Many of the hatchery strategies aimed to increase the survival of Chinook during the freshwater life stages, and the smolts were released at a size and time that was believed to result in the fish quickly migrating to the ocean, thus reducing freshwater mortality (Tatara and Berejikian 2012). At that time, it was unclear if density-dependent marine survival processes, measured over the smolt to adult life stages, could affect the intended benefits of enhancement programs since there were multiple hypotheses about marine survival processes. One view was that the abundance of juvenile salmon could not significantly affect their marine survival rate, and a doubling of smolt numbers should result in the same proportion returning as adults, whereas another view was that the marine conditions in the 1970s had not degraded enough to become limiting over the last 40 years, thus density-dependent process seemed unlikely (Peterman 1978). Peterman (1978) conducted a meta-analysis and reported that some stocks, 1 to 7 of 12 salmon cases, showed within-cohort density-dependent marine survival from the smolt to adult life stages. Subsequently, some salmon population dynamics investigations have represented density-dependent processes in the early marine survival in Puget Sound (Greene and Beachie 2002) and the Strait of Georgia (Crittenden 1994).

About 40 years after the major BC enhancement projects were initiated, Southern BC Chinook salmon abundance continued to decline (Riddell et al. 2013), with several DUs reaching Threatened or Endangered levels (COSEWIC 2019). Not only can the low abundance of Chinook affect fisheries, but it can also affect the recovery potential for Endangered predator species, such as resident killer whales (Velez et al. 2014). In May 2019, the Minister of the Department of Fisheries and Oceans announced that the government of Canada would approximately double the Lower Fraser Fall Chinook (LFFC) released from the Chilliwack Hatchery by producing another 1,000,000 smolts in order to increase the amount of prey available for Endangered Killer Whales. During the DFO Salmon Enhancement Program planning over January to March 2019, several scientific and fishery management concerns were raised about potential hatchery-wild fish ecological interactions, outcomes, issues and risks associated with this action to Harrison Chinook (COSEWIC Threatened). These populations have the same life history and they are in the same geographic area, which leads to the potential for hatchery-wild fish ecological interactions in the habitats and periods that are important for early marine growth. For example, the Salish Sea may not be a limitless environment to produce Chinook Salmon, and simply adding more enhanced fish may not increase Chinook abundance for Resident Killer Whales due to complex ecological interactions occurring in the Salish Sea under poor ocean productivity conditions (Beamish et al. 2012). The DFO doubled the Chilliwack hatchery production for brood year 2019, with plans to continue the doubled production over the next 4 years and possibly longer. Since increased production may hinder the recovery of Harrison River Chinook Salmon, potential implications were discussed and considered in the SARA Recovery Potential Threats Assessment workshop.

G.2. METHODS

G.2.1. Data Sources

The smolt-age_2 survival data for Harrison and Chilliwack are from the Coded-Wire Tag (CWT) Exploitation Rate Analysis that was conducted by the Pacific Salmon Commission Chinook Technical Committee in 2019 (Table 1).

Hatchery smolt released data were attained from the Regional Mark Information System in January 2019. These data include the number of fall Chinook released from the Lower Fraser River PSC Production Basin (Table 2), the mean weight of Chinook for each release group, and the mean fork length for each release group when measurements were reported.

Spawner and recruitment data for Harrison River Chinook were provided by Dr. Gayle Brown in the fall 2019.

Ocean salinity data for Entrance Island, BC have been collected daily since 1967.

G.2.2. Data Treatments and Analysis

The influence of LFFC hatchery production as a threat to the Harrison DU was examined for both the smolt-age_2 survival and the recruit per spawner for Harrison.

The smolt-age_2 survival rates were measured for hatchery origin Harrison Chinook that were reared and released with CWT at the Chehalis hatchery, located on the Chehalis River tributary to the Harrison River. The hatchery fish were used to represent the survival of natural Harrison Chinook, since the survival for natural fish was not measured directly and it cannot be measured practically due to the small size that natural Chinook fry emigrate from the Harrison River. The survival rate for the CWT Harrison Chinook represents a significant amount of the variation in the recruits per spawner for the natural Harrison Chinook (Brown et al. 2001), and it likely represents at least some of the variability in the survival for the natural Harrison Chinook. The survival data were natural log transformed because survival was measured over multiple life history stages from the time the CWT fish were released from the hatchery to age_2, when cohort abundance was estimated. Thus, the smolt-age_2 survival rate was measured from the product of survival rates among multiple life stages, which results in a multiplicative heteroscedastic error structure as well as when measurement errors occur (Peterman 1981; Bradford 1995).

Smolt-age_2 survival for fall Chinook is often assumed to be affected more by density-independent processes than by density-dependent processes, but there are exceptions (Peterman 1978; Crittenden 1994; Greene and Beachie 2002). To represent density-independent processes that could influence survival, the local oceanic factors in the vicinity of the Fraser River estuary were indexed by the mean monthly salinity at Entrance Island, B.C. (Figure G1) in the spring (March-May) for the Ocean Entry Years for each Harrison Chinook cohort with brood years from 1981 to 2015. The abundance of Harrison Chinook fry peaks during April and May at the Fraser estuary near Woodward Island, B.C. (Levy and Northcote 1981), and the spring period was positively correlated with the growth rate for the Fraser Fall Chinook management unit (i.e. all ocean ages for Harrison and Chilliwack populations; Xu et al. in review). Density-dependent processes were represented by the abundance of LFFC production. Unfortunately, a direct measurement of natural Harrison fry production was not available from the downstream fry trapping program at Mission, B.C. because the sampling program was designed for pink salmon and sampling ends during the Chinook migration, the program operates during even years only, and Chinook fry catches have not been adjusted for Fraser River discharge (Matthew Townsend, stock assessment biologist, DFO Fraser-Interior

Area, personal communication). A natural smolt production index can be generated using backward cohort reconstruction of natural Harrison Chinook, CWT exploitation rate and escapement data for ages 2 to 5, and the smolt-age_2 survival estimate for Harrison Chinook. However, this smolt abundance index was not used to represent density-dependent processes because the investigation would be confounded by having the same survival data as part of the dependent and independent variables and it is confounded by density-dependent processes at the spawning and egg deposition life stages.

The LFFC at the Chehalis hatchery have had extremely poor survival for decades (DFO 1995), with egg-smolt mortality rate in the hatchery currently at 40%. The mechanisms have not been identified that cause the mortality, and new activities began with brood year 2006 to reduce the mortality and improve the health of the hatchery fish. Since these treatments could affect the smolt-age_2 survival of the Harrison Chinook, the relationship between the survival of Harrison and Chilliwack Chinook was examined for any changes between 1981-2005 and 2006-2015 (excluding 2004 because survival was not measured). No changes occurred with the Chilliwack hatchery practices, thus it was considered a reference site. No changes were detected between the pre-treatment and treatment period for Chehalis hatchery fish, which suggests that the treatments did not have a detectable effect on smolt-age_2 survival (Figure G2; ANCOVA: Homogeneity of slopes P = 0.778; homogeneity of intercepts P = 0.494). Part of the fish health improvement initiative was to raise the fish to a larger body size, as measured by weight, which could influence the survival rate if larger smolts survive better than smaller smolts. Investigating the effect of smolt size on survival would ideally be assessed as part of an experimental design. As this type of experiment had not been done previously for Harrison, the survival data were examined with the mean weight of the CWT smolts, which ranged from less than 2 g to about 12 g (Figure G3). There was no indication that Harrison survival increased or decreased with smolt size, and the survivals during 2006-2015 were within the range of the 1981-2005 values.

To investigate the potential effect of producing another 1 million LFFC, a regression model relating the transformed Harrison survival and LFFC hatchery production was used to estimate the median survival at the recent 10-year average hatchery production level, and then at a level of 1 million fish higher than this average. The relative percentage change in survival indicates the potential effect from the increased hatchery production, and confidence intervals were generated from a non-parametric bootstrap procedure involving resampling of regression residuals (Efron and Tibshirani 1993). Residuals were calculated as the difference between observed and predicted values. For each bootstrap sample, residuals were drawn randomly with replacement from an array of *n* residuals calculated from the original regression. A new data set consisting of the original independent variable and simulated dependent variable was generated, the median survival was predicted at the recent average and the increased production levels, and then the relative change in survival was recorded. The procedure was repeated 10,000 times creating the distributions for the relative change, and confidence limits were calculated with the percentile method (Efron and Tibshirani 1993).

The influence of the abundance of LFFC hatchery production on the recruits per spawner, a measure of productivity, of natural Harrison Chinook was examined using stock-recruitment analysis. Variation in recruits per spawner arises from density-dependent and density-independent factors. The abundance of spawners is one of the main density-dependent factors for Chinook salmon, but the abundance of fry or smolts can also be density-dependent factors if rearing habitats in freshwater, estuary, or marine areas in the Salish Sea have carrying capacities (Greene and Beachie 2002). The abundance limiting effects of these habitats can vary among years, and environmental conditions in one type of habitat may limit numbers in one year, whereas in another year a different habitat may limit numbers. To examine the influence, if any, of LFFC hatchery fish abundance on the productivity (Recruits Per Spawner) and stock-recruitment dynamics of natural Harrison Chinook, stock-recruitment models were examined based on a) spawner abundance, b) spawner abundance and smolt-age_2 survival, and c) spawner abundance, smolt-age_2 survival and LFFC hatchery production.

Estimates of the average length of LFFC released from hatcheries were compared to the lengths of Chinook sampled from the Fraser estuary, and nearshore and offshore habitats in Puget Sound. Most LFFC are usually released from hatcheries between mid-May and early June at average sizes in the range of 4 to 6 g. About 75% (359) of 487 the LFFC release records for hatchery fry and smolts did not have any length data reported, but mean weight was reported. To convert the mean weights to mean lengths, a linear regression model was developed using paired mean weight and mean length for Chinook fry and subyearling smolts released from southern BC hatcheries (n=2104 paired measurements; Figure G4).

G.3. RESULTS

When the actual (i.e. untransformed) survival data were examined with LFFC hatchery production, there was an exponential decay pattern (Figure G5A), and the transformed survival data show a density-dependent pattern of decreasing survival as LFFC hatchery production increased (Figure B5B; ANOVA, P=0.006). When a simple, linear model was fit to the untransformed survival data, the residuals had a non-normally distributed pattern, whereas the residuals were normally distributed when the survival data were logit transformed similar to the findings of Peterman (1981; Figure G6). The logit transformation involves the natural log transformation to normalize the multiplicative error structure and it constrained the y-axis to values between 0 and 1, which is necessary for survival data. When the unstandardized residuals were arranged by LFFC hatchery production, the residuals from the model using untransformed survival data had a heterscedastic pattern, whereas those from the transformed survival data were in a horizontal band with no apparent systematic features (Figure G7). The negative relationship between smolt-age_2 survival and LFFC hatchery was significant (ANOVA, P=0.006), but LFFC hatchery production represented only about 19% (adjusted r^2) of the variation in survival. A substantial amount of the unexplained variation is likely from factors such as measurement error, environmental conditions, and food availability for early marine growth, and predator abundance (Peterman 1978; Bradford 1995; Levin et al. 2001).

The highest Harrison survival observation was for the first brood year, 1981, which was almost twice as high as the next highest value, and it could be a statistical outlier that may define the relationship between Harrison survival and LFFC hatchery production (Figure G5). However when the survival data were transformed, the 1981 datum was not an outlier, and the residual was 2.2 standard deviations from the mean residual, which is consistent with the expected distribution for normally distributed residuals (Figure G6). Also, the leverage for the 1981 datum ranks 5th among 34 residuals, and the value (0.067) was less than the general criterion of 0.2 that is used to identify data of concern, so the 1981 datum was not defining the relationship. Also, the high survival observation for Harrison in 1981 was corroborated by the high survival measured at the Chilliwack River, which enters the Fraser River about 17 km downstream of the Harrison River mouth. Survival rates were moderately correlated for these stocks (r^2=0.42; Figure G2). The 1981 observation was a high value, but not unusually so, and there wasn’t anything unusual about it that provided good rationale to exclude it from investigations. Peterman (1981) found that a multiplicative, lognormal error distribution was most consistent for the marine survival of Pacific salmon, and that this phenomenon should be taken into account when planning salmon enhancement programs and their evaluation.

The survival pattern could be affected by the high LFFC production from the Chehalis hatchery more than production from other lower Fraser hatcheries, which are downstream of the Harrison, and potentially have less spatial overlap with Harrison Chinook (Figure G8). For example, fish from the Chilliwack River hatchery migrate through about 84% of the lower Fraser River that Harrison fish migrate through. Although, the actual spatial overlap could differ due to differences in migration timing and habitat use between Harrison natural and Chilliwack hatchery Chinook. Fall Chinook production from more distant hatcheries in the Strait of Georgia and Puget Sound could affect Harrison survival if resources were overlapping and limiting in more distant locations beyond the lower Fraser River and estuary. The survival for Harrison Chinook was more significantly associated with all LFFC hatchery production (Pearson correlation = -0.463, P=0.006)) than fall Chinook production from only the Chehalis (Pearson correlation = -0.422, P= 0.013) or the Chilliwack hatchery (Pearson correlation = -0.400, P = 0.019), and it was not significantly associated with fall Chinook production from hatcheries in the lower Strait of Georgia (Pearson correlation = -0.080, P=0.653) or Puget Sound (Pearson correlation = 0.247; P=0.159; Figure G9). There was a similar decreasing pattern of Harrison survival with increasing LFFC production from the Chehalis and Chilliwack hatcheries, but it was associated more with the cumulative production from all the lower Fraser hatcheries.

To examine if the Harrison survival pattern could predominantly be due to large releases from the Chehalis hatchery, the survival patterns were examined between brood years with high and low Chehalis hatchery production levels. High production was identified when more than 1 million hatchery fish were released, since this level was intermediate of two peaks in the frequency distribution of Chehalis production of LFFC (Figure G10). There was no significant difference in the relationship between Harrison survival for years with high versus low production at the Chehalis hatchery, since the slopes of the regression models were not significantly different (ANCOVA, P=0.493), and the intercepts were not significantly different (ANCOVA, P=0.901; Figure G11). To examine the influence of the time series effects on the smolt-age_2 survival patterns, the residuals were examined for autocorrelation, but none was detected (Figure G12). This indicates that patterns of decreasing survival with increasing LFFC hatchery production do not appear to be confounded by time series effects (i.e. periods of high or low survival coinciding with periods of low or high hatchery production, respectively; Figure G13).

Since Levin et al. (2001) found that the negative relationship between the survival of wild Snake River spring Chinook and hatchery production was exacerbated during ocean entry years of poor ocean conditions, the added effect of poor ocean conditions in the Strait of Georgia was examined. The spring salinity at Entrance Island, B.C. was used as an index of ocean conditions, since it was associated with the growth of Harrison Chinook (Xu et al. in review[33]). Years of poor ocean conditions were more than one standard deviation below the long term (1937-2019) mean, which was the same approach Levin et al. used to identify anomalies in the Oyster Condition Index. There were six years of poor ocean conditions from 1981 to 2015 (Figure G14), but there were no differences in the regression slopes (ANCOVA, P=0.325) or the intercepts (ANCOVA, P=0.654) when there were poor ocean conditions relative to others. These findings suggest that the much of the variation in Harrison survival may be affected by ecological factors other than physical ocean conditions represented by the spring salinity at Entrance Island.

Although smolt-age_2 survival was measured for Harrison and Chilliwack, only the Harrison showed a pattern of declining survival with increasing LFFC hatchery production. Hatchery smolts were about the same size at both sites, and the survival at each site was unrelated to

[33] Xu, Y., S. Decker, C.K. Parken, L. Ritchie, D. Patterson and C. Fu. In Review. Climate effects on size-at-age and growth rate of Chinook Salmon (*Oncorhynchus tshawytscha*) in the Fraser River, Canada.

average size of the hatchery smolts (ANOVA, P>0.74). The mechanisms were unclear that led to a pattern of declining survival for Harrison, but not Chilliwack smolts. Peterman (1978) described an indirect interaction that can occur when a stock depletes the local food supply and then moves away while shortly afterward another stock moves into a location before the food has recovered, and perhaps the more downstream release location of Chilliwack provides some advantage by enabling them to attain and defend preferred feeding habitats, or to acquire and perhaps deplete food resources before the arrival of the Harrison CWT fish. Based on information from CWT Chinook stocks in Puget Sound, Duffy and Beachamp (2011) reported that the marine survival of Chinook salmon depended strongly on their body size in July, and that rapid growth during the early marine period (through at least mid-July) was critical for improved survival. Chilliwack fish have higher survival (transformed) than Harrison (paired samples t-test, P<0.001; Figure G2), which suggests Chilliwack fish grow more rapidly during the early marine phase and have a larger body size in July than Harrison, since these stocks are released from the hatcheries at about the same size (paired samples t-test, P=0.18). Larger fish are generally more resilient to periods of food deprivation than smaller fish and less vulnerable to predation (Peterman 1978). In the neritic waters of Puget Sound, Rice et al. (2011) found that hatchery Chinook did not exhibit strong density-dependence in size compared to wild fish. They suggested that the larger average size of hatchery fish allows them to dominate competitive interactions with wild fish in the estuary, thereby leaving them unaffected by competition. They also suggested that hatchery fish had higher turnover rates than wild fish due to fast migration rates, which would reduce the apparent competition for prey in their study.

The logistic regression model was used to represent the pattern of declining Harrison survival with increasing LFFC production, and to estimate the median survival at different levels of LFFC hatchery production. For brood years 2007-2016, LFFC production averaged 1,652,730 fish, which corresponds with a median smolt-age_2 survival of 1.48%, whereas an additional Chilliwack production of 1,000,000 fish corresponds with a median survival of 1.09%. The relative reduction in the Harrison survival between the recent 10-year average LFFC hatchery production and the increased production level had a median of 26%, with 80% confidence intervals from 16% to 35% (Figure G16).

For natural Harrison Chinook, the transformed recruits per spawner depends on the abundance of spawners and the smolt-age_2 survival (Brown et al. 2001). For brood years 1984-2013, excluding 2004 due to an absence of survival data, spawner abundance explained 11% (adjusted r^2) of the variation in recruits per spawner, however about 35% of the variation was explained when survival data were included, which increased to 39% when LFFC hatchery production was included.

G.4. DISCUSSION

The ecological interactions between hatchery and natural origin LFFC are largely undescribed during their first year. Several investigations have described habitat use for natural Chinook in the lower Fraser River and the nearshore areas of the estuary (Levy and Northcote 1982, Levings et al. 1991), and elsewhere in the Salish Sea. Chinook fry use these ecological niches for weeks to months, and they appear to shift to progressively deeper, offshore habitats as they grow based on studies in the estuaries of Puget Sound (Duffy et al. 2010), the Nanaimo River (Healey 1980) and Campbell River (Levings et al. 1986), and also to redistribute among other estuaries in the Salish Sea later in the summer (Rice et al. 2011). These habitats are important nursery areas for Chinook salmon and they may play significant roles for salmon populations depending on the mechanism of density-dependence (Healey 1980; Greene and Beachie 2004).

The smolt-age_2 survival of Harrison Chinook was associated more with the cumulative LFFC production from all hatcheries than either the individual production from Chehalis and Chilliwack hatcheries, or Chinook fry and smolt production from all hatcheries in the Strait of Georgia or Puget Sound, and these findings are consistent with those from research in Puget Sound. In Puget Sound, the ecological conditions in the natal stream estuary that affect the growth of Chinook through to mid- to late-July appear to be the main factors influencing marine survival. Puget Sound Chinook rear and grow in different parts of their natal estuaries until July, when the fish begin to redistribute to other river estuaries and deeper waters of Puget Sound (Duffy et al. 2010; Rice et al. 2011). As the density of marked and unmarked (mainly wild) Chinook in the estuary increases, the growth of unmarked (mainly wild) Chinook decreases (Rice et al. 2011), and the average body size of CWT Chinook in July is strongly related to their marine survival (Duffy and Beauchamp 2011). Accordingly, the critical period for growth is likely March to July, and the locations are the rearing habitats that provide food resources from the natal stream to the natal stream system's estuary in the Salish Sea. Thus, hatchery production that enter the Salish Sea via distant estuaries are less likely to affect Chinook growth during the critical period and locations, since they do not appear to cohabitate in marine waters of the Salish Sea until afterward.

Hatchery-wild fish competition will ultimately result in a reduction of fitness, and competition can be identified by agonistic behavior, feeding behavior, growth, and survival (Tatara and Berejikian 2012). Survival has the strongest relationship to fitness relative to studies that measure the effects of hatchery fish on growth, food consumption, displacement, habitat use and behavior for wild fish (Tatara and Berejikian 2012). Intraspecific competition is greater than interspecific competition for salmon because the species differ in their ecological niches (see reviews in Groot and Margolis 1991). Within a species, competition is likely greatest among fish from the same biological population (e.g. similar geography, life history, and genetics), with less competition among populations within the same Wild Salmon Policy Conservation Unit (CU) (e.g. less similar geography and genetics, but similar life history), and even less competition among CUs in the same DFO stock management unit (e.g. different geography and genetics, and several differences in life history), and then less competition among different management units (e.g. different geography, life history and genetics). Harrison Chinook are a single spawning site CU, however the stock has been transplanted to several hatchery locations in the lower Fraser geographical area and these hatchery stocks will have very similar life history and ecological niches with some fine-scale differences due to the locations of the hatcheries and the times and sizes that the fish are released from each hatchery.

Hatcheries can grow fish at an accelerated rate and release them at a larger size than wild fish, with the intent that the Chinook smolts will quickly migrate to the ocean soon after they are released, which reduces freshwater mortality and the duration that hatchery and wild fish cohabitate (Tatara and Berejikian 2012). For LFFC, the roles of density-dependent mechanisms and life stages are not well understood. Competition occurs at the spawning life stage (e.g. redd defending to reduce superimposition) and possibly at juvenile life stages when resources are limiting for the life stages during the critical period and size hypothesis (Beamish and Mahnken 2001). The habitat use and potential ecological niche overlap is not known for LFFC hatchery and wild fish, but information from the nearby Puget Sound Chinook indicates unmarked (mainly wild) Chinook fry use neritic habitats near river mouths for a much longer period than hatchery marked Chinook, and that the lengths of unmarked Chinook were negatively related to the density of marked, unmarked and total Chinook, but the lengths of marked Chinook were not (Rice et al. 2011). For Harrison, the smolt-age_2 survival indicates a density-dependent effect from LFFC hatchery fish, however there are no data for the abundance or survival of wild Harrison fish in these life stages, thus the inferences rely on information from the Harrison CWT fish.

The potential ecological interactions between hatchery and natural Chinook in their first year could be quite complex, with several occurring simultaneously and the most influential interaction could vary among life stages in different years depending on specific conditions (e.g. whether or not food resources are limiting). For example, Beamish and Mahnken (2001) suggest that growth is important to reach a critical size by the end of the first summer and that the early natural mortality is mostly related to predation, which is followed by a physiologically-based mortality that happens during the first winter in the ocean. Rice et al. (2011) reported that the lengths of unmarked Chinook (primarily natural) in neritic waters in Puget Sound river mouth estuaries were negatively related to the density of marked Chinook salmon (R^2 ~54%), indicating a negative ecological interaction for natural fish due to competition for food resources. However, Nelson et al. (2018)[34] reported that hatchery releases were only correlated with productivity in 1 of 20 Pacific Northwest stocks, whereas harbor seal density was negatively correlated with productivity in 14 of 20 stocks. Gardner et al. (2004) discussed how enhanced salmon could have a negative effect on natural salmon through increased predation rates, by attracting predators, and a positive effect through decreased predation rates, by satiating predators. It is likely very challenging to discern the specific effects of hatchery origin fish on wild fish because there are many potentially complex mechanisms and synergies that will not be identified until there is a monitoring program for hatchery-wild fish interactions for Fraser or other Chinook in BC.

The smolt-age_2 survival for Harrison was negatively associated with the abundance of LFFC hatchery fish production among 34 years, which represented about 1/5th of the variation in survival. The inference for natural Harrison Chinook can only be made indirectly because (1) there were no direct measurements of survival or smolt abundance for natural Harrison Chinook and (2) the smolt-age_2 survival data were based on the CWT hatchery Harrison fish that were released into the Harrison River at a larger size and later in the spring than the natural fish emigration. Thus, it was difficult to say with certainty that this density-dependent pattern has a causal effect on wild Harrison survival. However, this is the most representative measure that exists for survival at this life stage for the wild stock and there is no evidence that the pattern is spurious and caused by other mechanisms (e.g. ocean conditions represented by spring salinity at Entrance Island, B.C that were associated with Harrison Chinook growth, confounded by high production from Chehalis Hatchery, high survival for brood year 1981). The effect of the LFFC hatchery production represented a small (4%) amount of the variation in recruits per spawner for natural Harrison Chinook, and most of the variation in recruits per spawner was represented by smolt-age_2 survival (24%), followed by the abundance of spawners (11%). The Harrison stock-recruitment data are highly variable and noisy relative to other Chinook stock-recruitment data sets where most of the variability in recruits per spawner was represented by the abundance of spawners (Parken et al. 2006).

The lower Fraser River and estuary are highly developed, with the vast majority of intertidal marsh habitats having been filled in, and riparian areas removed and armored with rip rap or vertical steel sheeting to create shoreline suitable for shipping and other industries (Levings et al. 1991). These modifications may have yielded a limited carrying capacity for Chinook salmon fry because critical habitats to produce food resources (e.g. riparian areas for insects, marsh habitats for gammarids and fish prey) and for Chinook fry to capture prey in the mid and lower tide zones have been significantly reduced, dredged and re-channelized relative to predevelopment conditions.

[34] Several assumptions and atypical treatments exist with stock-recruitment data used in this analysis and the results should be interpreted cautiously.

The natural Harrison Chinook fry may have a competitive disadvantage for food relative to LFFC hatchery fry because of their relatively smaller size. LFFC hatchery fish are typically released at mean lengths of 73-85 mm from mid-May to mid-June. In comparison, natural Harrison Chinook fry begin to arrive in the Fraser estuary in March, with mean lengths in the intertidal channels of about 40-45 mm, and then mean size increases to about 45-50 mm in mid- to late May, then to about 70-75 mm by late June and early July (Levy and Northcote 1982). The larger size of hatchery fish may enable them to dominate preferred feeding areas, as larger fish can be superior predators (Tatara and Berejikian 2012). The size of Chinook fry also appears to vary among estuarine habitats, with larger fish found in deeper habitats of Puget Sound Chinook, where mean sizes of Chinook fry in nearshore areas were 78-86 mm in May (range 39-115), 85-90 mm June (range 81-150 mm), and they were 127-164 mm in the deeper offshore areas during July (range 103-226 mm; Duffy et al. 2010). The larger size of the LFFC hatchery fish may give them a competitive advantage over the smaller wild Harrison fish, in terms of displacement (i.e. large fish displacing small ones via aggressive behavior), by directly competing for food resources in the same habitat since larger fish are often superior competitors, or larger fish bypassing shallow habitats and occupying deeper habitats, gaining a residence or temporary feeding territory (i.e. prior residence effect Tatara and Berjikian 2012) and depleting food resources that otherwise would have been available for natural fish. There is evidence that hatchery Chinook have more agonistic behavior than wild fish (Wessel et al. 2006). When hatchery and wild Chinook were placed in enclosures at similar densities, the hatchery fish had a greater negative effect on wild fish growth than an equal density of wild fish when food resources were thought to be limiting (Weber and Fausch 2005). Competition from LFFC hatchery fish could slow the growth rate of Harrison fish and affect their survival by extending the time period when wild fish are size-vulnerable to predators (i.e. gape-limited predators) and delaying the time for them to grow to critical sizes to redistribute from nearshore to offshore habitats with more food resources (Duffy et al. 2010), or to reach critical sizes for physiologically-based survival during the winter (Beamish and Mahnken 2001).

The message is not to shut down hatcheries, but to more actively collect information about the ecological interactions of hatchery and wild Chinook, to use enhancement to provide information about smolt-age_2 survival processes that will help future management of stocks, and to help inform any decisions about hatchery production levels and release strategies that may hinder the recovery of depleted wild populations. It could be helpful to increase research on the factors that affect the smolt-age_2 survival of Harrison and other Fraser Chinook in the tidal, freshwater parts of the Fraser River, its estuary and other parts of the Salish Sea. A randomized experiment to substantially vary the production of the LFFC in alternating years could increase knowledge about density-dependent effects on smolt-age_2 survival. From brood years 1981-2015, Harrison survival rates were highest when LFFC production was less than 1.5 million fish. Recent LFFC production has averaged fairly close to this level (1.6 million), however, increasing production by 1M fish is expected to relatively reduce survivals by a median of 26% (80% confidence interval: 16-35%).

In the U.S. Pacific Northwest, Chinook salmon conservation activities have been occurring for many decades, dating back to the period when dams were constructed on the mainstem of the Columbia River, which can provide helpful information for programs aimed at rebuilding depleted Southern B.C. Chinook. Many U.S. programs focus on the 4 H's of salmon recovery: Harvest, Habitat, Hydro-systems and Hatcheries. Hatcheries can be used for conservation objectives for some populations and to maintain fisheries for others. The negative effect of hatcheries has been reported for wild Chinook survival in the Columbia River, and numerous studies have reported hatchery-wild interactions that range from negative effects to no negative effects being detected on wild Chinook ranging from Sacramento, California to Puget Sound, Washington. Relatively little information is available about these ecological interactions in and around the Strait of Georgia, but there is information that indicates the food resources can be limiting in and around river estuaries and nearby deeper waters of the Salish Sea, and that the average body size in July is positively related to survival, which supports hypotheses about critical size and period for Chinook salmon survival and production. Increased LFFC hatchery production is one of many potential threats to the recovery of Harrison Chinook.

G.5. REFERENCES

Beamish, R.J., and C.M. Neville. 1995. Pacific salmon and Pacific herring mortalities in the Fraser River plume caused by river lamprey (Lampetra ayresi). Can. J. Fish. Aquat. Sci. 52:644-650.

Beamish, R.J. and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49:423-437.

Beamish, R.J., R.M, Sweeting, C.M. Neville, K.L. Lange, T.D. Beacham, and D. Preikshot. 2012. Wild chinook salmon survive better than hatchery salmon in a period of poor production. Environ. Biol. Fish. 94:135-148.

Beamish, R.J., K.L. Lange, C.M. Neville, R.M. Sweeting and T.D. Beacham. 2011. Structural patterns in the distribution of ocean- and stream-type juvenile chinook salmon populations in the Strait of Georgia in 2010 during the critical early marine period. NPAFC Doc. 1354. 27 pp.

Bradford, M.J. 1995. Comparative review of Pacific salmon survival rates. Can. J. Fish. Aquat. Sci. 52:1327-1338.

Brown, G., B. Riddell, D. Chen and M. Bradford. 2001. A biologically-based escapement goal for Harrison River fall Chinook.   Pacific Scientific Advice Review Committee Working Paper S2001-16.

Committee on Species of Endangered Wildlife in Canada [COSEWIC]. 2019. COSEWIC assessment and status report on the Chinook Salmon *Oncorhynchus tshawytscha*, Designatable Units in Southern British Columbia (Part One – Designatable Units with no or low levels of artificial releases in the last 12 years), in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxxi + 283 pp.

Crittenden, R.N. 1994. A model for the processes regulating recruitment for a sockeye salmon stock. Ecol. Modell. 71: 85-186.

Department of Fisheries and Oceans [DFO]. 1995. Fraser River Chinook. Fisheries and Oceans Canada, Vancouver, B.C.

Duffy, E.J., and D.A. Beachamp. 2011. Rapid growth in the early marine period improves the marine survival of Chinook Salmon (*Oncorhynchus tshawytscha*) in Puget Sound, Washington. Can. J. Fish. Aquat. Sci. 68:232-240.

Duffy, E.J., D.A. Beauchamp, R.M. Sweeting, R.J. Beamish, and J.S. Brennan. 2010. Ontogenetic diet shifts of juvenile Chinook Salmon in nearshore and offshore habitats of Puget Sound. Transactions of the American Fisheries Society 193:803-823.

Efron, B., and R.J. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, San Francisco.

Fraser, F.J., P.J. Starr and A.Y. Federenko. 1982. Areview of the chinook and coho salmon of the Frasre River. Can. Tech. Rep. Fish. Aquat. Sci. 1126.

Gardner J, Peterson DL, Wood A, Maloney V. 2004. Making Sense of the Debate about Hatchery Impacts: Interactions Between Enhanced and Wild Salmon on Canada's Pacific Coast. Vancouver, BC: Prepared for the Pacific Fisheries Resource Conservation Council. Vancouver, B.C. 190 p.

Greene, C.M. and T.J. Beechie. 2004. Consequences of potential density-dependent mechanisms on recovery of ocean-type chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 61:590-602.

Healey, M.C. 1980. Utilization of the Nanaimo River estuary by juvenile chinook salmon *Oncorhynchus tshawytscha*. Fish. Bull. 77:653-668.

Healey, M.C. 1981. Life history of Chinook Salmon (*Oncorhynchus tshawytscha*). In C. Groot and L. Margolis (editors). Pacific Salmon Life Histories. UBC Press, University of British Columbia, Vancouver.

Groot, C. and L. Margolis (editors). 1991. Pacific Salmon Life Histories. UBC Press, University of British Columbia, Vancouver.

Levin, P.S, R.W. Zabel, and J.G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. Proc. R. Society London, Britain. 268:1153-1158.

Levings, C.C., C.D. McAllister, and B.C. Chang. 1986. Differential use of the Campbell River estuary, British Columbia, by wild and hatchery-reared juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 43:1386-1397.

Levings, C.C., K. Conlin and B. Raymond. 1991. Intertidal habitats used by juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) rearing in the North Arm of the Fraser River estuary. Marine Pollution Bulletin, 22:20-26.

Levy, D.A. and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can J. Fish. Aquat. Sci. 39:270-276.

Nelson, B.W., C.J. Walters, A.W. Trites, and M.K. McAllister. 2019. Wild Chinook salmon productivity is not negatively related to seal density and not related to hatchery releases in the Pacific Northwest. Can. J. Fish. Aquat. Sci. 76:447-462.

Neville, C.M., R.J. Beamish and C.M. Chittenden. 2015. Poor Survival of Acoustically-Tagged Juvenile Chinook Salmon in the Strait of Georgia, British Columbia, Canada, Transactions of the American Fisheries Society, 144:1, 25-33.

Parken, C.K., R.E. McNicol, and J.R. Irvine. 2006. Habitat-based methods to estimate escapement goals for data limited Chinook salmon stocks in British Columbia, 2004. DFO Can. Sci. Advis. Sec. Res Doc. 2006/083. iv + 67 p.

Peterman, R.M. 1978. Testing for density-dependent marine survival in Pacific salmonids. J. Fish. Res. Board Can. 35:1434-1450.

Peterman, R.M. 1981. Form of random variation in salmon smolt-to-adult relations and its influence on production estimates. Can. J. Fish. Aquat. Sci. 38:1113-1119.

Rice, C.A. , Greene, C.M., Moran, P., Teel, D.J. , Kuligowski, D.R., Reisenbichler, R.R., Beamer, E.M., Karr, J.R. and Fresh, K.L. 2011. Abundance, Stock Origin, and Length of Marked and Unmarked Juvenile Chinook Salmon in the Surface Waters of Greater Puget Sound. Transactions of the American Fisheries Society, 140: 1, 170 — 189, Riddell, B., M. Bradford, R. Carmichael, D. Hankin, R. Peterman, and A. Wertheimer. 2013. Assessment of Status and Factors for Decline of Southern BC Chinook Salmon: Independent Panel's Report. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for Fisheries and Oceans Canada (Vancouver. BC) and Fraser River Aboriginal Fisheries Secretariat (Merritt, BC). xxix + 165 pp. + Appendices.

Roegner, G.C., R. McNatt, D.J. Teel, and D.L. Bottom. 2012. Distribution, size and origin of juvenile chinook salmon in shallow-water habitats of the lower Columbia River and estuary, 2002-2007. Marine and Coastal Fisheries: Dynamics, Management and Ecosystem Science 4:450-472.

Tatara, C.P. and B.A. Berejikian. 2012. Mechanisms influencing competition between hatchery and wild juvenile anadromous Pacific salmonids in freshwater and their relative competitive abilities. Environ. Biol. Fish. 94:7-19.

Tucker, S., M. Trudel, D.W. Welch, J.R. Candy, J.F.T. Morris, M.E. Thiess, C. Wallace, and T.D. Beacham. 2011. Life history and seasonal stock-specific ocean migration of juvenile Chinook Salmon. Transactions of the American Fisheries Society. 140:1101-1119.

Velez-Espino, L.A., J.K.B. Ford, H.A. Araujo, G. Ellis, C.K. Parken, R. Sharma. 2014. Relative importance of chinook salmon abundance on resident killer whale growth and viability. Aquatic Conservation: Marine and Freshwater Ecosystems, 25(6):756-780.

Volk, E.C., D.L. Bottom, K.M. Jones and C.A. Simenstad. 2010. Reconstructing juvenile Chinook salmon life history in the Salmon River estuary, Oregon, using otolith microchemistry and microstructure. Transactions of the American Fisheries Society 139:535-549.

Weber, E.D., and K.D. Fausch. 2005. Competition between hatchery-reared and wild juvenile Chinook salmon in enclosures in the Sacramento River, California. Transactions of the American Fisheries Society 134:44-58.

Wessel, M.L., W.W.Smoker, R.M. Fagen and J. Joyce. 2006. Variation of agonistic behavior among juvenile Chinook salmon (*Oncorhynchus tshawytscha*) of hatchery, hybrid, and wild origin. Can. J. Fish. Aquat. Sci. 63:438-447.

Figure G1 - The location of Entrance Island, B.C., in the Strait of Georgia.

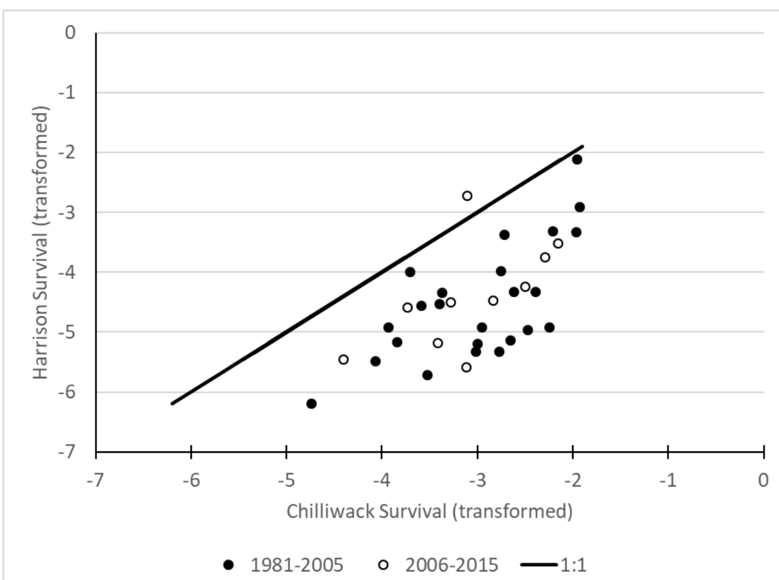


Figure G2 - Scatter plot of natural log transformed smolt-age_2 survival estimates for Harrison and Chilliwack River fall Chinook for brood years 1981-2005 and 2006-2015 (excluding 2004), with a 1:1 reference line for equality.

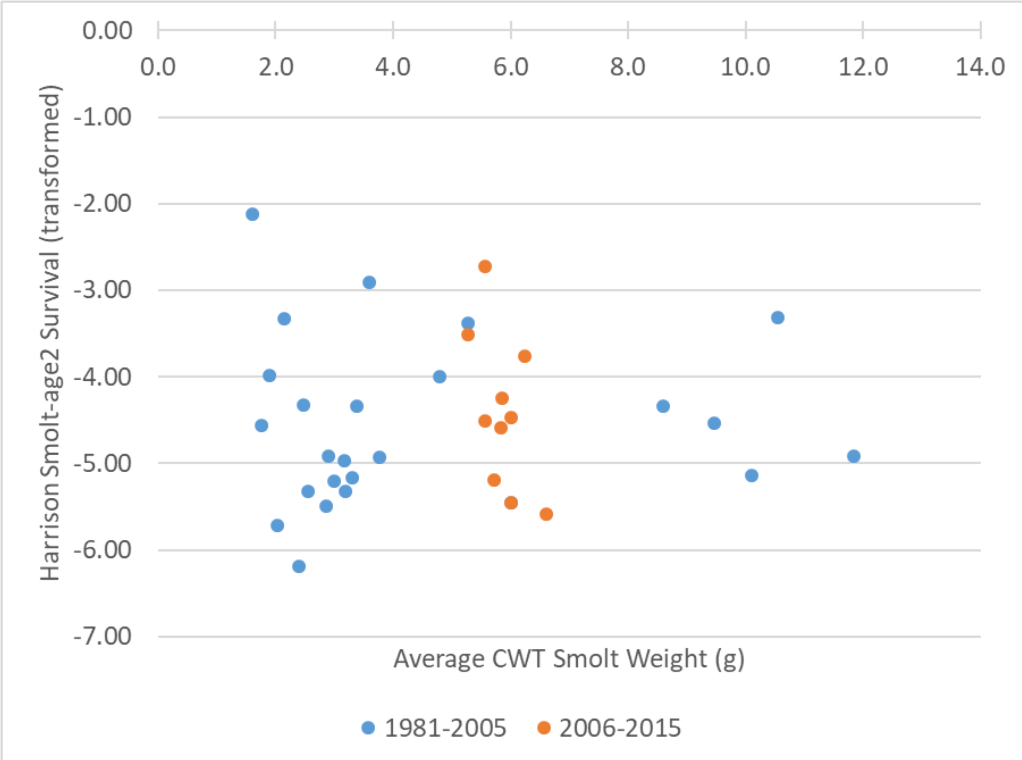


Figure G3 - Scatter plot of natural log transformed smolt-age_2 survival estimates and average weight for CWT smolts for Harrison River fall Chinook for brood years 1981-2005 and 2006-2015 (excluding 2004).

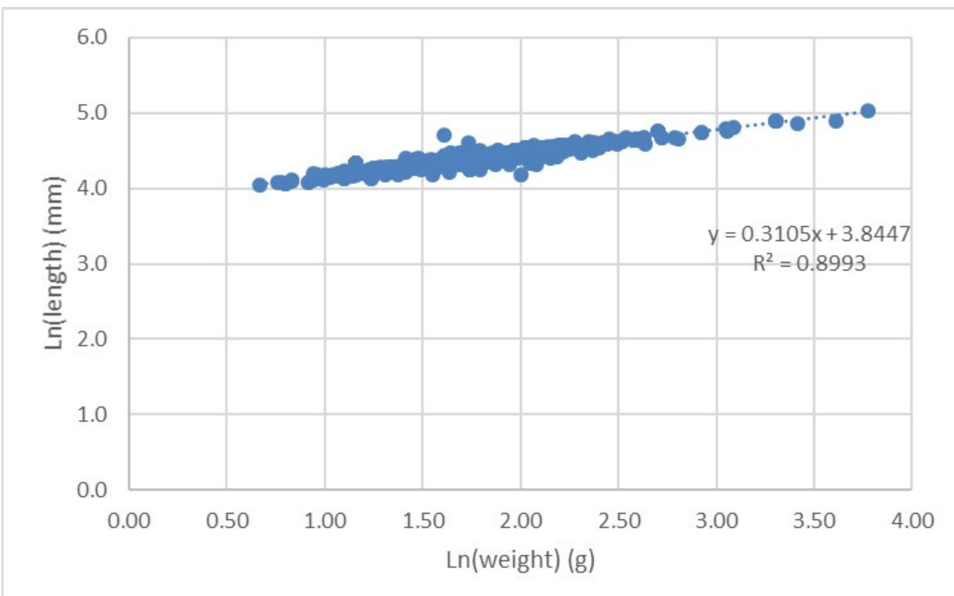
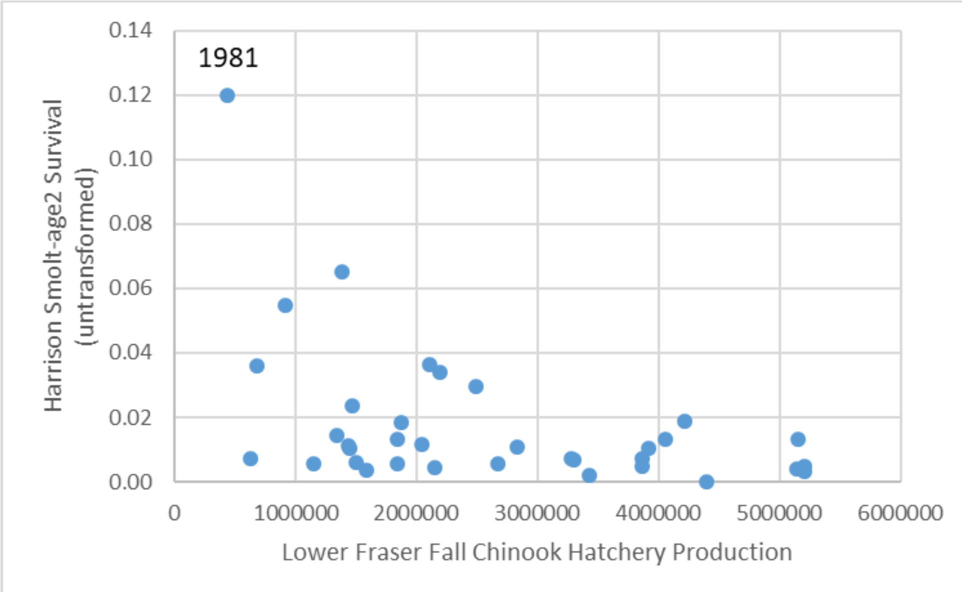
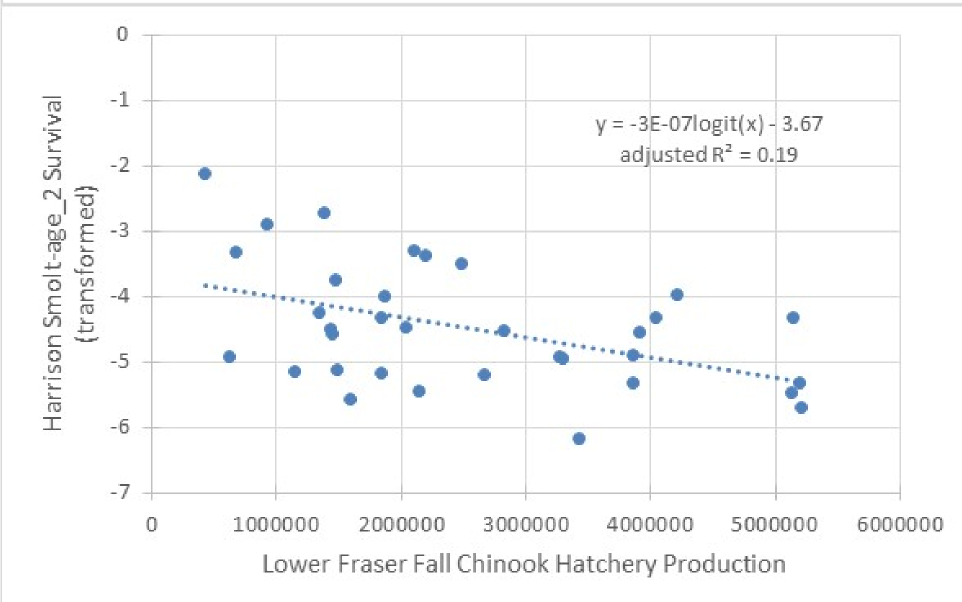


Figure G4 - Relationship between length (transformed) and weight (transformed) for Chinook fry released from southern BC hatcheries.

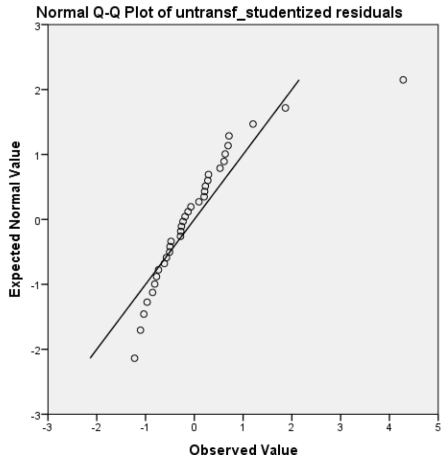


A.



B.

Figure G5 - Patterns of declining untransformed (A) and transformed (B) smolt-age_2 survival for Harrison Chinook, measured with Coded Wire Tags, and increasing hatchery production of Lower Fraser Fall Chinook, brood years 1981-2015 (excluding 2004).



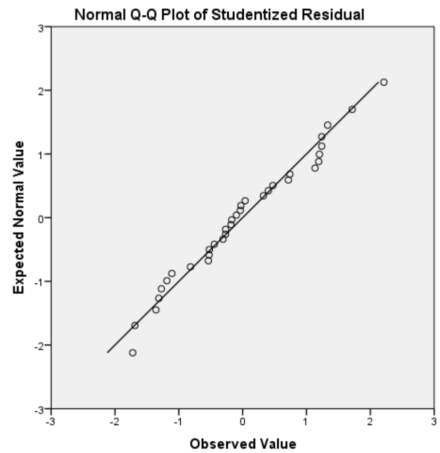
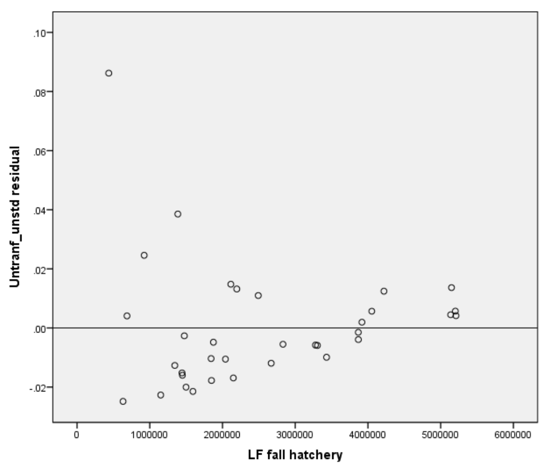


Figure G6 - Q-Q plots of standardized residuals from the models fit for untransformed (left) and logit transformed (right) Harrison survival and LFFC hatchery production.



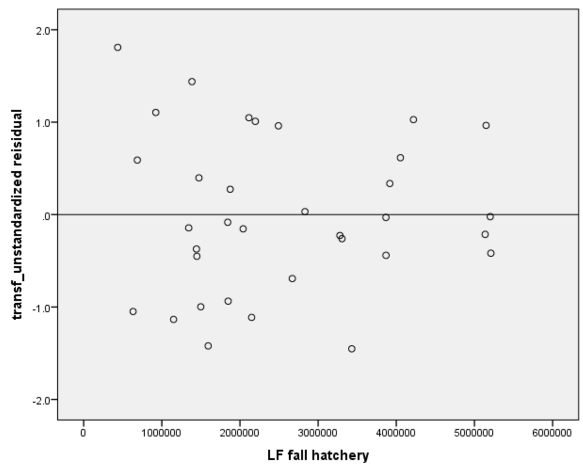


Figure G7 - Standardized residuals arranged by LFFC hatchery production from the models fit for untransformed (left) and logit transformed (right) Harrison survival and LFFC hatchery production.

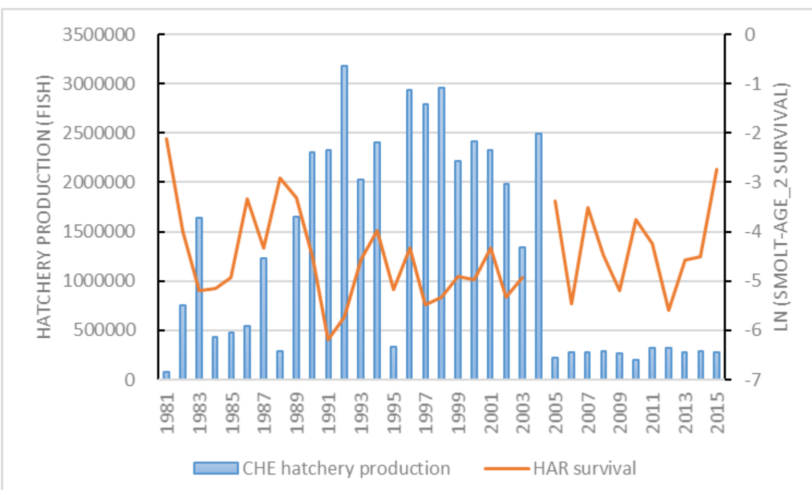


Figure G8 - Harrison smolt-age_2 survival illustrated with Chehalis Hatchery LFFC production for brood years 1981-2015.

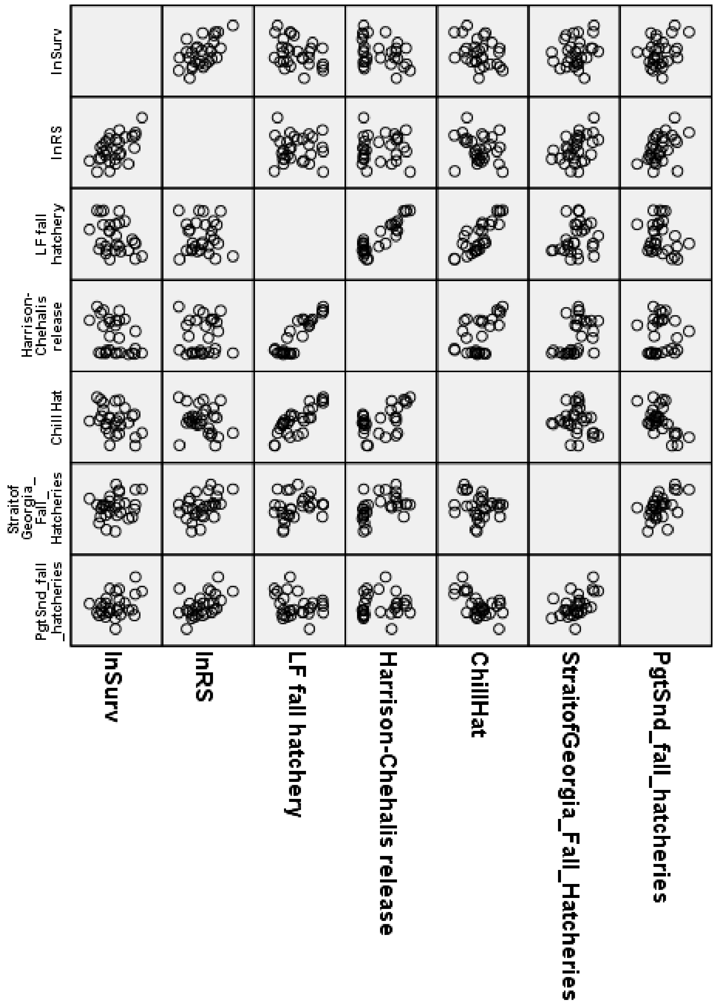


Figure G9 - Correlation matrix for Harrison smolt-age_2 survival (lnSurv), recruits per spawner for natural Harrison Chinook (lnRS), and fall Chinook production from hatcheries located in the lower Fraser, Chilliwack River, Strait of Georgia (excluding Fraser), and Puget Sound.

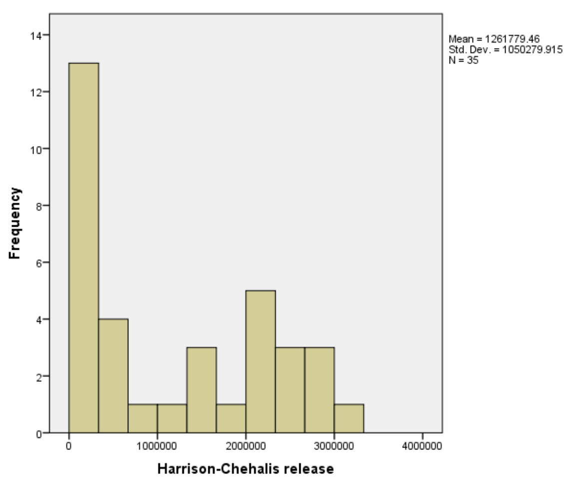


Figure G10 - Frequency distribution of fall Chinook released from the Chehalis River hatchery in Chehalis River and the Harrison River, 1981-2015.

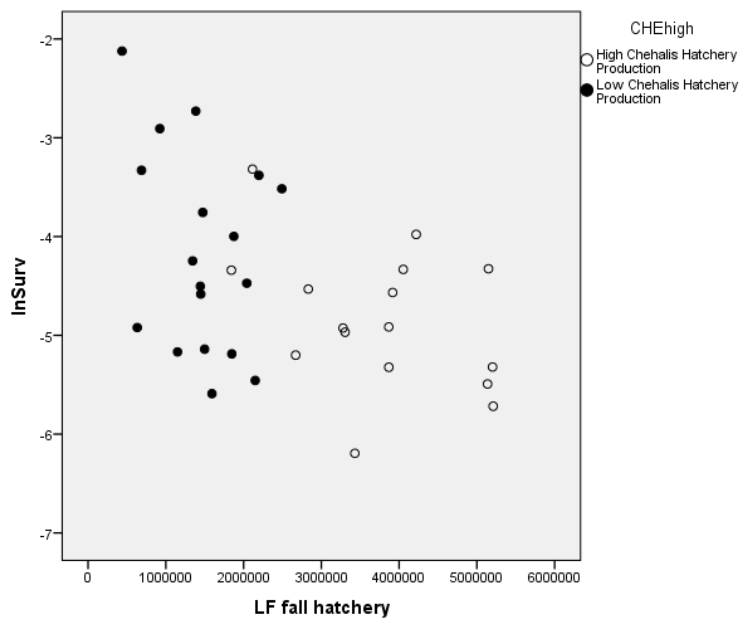


Figure G11 - Scatterplot of Harrison survival and LFFC hatchery production with years of high (open circles) and low (solid circles) production levels from Chehalis Hatchery identified.

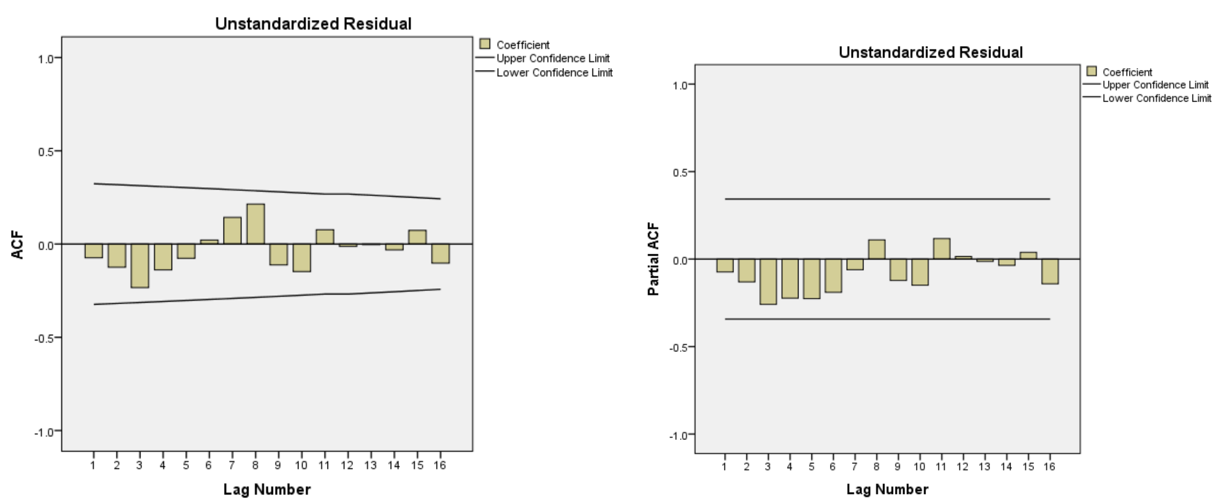


Figure G12 - ACF and PACF plots for the time series of residuals from Figure G5B.

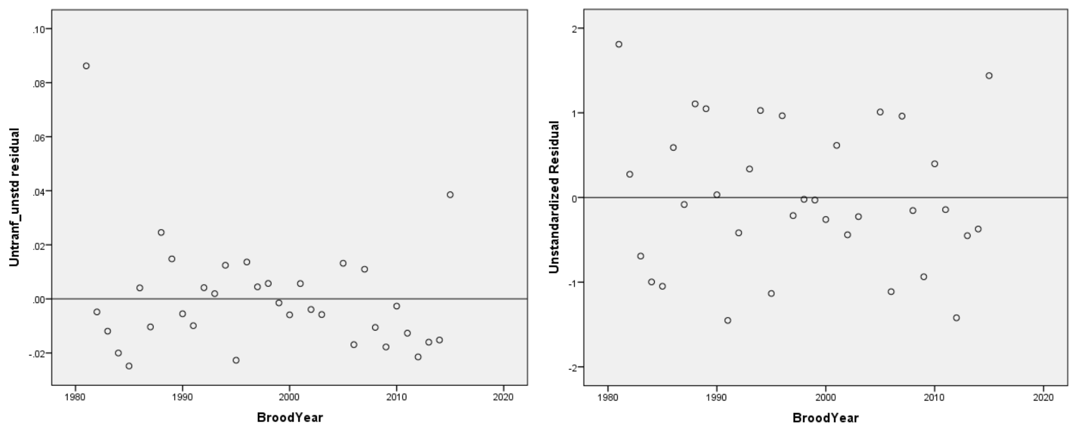


Figure G13 - Unstandardized residuals ordered temporally by brood year for the models fit for untransformed (left panel) and logit transformed (right panel) Harrison survival and LFF hatchery production.

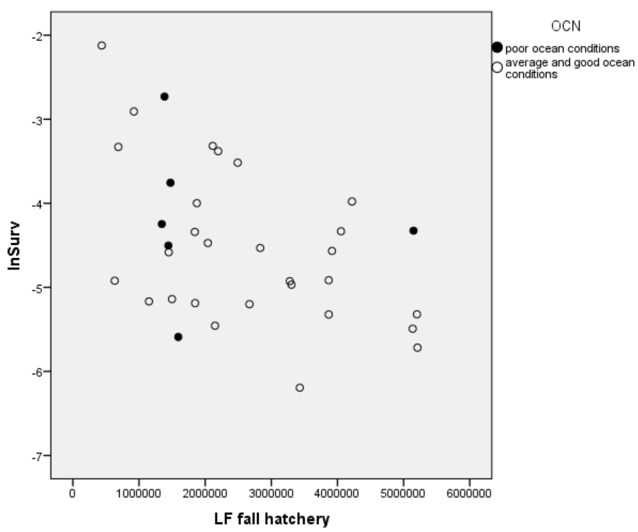


Figure G14 - Scatterplot of Harrison survival and LFFC hatchery production with Ocean Entry Years of poor ocean conditions (solid circles) distinguished from others (open circles).

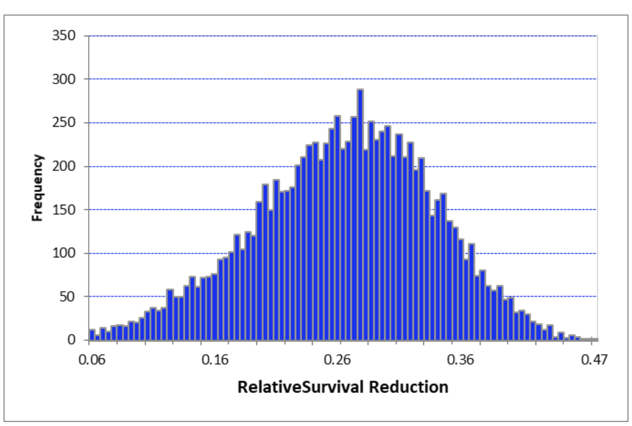


Figure G15 - Frequency distribution of the relative reduction in Harrison survival between the recent 10-year average LFFC production and the increased production of 1 million smolts.

Table G1 - Hatchery Fall Chinook Salmon smolts released at lower Fraser River locations, 1971-2016.

Release Year	Alouette R	Alouette R S	Big Silver Ch	Billy Harris Sl	Chehalis R	Chilliwack R	Coquitlam R	Grist/Maple Ch	Harrison R	McLennan Cr	Seabird Riffles	Stave R	Grand Total
1971	-	-	-	-	-	-	-	-	165,825	-	-	-	165,825
1980	-	-	-	39,298	-	-	-	-	-	-	-	-	39,298
1981	-	-	-	-	-	356,388	-	-	79,591	-	-	-	435,979
1982	-	-	-	-	683,630	1,120,729	-	-	70,138	-	-	-	1,874,497
1983	-	-	-	-	1,641,491	1,027,914	-	-	-	-	-	-	2,669,405
1984	-	-	-	-	435,227	978,395	-	-	-	-	-	85,000	1,498,622
1985	-	-	-	-	410,465	159,844	-	-	61,661	-	-	-	631,970
1986	-	-	-	-	543,355	143,217	-	-	-	-	-	-	686,572
1987	-	-	-	-	1,228,004	614,767	-	-	-	-	-	-	1,842,771
1988	-	-	-	-	290,273	632,413	-	-	-	-	-	-	922,686
1989	-	-	-	-	1,648,895	465,553	-	-	-	-	-	-	2,114,448
1990	-	-	-	-	2,299,629	531,732	-	-	-	-	-	-	2,831,361
1991	-	-	-	-	2,328,411	1,101,852	-	-	-	-	-	-	3,430,263
1992	-	-	-	-	3,184,390	2,025,267	-	-	-	-	-	-	5,209,657
1993	-	-	-	-	2,032,254	1,884,776	-	-	-	-	-	-	3,917,030
1994	-	-	-	-	2,406,890	1,613,410	-	-	-	-	-	199,223	4,219,523
1995	-	-	-	-	337,097	813,089	-	-	-	-	-	-	1,150,186
1996	-	52,593	75,000	-	2,930,980	1,905,632	10,200	-	-	-	-	174,392	5,148,797
1997	-	161,611	-	-	2,792,019	1,921,462	56,000	-	-	-	-	206,141	5,137,233
1998	-	171,828	-	-	2,957,979	1,807,651	37,091	-	-	-	-	227,046	5,201,595
1999	-	146,807	-	-	2,213,922	1,226,873	23,500	-	-	-	100,000	155,894	3,866,996
2000	-	84,794	-	-	2,414,999	624,672	58,000	-	-	-	-	122,880	3,305,345
2001	-	137,941	-	-	2,321,045	1,233,113	93,962	-	-	-	-	266,931	4,052,992
2002	-	125,000	-	-	1,986,702	1,532,064	53,800	-	-	-	-	170,216	3,867,782
2003	-	98,972	-	-	1,337,997	1,221,825	38,000	8,687	-	-	-	572,828	3,278,309
2004	-	250,933	-	-	2,491,742	1,313,736	142,244	-	-	-	-	195,201	4,393,856
2005	-	249,000	-	-	116,854	1,354,091	195,000	-	108,054	-	-	173,586	2,196,585
2006	-	201,486	-	-	72,221	1,285,371	168,500	-	206,723	-	-	214,631	2,148,932
2007	-	406,000	-	-	69,589	1,292,456	300,000	-	209,633	-	-	214,002	2,491,680
2008	-	349,800	-	-	-	1,114,112	285,456	-	291,153	-	-	-	2,040,521
2009	329,500	-	-	-	-	1,001,944	245,000	-	269,015	3,000	-	-	1,848,459
2010	50,027	76,750	-	-	-	1,030,145	122,943	-	195,332	-	-	-	1,475,197
2011	-	49,805	-	-	-	947,017	22,800	-	324,483	-	-	-	1,344,105
2012	-	83,620	-	-	-	1,135,130	50,000	-	324,003	-	-	-	1,592,753
2013	-	70,397	-	-	-	1,022,345	78,421	-	277,447	-	-	-	1,448,610
2014	-	72,822	-	-	-	1,011,688	67,176	-	291,658	-	-	-	1,443,344
2015	-	54,283	-	-	-	1,004,219	49,713	-	277,330	-	-	-	1,385,545
2016	-	66,012	-	-	-	1,038,916	75,940	-	276,215	-	-	-	1,457,083
Grand Total	**379,527**	**2,910,454**	**75,000**	**39,298**	**41,176,060**	**39,493,808**	**2,173,746**	**8,687**	**3,428,261**	**3,000**	**100,000**	**2,977,971**	**92,765,812**

Table G2 - Smolt to age-2 survival estimates for Harrison and Chilliwack rivers, with the mean weight of the CWT release groups.

Brood Year	Survival Data		Average Weight (g)	
	Harrison	Chilliwack	Harrison	Chilliwack
1981	0.11974	0.141074	1.6	5.4
1982	0.018349	0.024654	4.8	6.9
1983	0.005513	0.049935	3.0	6.1
1984	0.005857	0.070624	10.1	6.2
1985	0.007289	0.019679	11.8	5.8
1986	0.035813	0.139937	2.2	5.2
1987	0.013033	0.034305	8.6	4.2
1988	0.054617	0.146066	3.6	5.9
1989	0.036234	0.1095	10.5	5.3
1990	0.010761	0.033606	9.5	5.2
1991	0.002041	0.008759	2.4	6.2
1992	0.003288	0.029427	2.0	5.6
1993	0.010391	0.027696	1.8	5.7
1994	0.018713	0.063479	1.9	5.9
1995	0.005699	0.021419	3.3	5.6
1996	0.013221	0.091721	2.5	5.4
1997	0.004119	0.017088	2.9	5.2
1998	0.004889	0.062692	2.6	5.7
1999	0.007335	0.105744	2.9	6.2
2000	0.006956	0.084261	3.2	5.0
2001	0.013132	0.073233	3.4	5.4
2002	0.004879	0.048994	3.2	5.3

Brood Year	Survival Data		Average Weight (g)	
	Harrison	Chilliwack	Harrison	Chilliwack
2003	0.007255	0.052235	3.8	5.8
2004	No data	0.008618	No data	4.8
2005	0.034037	0.066114	5.3	5.7
2006	0.004268	0.012242	6.0	5.9
2007	0.029706	0.115814	5.3	6.3
2008	0.011424	0.059008	6.0	5.4
2009	0.005583	0.032785	5.7	5.3
2010	0.023389	0.100931	6.3	5.4
2011	0.014316	0.082567	5.9	5.1
2012	0.003733	0.044174	6.6	5.1
2013	0.010231	0.023925	5.8	4.4
2014	0.011076	0.03777	5.6	5.2
2015	0.065235	0.044653	6.1	5.5

APPENDIX H. RESOURCE MANAGEMENT FISHERIES TABLE

Table H1. List of fisheries (targeted and non-targeted) that impact Fraser River Chinook stocks.

Sector	Fished Species	Gear	Fishery Type & Area	Fishing Season Dates	Which DU is implicated?	Source for ER Info (or similar metric of impact)
Commercial	Targeted - Chinook	Troll	NBC AABM (Area F)	June 15 to September 30	All Fraser Stocks	PSC Chinook Technical Committee, Run-reconstruction, (CWT, DNA)
Commercial	Targeted - Chinook	Troll	WCVI AABM (Area G)	Year-round except March/April and June/July	All Fraser Stocks	PSC Chinook Technical Committee, Run-reconstruction, (CWT, DNA)
Commercial	Targeted - Chinook	Troll	WCVI AABM (T'aaq-wiihak)	March - September	All Fraser Stocks	PSC Chinook Technical Committee, Run-reconstruction, (CWT, DNA)
Commercial	Targeted - Chinook	Seine & Gillnet	Kamloops Lake Chinook Demonstration Fishery	August and September	DU16 BC North Thompson Stream Spring	PSC Chinook Technical Committee, Run-reconstruction, (CWT, DNA)
Commercial	Bycatch - Sockeye	Troll	WCVI (Area G)	July-September	All Fraser Stocks	Unknown - often occurs with non-retention Chinook. Total mortality accounting with CTC?
Commercial	Bycatch - Sockeye	Troll	WCVI (T'aaq-wiihak)	July-September	All Fraser Stocks	Unknown - often occurs with non-retention Chinook. Total mortality accounting with CTC?
Commercial	Bycatch - Sockeye	Troll	Fraser sockeye JST fisheries	June-September	All Fraser Stocks	Unknown - fishery only occurs with non-retention Chinook
Commercial	Bycatch - Sockeye	Seine & Gillnet	Fraser sockeye JST fisheries	July to Sept	All Fraser Stocks	Unknown - fishery only occurs with non- retention Chinook
Commercial	Bycatch - Pink	Seine & Gillnet	Fraser Pink JST Fisheries	Aug to Sept	All Fraser Stocks	Unknown - fishery only occurs with non- retention Chinook
Commercial	Bycatch - Chum	Seine & Gillnet	JST Mixed Stock Chum fisheries (terminal Chum fisheries MVI & SEVI)	October (to November)	All Fraser Stocks	Unknown - fishery only occurs with non- retention Chinook
FSC	Targeted - Chinook Bycatch - Sockeye	Various	South Coast	Based on fishing events reported 2016-2018: May to September (Chinook catches) April to November (salmon catches)	Unknown and dependent on fishing area. Expected to be primarily South Coast stocks, with co-migration of Fraser, US and other passing stocks.	Unknown, more data required.
FSC	Targeted - Chinook	Various	Lower Fraser	April 1 to Oct. 1	All Fraser Stocks	Unknown, more data required.
FSC	Targeted - Chinook	Various	BC Interior - d/s of Thompson Confluence	April 1 to Oct. 1	All except DU4 - Lower Fraser Stream Type and DU2 BC Lower Fraser River Ocean Fall	Unknown, more data required.

Sector	Fished Species	Gear	Fishery Type & Area	Fishing Season Dates	Which DU is implicated?	Source for ER Info (or similar metric of impact)
FSC	Targeted - Chinook	Various	BC Interior - u/s of Thompson Confluence Note: the only Chinook in the area are Spring 5_2 and Summer 5_2.	June 1 to October 31	DU9 BC Middle Fraser River Stream Spring DU11 BC Upper Fraser River Stream Spring DU10 BC Middle Fraser River Stream Summer	Five year review.
Recreational	Targeted - Chinook	Hook & Line	NBC AABM	Year round, but effort primarily between May-September	All Fraser Stocks	PSC Chinook Technical Committee, Run-reconstruction, (CWT, DNA)
Recreational	Targeted - Chinook	Hook & Line	NBC ISBM	Year round, but effort primarily between May-September	All Fraser Stocks	PSC Chinook Technical Committee, Run-reconstruction, (CWT, DNA)

APPENDIX I. ESTIMATION OF A SUSTAINABLE EXPLOITATION RATE FOR DU2

I.1. ESTIMATION OF A SUSTAINABLE EXPLOITATION RATE FOR DU2 – HARRISON RIVER CHINOOK

These analyses were conducted by Catarina Wor, Antonio Velez-Espino, and Brooke Davis for the Pacific Salmon Treaty's Chinook Technical Committee (PSC CTC). Summary written by Brittany Jenewein and reviewed by the biologists noted above.

I.2. OBJECTIVE

Two versions of a stock-recruit model were developed to provide estimates of stock and recruitment parameters for DU2 – Lower Fraser River Ocean Fall. This work was originally assigned by the PSC CTC with the objectives of exploring recruitment dynamics of the stock and providing estimates for use in the Viability and Risk Assessment Procedure (VRAP) simulation tool. This Appendix is designed to detail the model forms and present results only on the estimates of the exploitation rate that would produce maximum sustainable yield (U_{MSY}); Further description will be made available at a later date.

I.3. DATA AND MODELS

This analysis was conducted using spawner and recruit data of Harrison River Chinook Salmon from 1984 to 2013.

The two versions of the model used are based on the Ricker curve: a standard form of the Ricker model and a recursive Bayes model with time-varying productivity. All models were fit using R (R Development Core Team 2008) and TMB software (Kristensen et al. 2016). Models were fit to data using Bayesian procedures, but priors for all the estimated parameters or derived quantities were not explicitly considered except for the hyper-parameters of the recursive Bayes version (ρ). For the other parameters, bounds were placed on the estimable parameters, which is comparable to using uniform priors. All Bayesian posteriors were based on 100,000 iterations and three MCMC chains. A burn-in period of 50,000 iterations was used and convergence was evaluated with visual inspection of standard diagnostic plots available for the package tmbstan.

The traditional linear formulation of the Ricker function was used for the first model:

$$R_t = S_t * \ a \quad * e^{(-b \cdot S_t + \omega_t)}$$
$$log \frac{R_t}{S_t} = \log a \quad - b * S_t + \omega_t$$
$$\alpha = e^{a_t}$$
$$S_{max} = \frac{1}{b}$$
$$\omega_t \sim N(0, \sigma_R)$$

The model fit is shown in Figure I1. Estimates of U_{MSY} are shown in Table I1 and were based on the equation provided by Hilborn and Walters (1992):

$$U_{MSY} = 0.5 * \log a - 0.07 * (\log a)^2$$

The second model, a recursive Bayes Ricker model for time-varying productivity, is nearly identical to the above formulation for the standard Ricker curve except the variability in the parameter α is given by a recursive Bayes function in which:

$$\begin{cases} a_t = a_0 + v_0 & t = 0 \\ a_t = a_{t-1} + v_1 & t > 0 \end{cases}$$

$$v_t \sim N(0, \sigma_v)$$

The model's observation (σ_R) and process (σ_v) standard errors were partitioned as follows:

$$\sigma_R = \sqrt{\rho} * \sigma_\theta$$

$$\sigma_v = \sqrt{1 - \rho} * \sigma_\theta$$

where ρ is the proportion of total variance associated with observation error, and σ_θ is the total standard deviation. An informative prior was included on the ρ parameter. The results presented here originated from a model definition with an informative prior on ρ centered around 0.5 (Beta(3,3)). The model fit is shown in Figure I1. Estimates of U_{MSY} are given in Table C1.

I.4. SUSTAINABLE EXPLOITATION RATE

It is expected the second model provides a more accurate estimate of current U_{MSY} than the standard Ricker model because the productivity cycles seem to be more in line with the observed time series. Because of this, the median value of 0.16 estimated for 2013 was subsequently used as a reference when discussing the potential future threat from fishing during the Threat Workshop that was part of this Recovery Potential Assessment.

I.5. UNCERTAINTY

The recursive model results are sensitive to the prior used for the ρ parameter, meaning it may influence the magnitude of the changes in the productivity parameter (α), so choice of prior is important. Sensitivity analyses (not presented here) show that alternative prior assumptions lead to more or less error being allocated to the process error (σ_v) and consequently, alter the magnitude of the changes in both α and U_{MSY} over time. However, the general trend of declining productivity and sustainable harvest rate does not appear to change under a variety of values for the ρ parameter. The use of proper priors might improve the estimates and confidence bounds around both α and U_{MSY}.

I.6. REFERENCES

Hilborn, R. and Walters, C. J. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty/Book and Disk. Springer Science & Business Media.

Kristensen, K., Nielsen, A., Berg, C. W., Skaug, H., and Bell, B. M. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software, 70(5):1–21.

R Development Core Team (2008). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

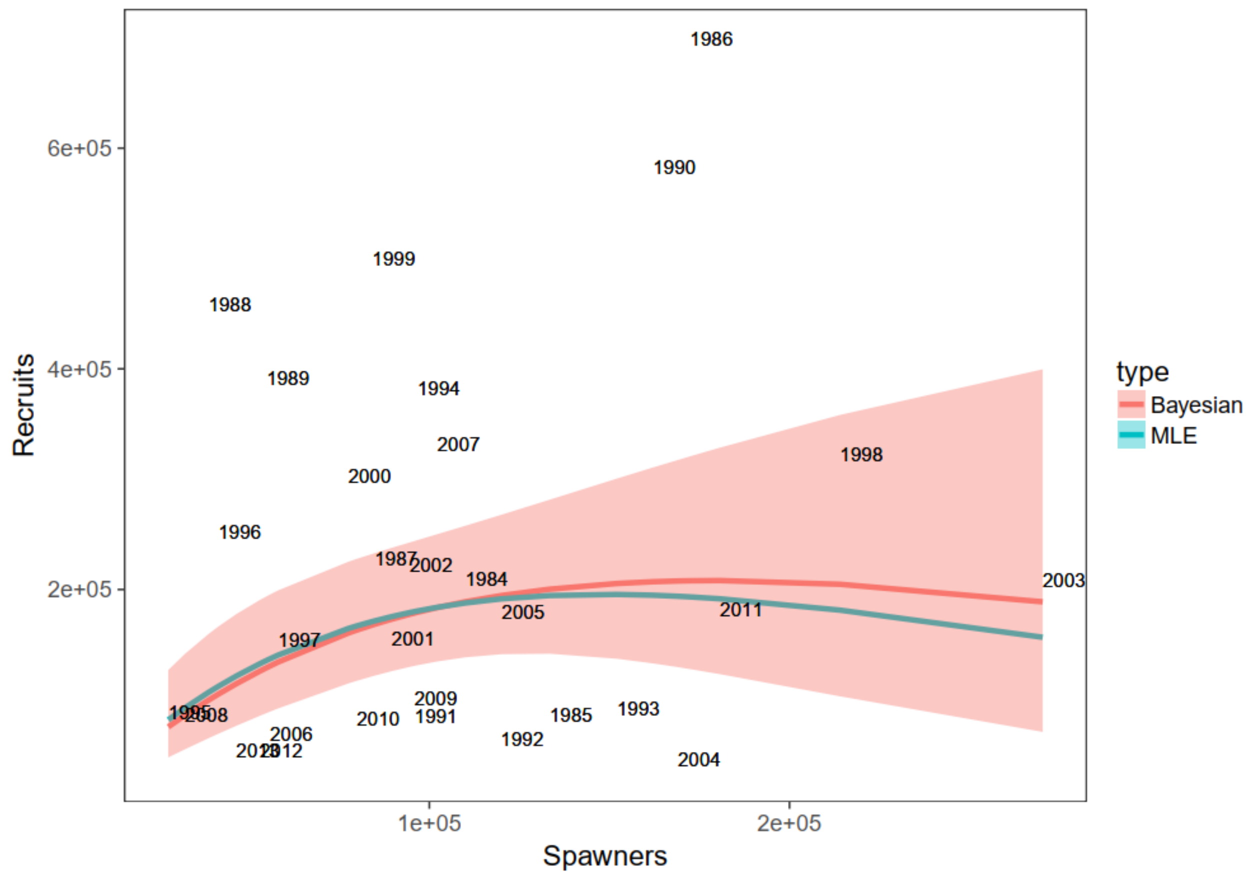


Figure I1. Traditional Ricker model fit for DU2 – Lower Fraser River Ocean Fall. Individual observations are represented by the years text on the graph. Maximum likelihood estimates (MLE) are shown in blue and Bayesian median and 95% credible intervals are shown in red.

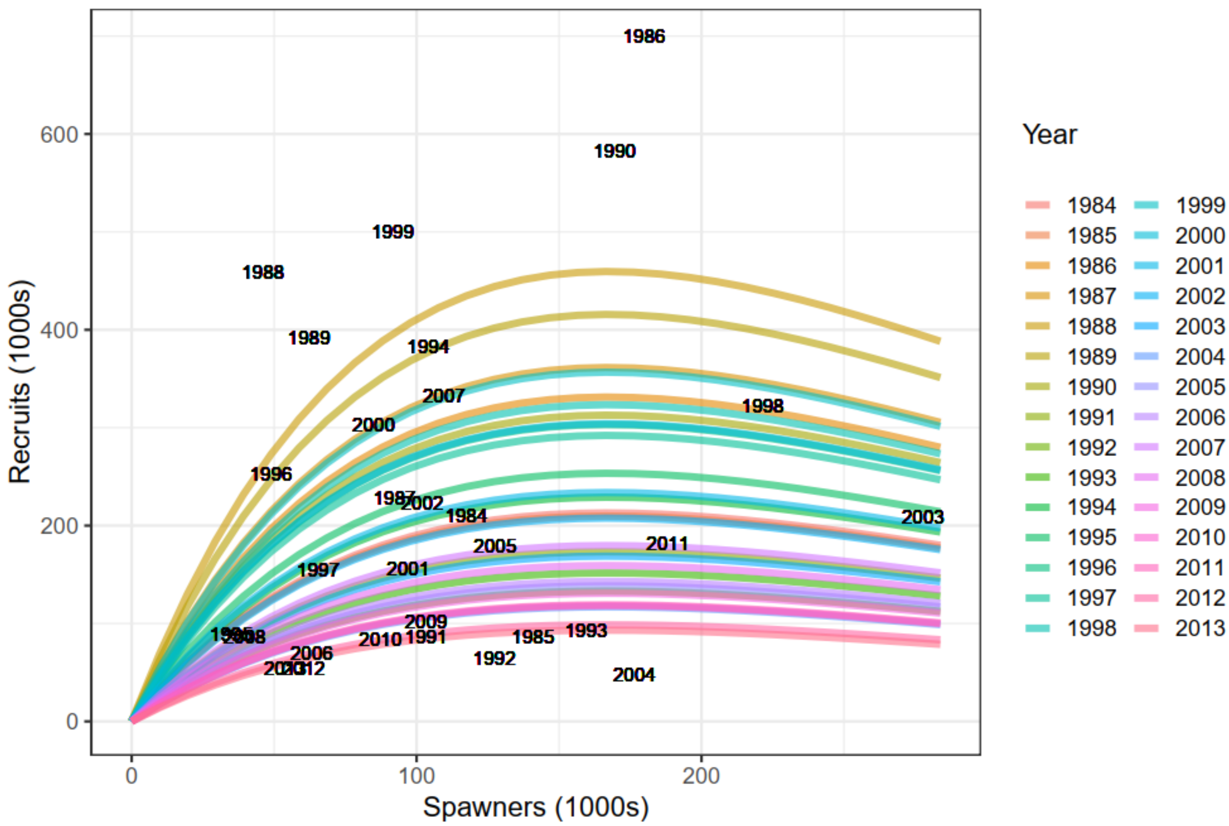


Figure I2. Recursive Bayes Ricker model for DU2 - Lower Fraser River Ocean Fall. Colours indicate predicted values using year-specific α parameters. Individual observations are represented by the years text on the graph.

Table I1. Estimates of U_{MSY} from the traditional Ricker model fit.

MLE	Median	Lower	Upper
0.52	0.49	0.28	0.68

Table I2. Estimates of U_{MSY} from the recursive Bayes Ricker model fit.

Year	MLE	Median	Lower	Upper
1984	0.51	0.48	0.13	0.75
1985	0.51	0.44	0.02	0.73
1986	0.64	0.62	0.34	0.82
1987	0.67	0.64	0.38	0.81
1988	0.72	0.72	0.49	0.86
1989	0.70	0.70	0.45	0.84
1990	0.63	0.61	0.33	0.80
1991	0.44	0.38	-0.03	0.68
1992	0.34	0.26	-0.25	0.62
1993	0.39	0.33	-0.12	0.65
1994	0.54	0.52	0.22	0.74
1995	0.57	0.55	0.28	0.75
1996	0.62	0.61	0.36	0.79
1997	0.61	0.58	0.30	0.77
1998	0.64	0.60	0.30	0.80
1999	0.66	0.65	0.38	0.82
2000	0.62	0.60	0.32	0.79
2001	0.54	0.50	0.18	0.74
2002	0.50	0.47	0.12	0.73
2003	0.43	0.37	-0.08	0.70
2004	0.29	0.19	-0.39	0.59
2005	0.36	0.31	-0.09	0.62
2006	0.37	0.33	-0.03	0.61
2007	0.46	0.45	0.12	0.69
2008	0.41	0.40	0.07	0.65
2009	0.34	0.30	-0.07	0.59
2010	0.30	0.25	-0.14	0.56
2011	0.30	0.26	-0.14	0.58
2012	0.22	0.18	-0.23	0.51
2013	0.20	0.16	-0.30	0.52