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Recovery Potential Assessment for Southern British Columbian Chinook Populations, Fraser and Southern Mainland Chinook Designatable Units (1, 6, 13 and 15)

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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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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Four Southern British Columbian Chinook Salmon (SBCC) (*Oncorhynchus tshawytscha*) Designatable Units (DU) were assessed as Threatened or Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2020 and are currently under consideration for addition to Schedule 1 of the *Species at Risk Act* (SARA). The first half of the Recovery Potential Assessment (RPA) (Elements 1-11) first 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. All four DUs are considered to be at an extreme threat risk due to the severity and number of threats these DUs are facing. Based on the assessed threats, a population level decline of 71% to 100% is expected for DUs 1, 6, 13 and 15. Alleviating the multiple and complex threats to these DUs will be difficult, especially as many of the threats are exacerbated by climate change. The second half (Elements 12-22) provides potential recovery targets, a discussion of mitigation measures, population projections and a recommendation of allowable harm. Survival and recovery targets for each DU were suggested based on Wild Salmon Policy (WSP) benchmarks, with additional requirements about observed percent change in spawners. Data limitations from incomplete escapement coverage and unknown hatchery influences prevented many quantitative assessments and no modelling was completed. The risks imposed by climate change and continued anthropogenic development add additional uncertainty that was only described qualitatively. Based on the qualitative assessment for all four DUs, further harm may continue to jeopardize recovery. Therefore, to promote the survival and recovery of these DUs, it is recommended that all future and ongoing human-induced harm should be prevented so as not to jeopardize recovery**.** It is important to note that some activities in support of survival or recovery could result in harm but may have a net positive effect on the population and should be considered.

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 2020).

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 2020). 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 2020); 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 (2020) and Brown et al. (2019), respectively.

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

[1] Vedan, A. 2002. Traditional Okanagan Environmental Knowledge and Fisheries Management. Westbank, BC.

Boundary Bay drainages (see COSEWIC 2020 for detailed description of SBCC 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 SBCC DUs are provided in Table 2, which will be used to refer to DUs throughout the document.

Table 1. Southern British Columbian Chinook (SBCC) Salmon Designatable Units (DU) and COSEWIC status (2020).

Management Unit (MU)	Conservation Unit (CU)	Designatable Unit (DU)	COSEWIC Status	Reasoning for Status
Spring 4_2	CK-17 Lower Thompson	DU15 – Lower Thompson Stream Spring	Endangered	From 2013-2018, the number of mature individuals steeply declined and marine survival has been low since 2000. Deforestation, wildfires, habitat destabilization, agricultural water withdrawal and climate change induced disruption to water quality are continuing threats to this population and exacerbated by a relatively long freshwater residence.
Spring 5_2	CK-14 South Thompson 1.3	DU13 – South Thompson Stream Summer 1.3	Endangered	This summer run of Chinook has declined and is projected to continue declining. Water levels, agricultural runoff, pollution, and modified freshwater habitats are continuing threats to this population and are emphasized due to a relatively long freshwater residence.
Summer 4_1	CK-07 Maria	DU6 – Lower Fraser River Ocean Summer (Maria Slough)	Endangered	This summer run of Chinook spawning at a single site (Maria Slough) has declined. In 2018, failed water control structures and low water levels prevented spawners from accessing the spawning site. Declines in water quality and quantity and freshwater and marine habitat quality are continuing threats to this population.
-	CK-02 Boundary Bay	DU1 – Boundary Bay Ocean Fall	Threatened	Hatchery releases, which are ongoing and have included fish from other populations, have allowed the total population size to increase while threatening the genetic integrity of the remaining wild fish. This fall run of Chinook spawning in Boundary Bay drainages occurs in highly altered marine and freshwater habitats. Persistent low abundances, low marine survival, bycatch, and fish culture effects are continuing threats to this population.

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

DU	CU	MU	DU Full Name	DU Short Name
DU1	CK-02	Fall	Southern Mainland - Boundary Bay Ocean Fall	BB
DU6	CK-07	Summer	Lower Fraser River Ocean Summer (Maria)	Maria
DU13	CK-14	Summer	South Thompson Stream Summer 1.3	STh-1.3
DU15	CK-17	Spring	Lower Thompson Stream Spring 1.2	LTh-1.2

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 Southern British Columbian 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 2020, COSEWIC assessed the status of 12 of 28 Chinook Salmon DUs in southern BC (COSEWIC 2020). These DUs were considered to have received artificial supplementation over the past three generations or were previously considered by DFO to have insufficient data for assessment. This latest assessment led to the status assignment of 4 DUs as *Endangered*, 3 as *Threatened*, 1 as *of Special Concern,* and 1 as *Not at Risk*, while three DUs were deemed to have insufficient data for assessment. Prior to this COSEWIC assessment (COSEWIC 2020), the remaining 16 of 28 Southern British Columbian DUs and the Okanagan DU were evaluated (COSEWIC 2017). All 16 DUs considered to have received little to no artificial supplementation over the last three generations were segregated from the 12 DUs in this COSEWIC assessment (COSEWIC 2020).

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 four DUs of Chinook Salmon that spawn in Southern British Columbia, all of which have been designated as either *Threatened* or *Endangered* by COSEWIC (2020); the remaining eight DUs from this latest COSEWIC assessment are addressed in a separate RPA. Specifically, this report addresses the 22 elements outlined in the Terms of Reference for completion of RPAs for Aquatic Species at Risk (DFO 2014a), which includes:

- summaries of SBCC biology, abundance, distribution and life history parameters (Element 1-3)
- descriptions of SBCC 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 SBCC (Element 8-11)
- proposed recovery targets for SBCC 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 Fraser River and Boundary Bay Chinook stocks. A summary of general biological knowledge for Chinook Salmon is reported here, and information specific to the four DUs is identified and presented when possible.

2.1.1. Morphology

The 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 SBCC throughout the entire Fraser River and Boundary Bay drainages. 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. A series of eastward-draining glacial lakes was formed from melting ice sheets across the Nicola and Thompson watersheds (Mathews 1944). An enlarged Nicola Lake drained eastward down the Salmon River and then into the Okanagan watershed. A body of water known as Lake Thompson reached from the Deadman River, up the North Thompson and extending to the South Thompson valleys where an ice-covered Shuswap Lake diverted water southward (Mathews 1944). 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. Fish presumably migrated through postglacial lake connections in the Okanagan-Nicola areas and across lower elevations between the Columbia and Eagle Rivers into the Shuswap system (McPhail and Lindsey 1986; Northcote and Larkin 1989). The Fraser lowland has a complex history involving marine and non-marine, glacial and non-glacial deposition. Its Serpentine-Nicomekl basin is a flat-bottomed valley that was covered with 2300m of ice during past glaciations which depressed the land (Holland 1976) and formed headwaters on a 100m high moraine on the north side of the valley[2].

Multiple colonization events throughout the glaciation history of the contemporary Fraser River watershed and Boundary Bay rivers led to unique groups of SBCC populations (organized into CUs and DUs) within the Fraser watershed that do not readily interbreed. The presence of genetically distinct SBCC populations in the lower Fraser River watershed (downstream of Hells Gate) and Boundary Bay rivers 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 SBCC 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).

2.1.2.1 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 (Brannon et al. 2004; 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 et al. 1957; Healey and Jordan 1982).

There is also considerable variation in the time of year when sexually mature Chinook Salmon 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 SBCC 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

[2] Cox, B. and McFarlane, S. 1978. Fish and wildlife resources of the Serpentine-Nicomekl watershed. MOE.

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 Columbian Chinook Salmon (Parken et al. 2008). Adult run timing for SBCC 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 SBCC 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	DU15 LTh-Spring
Summer	≥ 50% of the spawners pass through the lower Fraser River between July 15th and August 31st	DU6 LFR-Summer (Maria) DU13 STh-Summer
Fall	≥ 50% of the spawners pass through the Little Campbell River fence after August 31st	DU1 Boundary Bay-Fall

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[3]). 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). 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 ≈ 300mg). 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

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

particles depending on gravel size (Diewart 2007[4]). 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 et al. 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 et al. 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

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

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). Genetics, environmental factors and fishing pressure 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 et al. 1979; Levy et al. 1979). 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 favor 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 72cm 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 et al. 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 Populations

The four DUs in this report are distributed throughout the Lower Mainland (DUs 1 (BB) and 6 (Maria)) and the Thompson River basin (DUs 13 (STh-1.3) and 15 (LTh-1.2)). Each of these DUs correspond to a single CU, and hence there are no COSEWIC-recognized sub-populations. DU6 has a single spawning site, while the rest of the DUs spawn in multiple systems.

COSEWIC (2020) reported an Index of Area of Occupancy (IAO) for SBCC DUs based on the distribution of spawning areas using a 2x2km 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 SBCC (Porter et al. 2013). There is some error associated with the values reported in Table 4 for DUs 13 and 15 (STh-1.3 and LTh-1.2) as they have large geographical distributions and several systems within each DU do not have dedicated escapement programs. DU1 (BB) also lacks a dedicated escapement program for two of the three systems and total stream area may be inaccurate due to limited data about spawning grounds. Estimation of IAO for Maria does not carry the same error as this DU spawns in a single known location. Table 5 lists persistent spawning streams used for trend analysis within each DU but does not necessarily contain all SBCC-bearing streams within that DU.

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

DU	Data Quality	Index of Area Occupancy (km^2)	Stream length (km)	% of total stream length of all SBCC DUs
DU1 SM-Boundary Bay	Relative Abundance	157	78	0.76
DU6 LFR-Summer (Maria)	Relative Abundance	30	15	0.15
DU13 STh-Summer 1.3	Relative Abundance	424	212	2.11
DU15 LTh-Spring 1.2	Relative Abundance	1330	665	6.61

Table 5. List of persistent spawning sites for each SBCC DU, with the CU number for additional reference. All sites without an asterisk were used in the trend analyses.

DU	DU Name	CU	Stream Name(s)	
DU1	Boundary Bay Ocean Fall	CK-02	Little Campbell River	
			Nicomekl River*	
			Serpentine River*	
DU6	Lower Fraser Ocean Summer - Maria	CK-07	Maria Slough	
DU13	South Thompson Stream Summer 1.3	CK-14	Eagle R	Scotch Cr*
			Salmon R	Seymour R*
DU15	Lower Thompson	CK-17	Bonaparte R	Nicola R
			Coldwater R	Spius Cr
			Deadman R	Louis Cr

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 2018, 2019 and 2020 for DU6 (Maria), and 2019 and 2020 for the other DUs. A brief review of the data treatment process is provided below. Additional details of the process can be found in the COSEWIC report (COSEWIC 2020). Any differences in the data treatment methods between the COSEWIC report and those used for the RPA will be described below.

Annual escapement estimates for several populations within these SBCC DUs are not regularly assessed, and as such all escapement estimates presented in this report are relative abundance. Three of the four DUs assessed in this report consist of multiple populations with varying levels escapement data quality, and in many cases not all spawning areas are surveyed within a DU. DU6 (Maria) consists of a single spawning location, where some escapement estimates are based on fence counts and others on visual surveys, which do not provide absolute abundance estimates, and are not conducted each year. This results in an incomplete time series of relative escapement for this DU.

Escapement estimates exist in most systems prior to the start of the time series presented in this report, but were excluded after 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. Time series datasets begin in 1980 for DU1 (BB), 1995 for DU15 (LTh-1.2), 1996 for DU6 (Maria), and 1999 for DU13 (STh-1.3). Time series lengths differ due to changes in data collection through time between DUs. For example, the time series for DU1 begins in 1980 due to the escapement from the counting fence located in the Little Campbell River operating since 1980, while the time series for DU15 begins in 1995 as data quality and consistency increased at this time. Data quality and consistency did not improve until 1999 for DU13 and until 1996 for DU6. 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).

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).

Rates of change in spawner escapement over time were calculated using a maximum likelihood estimation framework using generalized least squares regression with a first order autocorrelation to account for temporal autocorrelation between years. The slopes of each regression were then converted to percent change in abundance using the slope of the best fit regression line. The regressions were completed using the nlme package in R (Pinheiro 2021; R Core Team 2021).

The long and short term trends in spawner abundance for DU1 (BB) are highly positive for both the COSEWIC report and this analysis, with the trends becoming even more positive with the addition of the past two years of data. However, external marking of hatchery released Chinook in the Little Campbell River (LCR) ceased since 2014, which no longer allows hatchery and wild Chinook to be separated during counting at the LCR fence (Tyler Thibault, DFO Pacific, Delta, BC, pers. comm.). The inability to separate wild from hatchery fish likely leads to a substantial overestimate for this DU due to the volume of releases of hatchery smolts to this location. In addition to the Little Campbell hatchery fish, adipose clipped Chinook have been regularly appearing at the fence since 2012. The origin of these fish is unknown, but they are strays from another population and, as such, were removed from the time series. The long term trend for DU6 (Maria) remains positive with the addition of the next three years of data (2018 – 2020), but the rate of increase is smaller with the updated data. The change in magnitude of the positive trend is likely driven by two of the three years exhibiting near zero escapement estimates due to declining productivity and access issues to the spawning ground which will be discussed in subsequent sections. The trend in abundance for the past three generations for DU6 is strongly negative for both the COSEWIC report and this analysis. Trends in spawner abundance for DU13 (STh-1.3) are negative over the entire data series and over three generations, but the recent trend has decreased in the magnitude of decline. This can be attributed to several years of fairly stable escapements of between 1000 and 1500 adults, with the additional years of data included in the analysis. The recent trend for DU15 (LTh-1.2) has changed from positive to slightly negative with the additional years of data and the long term trend has become increasingly negative.

When considering the trends presented in this report, it is imperative to remember that all of the abundance estimates are relative abundances, not absolute abundances. Thus, the trend represents partial counts from only a portion of the spawning systems in that DU with the exception of DU6 (Maria). DU6 abundance estimates cover the whole spawning area but are considered relative escapements that rely on moderate quality survey methods. While accurate estimates of spawner abundance are available for DU1 from the Little Campbell River fence, this represents only one system, as the Nicomekl and Serpentine rivers do not have escapement monitoring programs. In the case of DU13 and DU15 (STh-1.3 and LTh-1.2), the trends are largely based on counts from a few systems in a vast area. It should also be noted that the trends presented for DU13 for this report represent the change in abundance of both hatchery and wild Chinook while the COSEWIC report presented the trends for the wild population. While data exist to adjust for hatchery influence for some populations within this DU, hatchery status is determined through examination of clip status via visual surveys at a counting fence and there is a component of hatchery releases that are unmarked. The trends in spawning abundance for these DUs are uncertain due to the lack of data for the other systems 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. As such, the trends may indicate DU-level population trajectories but are subject to considerable uncertainty.

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 percent change based on the trend over the last three generations and the whole time series. The previous calculations from the COSEWIC report are also included in the tables for comparison.

2.2.2.1 DU1 – Boundary Bay Ocean Fall

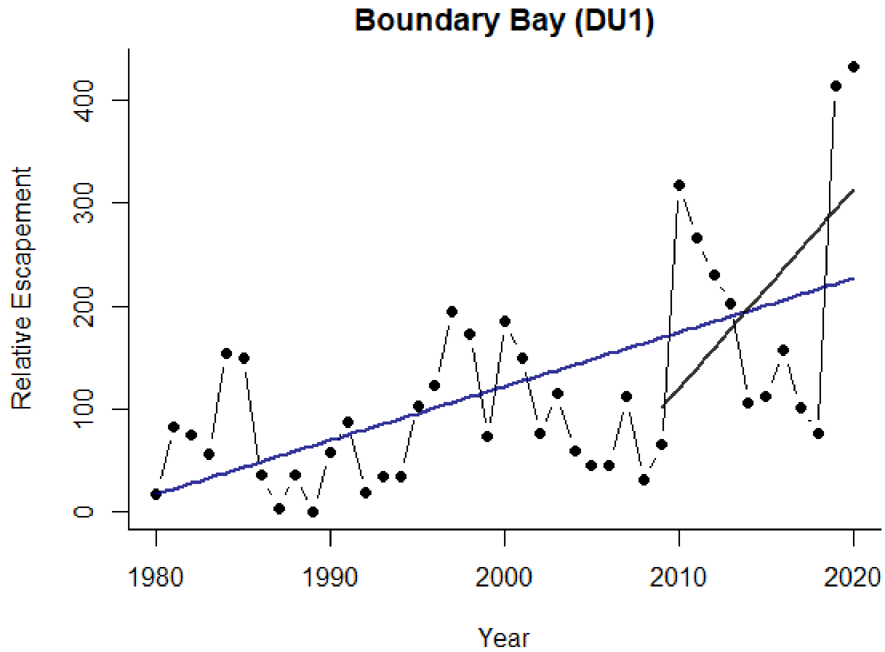

Figure 1. DU1 Boundary Bay: time series of absolute escapement from 1980 to 2020 with two estimates of the rate of change in escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (black) (2) rate of change over the last three generations based on all available data (blue).

Table 6. Summary of estimated rate of change in spawner abundance over the last three generations 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	Hatchery, Wild or Both	Report	Time Series Length	Years	Average % Change	95% CI
DU1	SM-Boundary Bay	Both	COSEWIC	3 Gens	2007-2018	121	-57, 960
				All Years	1980-2018	387	90,1148
		Both	RPA	3 Gens	2009-2020	210	-40, 1296
				All Years	1980-2020	632	67, 1187

2.2.2.2 DU6 – Lower Fraser River Ocean Summer (Maria)

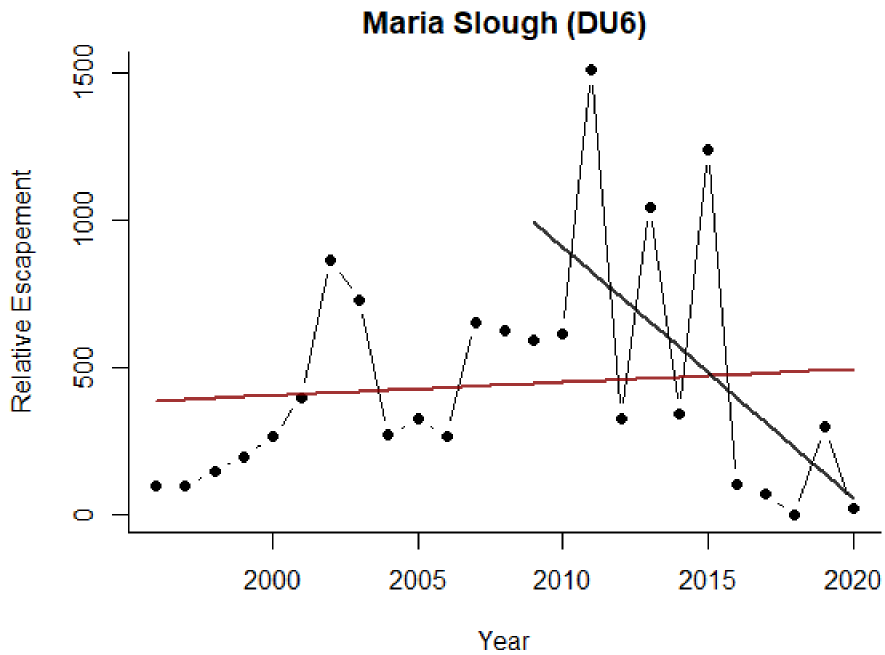

Figure 2. DU6 LFR-Maria: time series of relative escapement from 1996 to 2020 with two estimates of the rate of change in escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (black) (2) rate of change over the last three generations based on all available data (red).

Table 7. Summary of estimated rate of change in spawner abundance over the last three generations 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	Hatchery, Wild or Both	Report	Time Series Length	Years	Average % Change	95% CI
DU6	LFR – Maria	Both	COSEWIC	3 Gens	2006-2017	-71	-95, 95
				All Years	1996-2017	77	-56, 620
		Both	RPA	3 Gens	2009-2020	-94	-117, -52
				All Years	1996-2020	26	-73, 904

2.2.2.3 DU13 – South Thompson Stream Summer

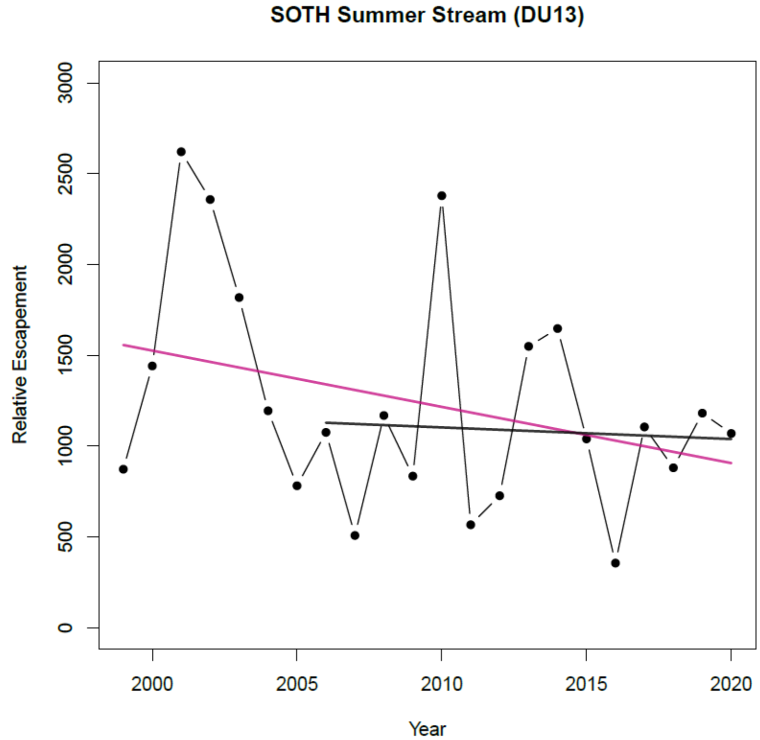

Figure 3. DU13 STh-Summer 1.3: time series of relative escapement from 1999 to 2020 with an estimate of the rate of change in escapement through time over the last three generations (black) and based on all available data (pink).

Table 8. Summary of estimated rate of change in spawner abundance over the last three generations 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	Hatchery, Wild or Both	Report	Time Series Length	Years	Average % Change	95% CI
DU13	STh-1.3	Wild	COSEWIC	3 Gens	2004-2018	-22	-67, 90
				All Years	1999-2018	-9	-58, 93
		Both	RPA	3 Gens	2006-2020	-9	-93, 1032
				All Years	1999-2020	-42	-79, 30

2.2.2.4 DU15 – Lower Thompson Stream Spring

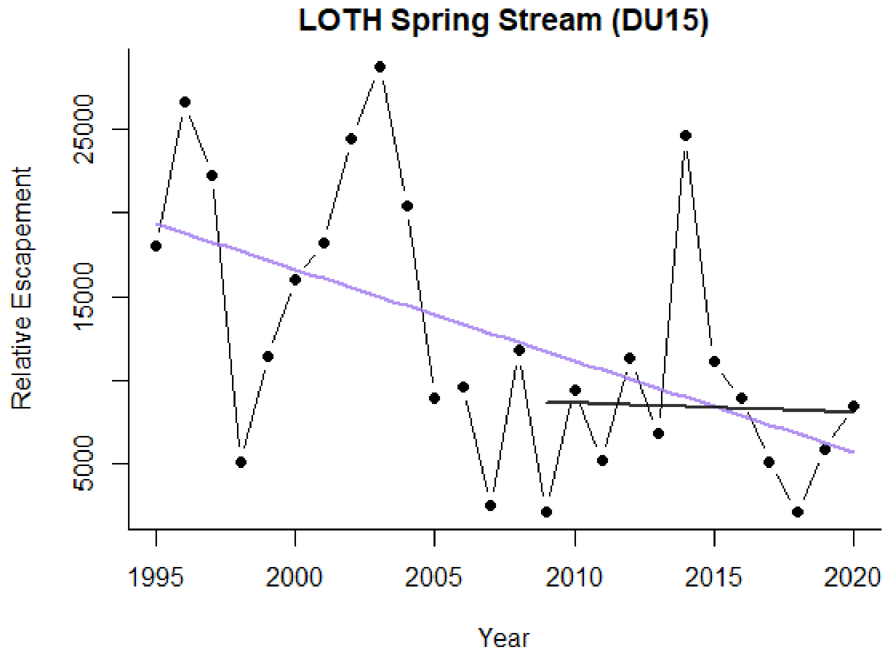

Figure 4. DU15 LTh-Stream Spring 1.2: time series of relative escapement from 1995 to 2020 with two estimates of the rate of change in escapement through time: (1) rate of change over the last three generations based only on the last three generations of data (black) (2) rate of change over the last three generations based on all available data (purple).

Table 9. Summary of estimated rate of change in spawner abundance over the last three generations 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	Hatchery, Wild or Both	Report	Time Series Length	Years	Average % Change	95% CI
DU15	LTh – 1.2	Both	COSEWIC	3 Gens	2006-2018	47	-69, 585
				All Years	1995-2018	-68	-87, -18
		Both	RPA	3 Gens	2009-2020	-6	-55, 78
				All Years	1995-2020	-70	-101, -13

2.2.3. Hatchery Influence

2.2.3.1 Hatchery Methodology

Hatchery production of Chinook Salmon typically falls within four objectives. The first objective is conservation or rebuilding enhancement. Conservation enhancement occurs when COSEWIC, WSP, or other formal status assessment defines a population at high risk of extirpation or extinction. However, populations with declining escapement trends that are informally assessed with an "at-risk" status may be considered for conservation enhancement, especially if they have highly unique genetic characteristics. The enhancement objective will transition to a rebuilding objective once the population stabilizes to a certain spawner abundance. Rebuilding enhancement occurs when a population is below optimal escapement but the magnitude of decline does not warrant conservation enhancement. It intends to restore a wild population and therefore has low risk tolerance for the loss of wild adaptive traits. The second objective is based on stock assessment information, which is typically gathered from coded wire tagged (CWT) fish that provide smolt-adult survival rates, fishery exploitation rates, fishery planning support and information on the proportion of hatchery fish in catch and escapement. The third objective is to provide harvest opportunities, which occurs when a fishery is heavily dependent on hatchery production and would become severely constrained without it. The last objective is for stewardship and education, where small numbers of fish are produced to increase community involvement and provide awareness about salmon. Current enhancement objectives are summarized in the Table 10.

Table 10. Current enhancement objectives (2021) for all enhanced populations.

DU	Broodstock	Stage	Release Site	Enhancement Objective
DU1	L Campbell R	Smolt 0+	L Campbell R	Harvest
	Nicomekl R	Smolt 0+	Nicomekl R	Stewardship
	Serpentine R	Smolt 0+	Nicomekl R	Stewardship
	Nicomekl R	Smolt 0+	Serpentine R	Stewardship
	Serpentine R	Smolt 0+	Serpentine R	Stewardship
DU6	Maria Slough	Smolt 0+	Maria Slough	Assessment/Rebuilding
DU13	Salmon R	Fed Fry	Salmon R	Rebuilding
DU15	Bonaparte R	Fed Fry	Bonaparte R	Conservation
	Coldwater R	Fed Fry	Coldwater R	Rebuilding
	Coldwater R	Smolt 1+	Coldwater R	Rebuilding
	Nicola R	Fed Fry	Spahomin Cr	Assessment/Rebuilding
	Nicola R	Smolt 1+	Nicola R	Assessment/Rebuilding
	Spius Cr	Smolt 1+	Spius Cr	Rebuilding

Hatchery production planning, which is part of the Integrated Fisheries Management Planning (IFMP) process, combines priorities from all DFO sectors with partner and stakeholder input to develop a comprehensive production plan that addresses production targets by species, stock, release site and release strategy. Production targets generated from this process are intended to achieve a number of returning adult salmon and calculated using survival rates by species and release stage. Although hatchery salmon can be released at multiple life stages, including fertilized eggs into natural streambed or smolts into coastal waters, the hatchery-origin Chinook in DUs 1, 6, 13 and 15 have all been released into their respective DU freshwater habitat as fry or smolts. Multiple considerations, including life history traits and habitat conditions, influence the life stage at which they are released. As fry, fish can be released as unfed, fed, or delayed types, where delayed fry are released during fall months. The slower early growth of unfed and fed fry when they are released into the system may produce a more natural age class structure and allow more opportunity for natural selection to occur with competition and predation, but they typically have lower survival compared to smolts. However, fed fry require rearing habitat and might therefore displace wild fry if a competitive advantage exists. Delayed fry releases reduce interactions with wild stocks at the fry stage but also increase domestication and therefore may exacerbate differences between wild and hatchery fish. Sub-yearling smolts have the highest survival rates for ocean-type Chinook Salmon, but their larger size at release may produce higher proportions of jacks. Yearling smolts are typically released into populations with stream-type life histories to reduce impacts on wild fish or for ocean-type populations with poor stock status to help increase survival.

2.2.3.2 Measuring Hatchery Influence

Canadian Chinook enhancement programs are managed as integrated populations wherein wild and hatchery salmon spawn together in both hatchery and natural environments. As a result, the Wild Salmon Policy (WSP) has defined three types of salmon in these integrated populations: 'hatchery-origin' that are born in a hatchery, 'natural-origin' that are born in the wild, and 'wild' that are born in the wild from fully wild parents. DFO uses three techniques to distinguish hatchery-origin Chinook Salmon. First, adipose fin clips (AFCs) and coded-wire tags (CWTs) are typically used in conjunction and applied to Chinook smolts or fed fry whose larger body size facilitates the application of these marks. Adipose fin clips are an obvious external mark that depict hatchery-origin, which allows for easy identification of hatchery-origin spawners, while CWTs are inserted into the head of the fish, which informs stock and brood year. Other types of fin clips, such as ventral fin clips, can also be used as an obvious external mark. Second, hatchery water temperatures can be manipulated to produce thermal marks on otoliths (Volk et al. 2005). However, adequate otolith sampling must occur when fish are recovered in fisheries or on spawning grounds. Depending on the size of the hatchery program and available resources, sometimes only a proportion of hatchery-origin fish are marked. Third, parentage-based tagging (PBT) uses molecular-based approaches to conduct large-scale parentage assignments and can genetically identify millions of hatchery progeny. Parental genotypes are identified for all broodstock, which essentially "tags" all of their offspring through DNA. A non-lethal tissue sample from a recovered hatchery offspring can therefore identify their parents, stock-of-origin, and age. Estimating the relative contribution of hatchery and wild origin spawners is therefore contingent on well-designed marking and recovery programs using CWT or PBT methods.

The proportionate natural influence (PNI) metric is designed to estimate the relative strength of the hatchery and natural selective pressures resulting from gene flow between the wild-origin and the hatchery-origin populations (Withler et al. 2018). It assumes that hatchery and wild salmon have different optimal phenotypes and hatchery ancestry does not affect sexual selection or fecundity. This metric is shown below, where pNOB is the proportion of natural-origin broodstock and pHOS is the proportion of hatchery-origin spawners.

$$PNI \approx \frac{pNOB}{pNOB + pHOS}$$

Wild abundances are derived from the total abundance multiplied by pNOS[2], where pNOS is the proportion of natural origin spawners (no mark). Estimates of natural-origin spawners, and thus the wild population, can be inaccurate if hatchery mark and recovery programs are inconsistent or absent, causing hatchery-origin fish to be undiscernible from their natural-origin counterparts. If unmarked hatchery-origin fish are present, the pNOS can therefore be overestimated. Long and consistent time series of pNOS are not available for most enhanced populations, even in populations with established escapement and hatchery programs. Instead, long-term averages of pNOS were used to infill wild-spawner estimates, which fail to capture how the proportion of wild spawners changes relative to hatchery production. Averaging the PNI can cause further inaccuracies when multiple life stages are released within and between years due to differing survival rates. Additionally, there is no way to mark second generation spawners, which can cause an overestimation of wild spawners if second generation spawners are subject to more pronounced hereditary genetic and epigenetic factors from introgression than their parental generation.

There are three types of integrated populations that differ based on the range of their PNI values and thus have guidelines for genetic risk management. First, integrated-wild populations have a high PNI (≥0.72), meaning wild individuals constitute more than 50% of the spawning population and nearly 75% is of natural-origin. Second, the PNI for integrated-transition populations ranges from 0.5 to <0.72, indicating there is net positive gene flow from natural-origin fish to hatchery-origin fish. The number of wild spawners ranges from 25-50%; however, this population type may not be self-sustaining without hatchery production because the equilibrium adaptive state could fluctuate between hatchery and natural optima. Third, integrated-hatchery populations have a low PNI (<0.50) and <25% of fish are wild. Hatchery fish dominate both broodstock and natural spawning components, causing net gene flow from the hatchery environment. This magnitude of hatchery production is often recognized to exert negative impacts on the fitness and productivity of the integrated population (Withler et al. 2018).

Available PNI values for the populations assessed in this RPA are displayed in Table 11. It should be noted that, with the exception of the Nicola River, all PNI estimates are based on visual assessments of adipose fin presence/absence from counting fences or indirectly by using 1 – pNOB to estimate pHOS and calculate PNI. No methodology currently exists to discern second generation hatchery fish from wild fish and the full impact of hatchery fish is unknown. The PNI values presented below are estimated based on the best available data, but considerable uncertainty remains.

*Table 11. PNI values for enhanced populations within each DU. *Note that current assessment methods are not able to parse wild from hatchery.*

DU	River	Year Range	Minimum PNI	Maximum PNI	Average PNI
DU1	L Campbell R	1986-2018	0.31	0.95	0.58
	Nicomekl R	NA	NA	NA	NA
	Serpentine R	NA	NA	NA	NA
DU6	Maria Slough	2000-2003	0.10	0.64	0.43
DU13	Salmon R	1986-2018	0.56	0.94	0.76
	Eagle R	1986-1996	0.07	0.96	0.57
DU15	Bonaparte R	1986-1996	0.29	0.98	0.74
	Coldwater R	1987-2004	0.21	0.98	0.75
	Nicola R	1987-2018	0.24	0.96	0.71
	Spius Cr	1987-2004	0.12	1.00	0.74
	Deadman R	1988-1995	0.56	1.00	0.87

2.2.3.3 Hatchery History

The Chinook hatchery history, techniques, and management varies within and between the four DUs. Canadian programs typically use thermal marks or PBT for efficient mass marking, while CWTs and adipose fin clips are used in conjunction to easily identify hatchery-program and hatchery-origin, respectively. In DU1, community hatchery programs operate in the Little Campbell River (est. 1983), Nicomekl River (est. 1984) and Serpentine River (est. 1988). Broodstock are collected at hatchery fences and fish are reared in hatcheries located on their spawning river with brood-take and rearing procedures decided by community hatcheries with input from DFO community advisors. Chilliwack fall Chinook and Chilliwack summer red Chinook (a transplanted mixture of DUs 4, 10, 11, and 16) were released into DU1 from 1990-2003 (Brown et al. 2013); the genetic differences between both populations are unknown but are assumed to be consequential. Most Chinook Salmon were released as sub-yearling smolts, with release timing and duration varying between March and July. Fed fry were released into DU1 during four years: DU1-origin in 1985 and 1990, Chilliwack-origin in 2000, and Chilliwack-Harrison-origin in 2001. Hatchery releases into the Little Campbell River had either left ventral, right ventral, or adipose fin clips between 1984 to 2015. Since ventral clipping ceased, there has been no consistent or population-specific marking for hatchery Chinook Salmon in this DU. DU1 appears to be genetically similar to Green River Chinook Salmon rather than other native fall Chinook populations that are in closer proximity, such as Fraser River fall Chinook or Skagit River fall Chinook. Green River Chinook Salmon were the population that formed the founding stock for the fall Chinook commonly used by hatchery programs within Puget Sound. Therefore, it is thought that Green River origin hatchery strays established a natural population within the

Little Campbell River over the last 130 years that was then introduced by SEP over the past twenty years into the Serpentine and Nicomekl rivers.

In DU6, Maria Slough Chinook were annually enhanced from 1988 to 2010, during which time fry were released into Van Dyke Channel, Seymour Narrows Channel, and McNeil Channel and sub-yearling smolts were released into Maria, Hope and Camp Sloughs. From 1998-2002, a proportion of sub-yearling smolts in each cohort received CWTs. From 2019 to present, sub-yearling smolts were released into Maria Slough with CWTs and adipose fin clips applied in the 2021 release year.

The Eagle (1983 to 1994) and Salmon (1984 to present) rivers are the only tributaries with Chinook hatchery enhancement in DU13. Release strategies have varied throughout the enhancement history with combinations of fed fry, fall fry, sub-yearling smolts and yearling smolts released in a single year. From 1983 to 2003, CWTs and adipose fin clips were applied with relative consistency but have only occurred in two brood years (2006 and 2008) since 2004. Unmarked fed fry have been released in the Salmon River in May and June from 2010 to present.

Hatchery enhancement has occurred in all tributaries of DU15 except Louis Creek. Fed fry, fall fry and sub-yearling smolts were annually released into the Deadman River (1984 to 2001) and Bonaparte River (1980 to 1992), with fry originating in Deadman River released in the Bonaparte River in 2018. CWTs and adipose fin clips were applied to a proportion of these fish, with some years lacking any hatchery mark. All populations in the Nicola basin have experienced significant hatchery enhancement. Unmarked hatchery-origin Chinook Salmon have been released into the Spius Creek watershed (est. 1986) and the Coldwater River (est. 1984) with annual cohorts of both fed fry and yearling smolts released since the early 2000s. Marks have not been applied to these two populations, with the exception of occasional marking of a proportion of releases in the Coldwater River from 1984 to 2001. Hatchery enhancement in the Nicola River has occurred annually since 1982 with a consistent CWT marking and recovery program. Combinations of all juvenile life stages were released into the Nicola River until 2002 when the strategy stabilized to release only fed fry and yearling smolts. A proportion of Spius Chinook was also marked in the 1990s (1992, 1995-97) while PBT marking has occurred since 2013, except for 2016-17 brood years.

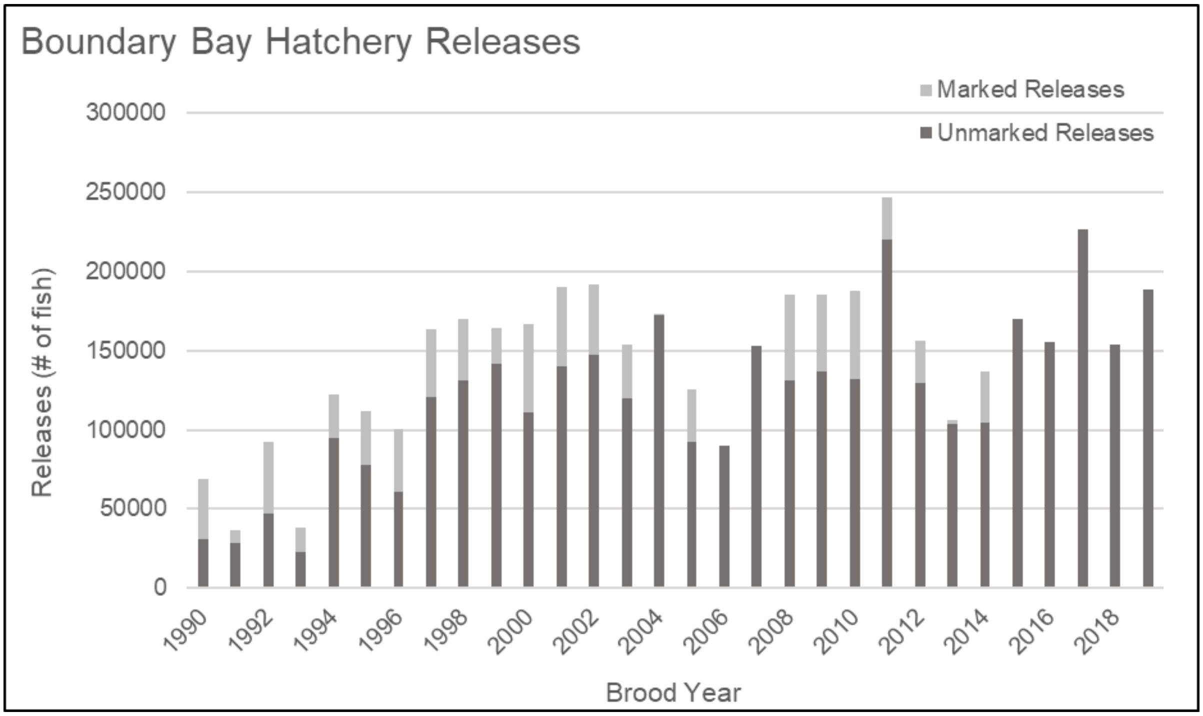

Figure 5. Number of unmarked and marked (fin clip and/or CWT) hatchery-origin Chinook Salmon released into DU1 each year.

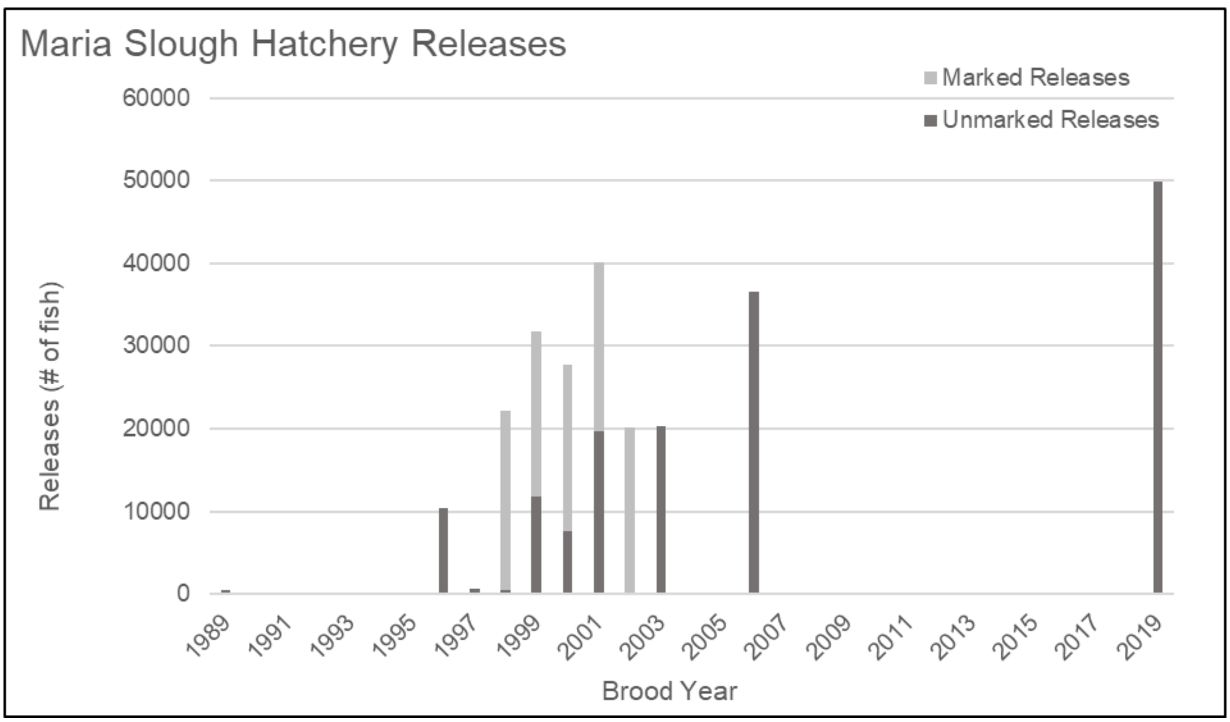

Figure 6. Number of unmarked and marked (fin clip and/or CWT) hatchery-origin Chinook Salmon released into DU6 each year.

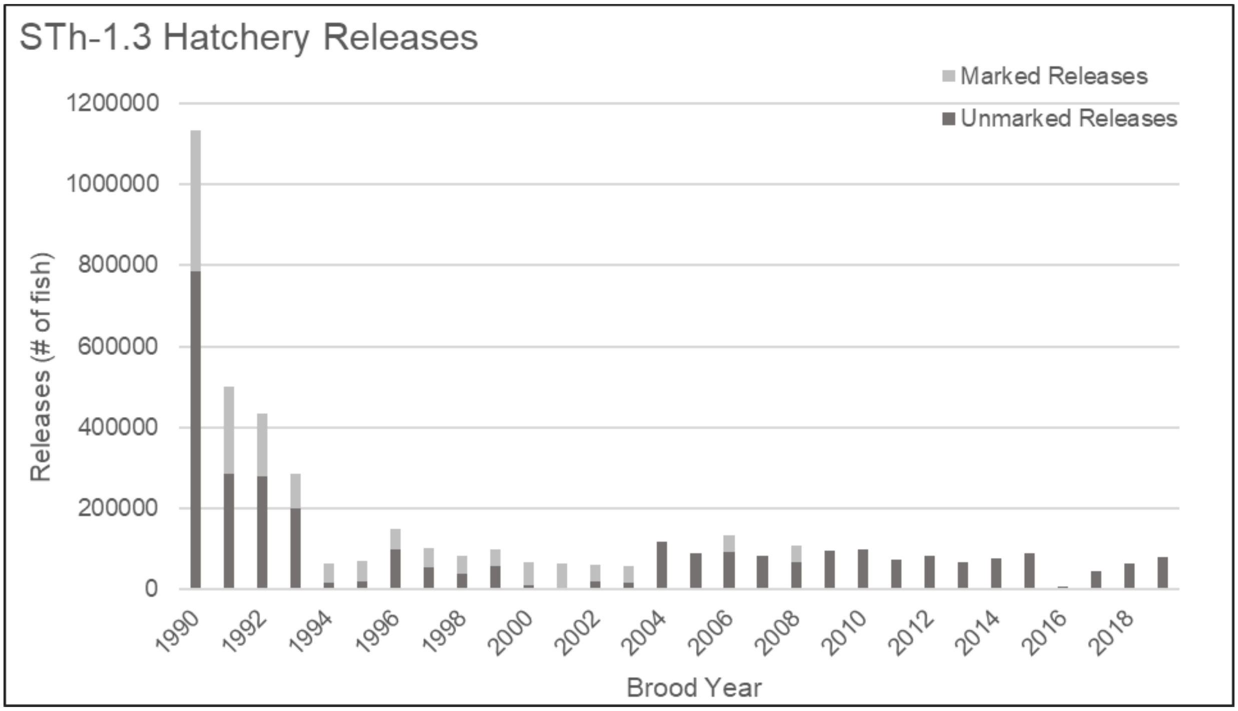

Figure 7. Number of unmarked and marked (fin clip and/or CWT) hatchery-origin Chinook Salmon released into DU13 each year.

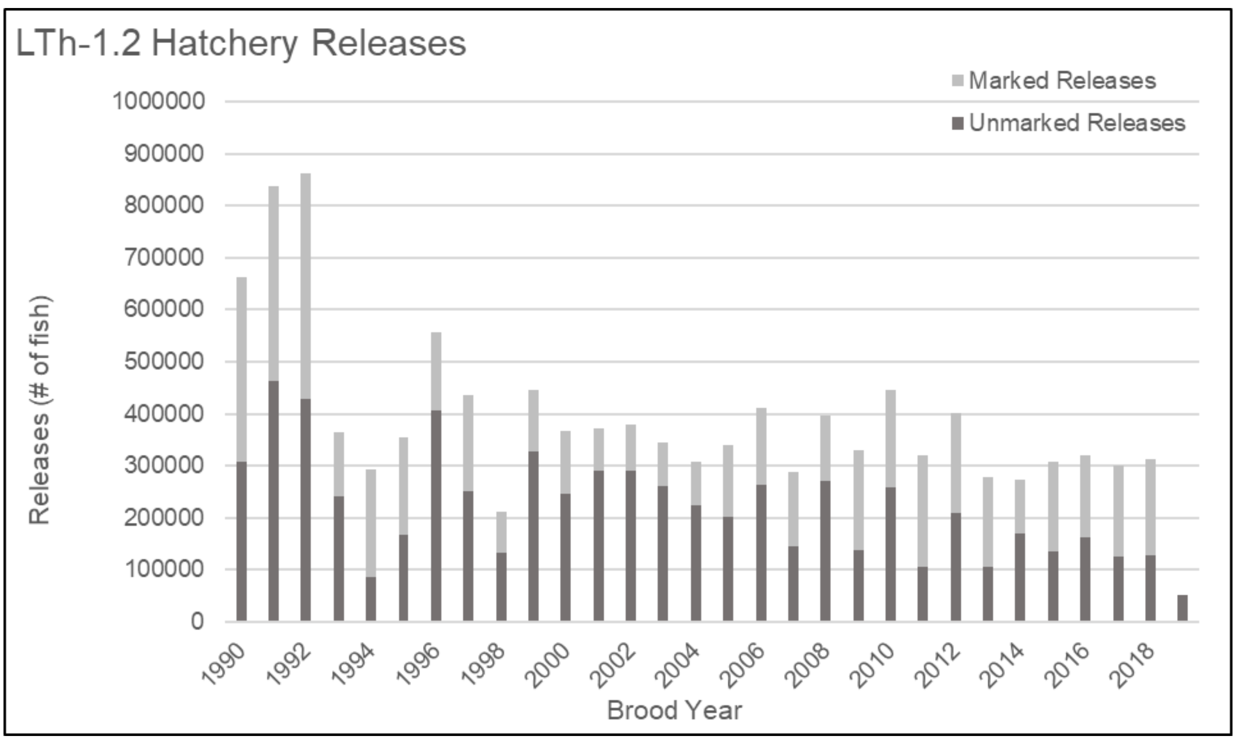

Figure 8. Number of unmarked and marked (fin clip and/or CWT) hatchery-origin Chinook Salmon released into DU15 each year.

2.2.3.4 Differences Between Hatchery and Wild Fish

It is well-established that hatchery fish often have lower fitness than wild fish (Grant 2012). Multiple factors incite significant genotypic and phenotypic differences between hatchery and wild salmon, which can cause unintended effects on wild populations. First, differences arise in hatchery fish via genetic and epigenetic mechanisms (Araki et al. 2010, Christie et al. 2014a). The significance of this difference depends on how genetically distinct the hatchery and wild populations are, the amount of gene flow that occurs between them, and the selective pressures that each cohort experiences. Hatchery practices often reduce genetic diversity in hatchery-origin fish by producing cohorts from smaller gene pools and exposing them to artificial selection pressures (Gardner et al. 2004). The diversity of wild fish can be underrepresented if broodstock are taken over a narrow time frame, if maturity stages or size are favored, and if unnatural combinations of gametes are made. In the hatchery environment, fish are subjected to artificial selection pressures from practices such as: mating without sexual selection, consistent feeding schedules, no predation, and controlled abiotic conditions, which can alter both phenotypes and cohort demographics of fish that survive to the release stage. Epigenetic differences can also manifest between hatchery and wild fish due to differences in their incubating and rearing environments, resulting in the expression of altered phenotypes and a possible reduction in fitness (Le Luyer et al. 2017). Knowledge about the epigenetic consequences is limited; however, a heritable reduction in fitness can occur in a single generation, which is more accelerated than changes in allele frequencies from genetic drift or domestication (Araki et al. 2007; Christie et al. 2016).

Second, the dissimilarities between hatchery and natural rearing environments cause distinct differences in the behavior, physiology, and morphology of hatchery fish (Flagg and Nash 1999). Salmon reared in artificial environments are susceptible to display altered phenotypes because they have a propensity for high developmental plasticity (Einum and Fleming 2001). Due to reduced mortality from the egg to fry life stage in hatchery-origin salmon, differences may be caused by expression of traits in the hatchery that would be selected against in the wild. Hatchery-origin Chinook Salmon can have a more compressed body, narrower head, shorter maxillae, and narrower caudal peduncle than wild fish (Wessel et al. 2011); they are usually larger and grow faster than their wild counterparts within the same cohort because broodstock selection can favor fish that mature early and hatchery diets produce faster growing fish. Hatchery-origin fish may also be more susceptible to predation because they display less avoidance behavior and predators favour their larger body size (Nelson et al. 2019). Most aggression studies reported that hatchery-reared salmon and their offspring are more aggressive than their wild counterparts; however, these results are not universal. Hatchery fish can display more aggressive behaviors after release into streams because the hatchery environment interfered with the opportunity to establish social hierarchies; wild fish, however, have already developed dominance hierarchies, so aggressive behaviors to maintain them occur less often (Steward and Bjornn 1990). Similarly, hatchery fish show higher levels of growth hormone (Fleming et al. 2002), which can increase aggressive behavior in salmonids (Einum and Fleming 1997). Hatchery reared salmonids released into streams display less efficient feeding strategies compared to their wild counterparts (Bachman 1984), which may be compounded by reduced athletic ability (Kitada and Kishino 2019), resulting from cardiac abnormalities (Twardek et al. 2021). Other aggression studies report that wild-origin fish are more aggressive than hatchery-origin fish, although impacts to competitive dominance are small (Pearsons et al. 2007).

2.2.3.5 Interactions Between Hatchery and Wild Fish

The specific characteristics that differentiate hatchery fish depend upon the hatchery practices to which they were exposed and the management targets they are intended to fulfill. An overall consensus about the effects that hatchery fish incur on wild Chinook populations has not been reached. The interactions between hatchery and wild fish can be clustered into genetic (hereditary and epigenetic), ecological (competition, predation, and fish health) and fisheries (mixed-stock) categories and depend on where they occur in the salmon lifecycle.

Genetic risks are of significant concern for Pacific Salmon because their genetic adaptations are tailored to optimize phenotypes in local environmental conditions (Taylor 1991). While the degree of genetic risk can be managed, it cannot be avoided (Waples 1999). In the long term, unmanaged gene flow from hatchery fish can homogenize the genetic structure of wild populations (Eldridge and Naish. 2007), thus reducing their capacity to adapt to changing conditions (McGinnity et al. 2009). Salmon enhancement can cause genetic risks from inbreeding depression (Wang et al. 2002), domestication selection (Lynch and O'Hely 2001), and outbreeding depression (Flagg and Nash 1999), with the magnitude of risk typically increasing in populations with lower PNI values. The founder effect refers to changes in the genetic composition of a new population due to its origin from a small number of individuals from a larger source population. It can occur if broodstock are collected from a small number of individuals that underrepresent the diversity in the wild population. Inbreeding can occur if related individuals are mated as broodstock, leading to a greater opportunity for deleterious recessive genes to be expressed. However, the rate of inbreeding in any population is inversely related to the genetically effective population size (Falconer 1981). Therefore, unfavorable genotypes are more likely to arise if the hatchery population has low genetic diversity or the wild population is small. These factors can occur in both hatchery and wild populations, but their cumulative effects are greater in highly enhanced populations and can severely depress the genetically effective population size. Outbreeding effects can develop if fish originating from another population are introduced, but the magnitude of the effect depends on the genetic divergence of the populations. Populations adapted to different environmental conditions can produce offspring that are not well suited to a different system. Conversely, hybrid vigor can occur if populations have similar adaptations, but different recessive deleterious genes, producing fitter offspring that are not homozygous for the recessive gene (Birchler et al. 2006). All hatchery-origin Chinook Salmon in DUs 1, 6, 13, and 15 are managed as integrated populations and therefore interbreed with wild stocks, reducing the genetic diversity and potentially affecting productivity, behavior, and population adaptability (Waples 1991). A growing pool of evidence suggests there are intergenerational declines in the fitness of wild populations when hatchery-origin fish are present (Fleming 2002, Berejikian and Ford 2003, Grant 2012).

Ecological interactions between hatchery and wild fish depend upon interrelated factors in the enhancement design, including release life stage and body size, release timing, and hatchery proportions. Hatchery salmon can compete with wild salmon for spawning habitat, freshwater rearing area, and food when survival rates are density-dependent for life stages after hatchery releases; competitive advantages can arise if hatchery fish have a larger body size (Rhodes and Quinn 1998), display more aggressive behaviors (Weber and Fausch 2003), and are released before wild fish enter the system (Rhodes and Quinn 1998).

In the freshwater environment, the survival of wild juveniles can be compromised if there is a large addition of hatchery releases into the foraging area. Evidence suggests that large releases of hatchery pre-smolts at suboptimal times and sizes can increase competition with wild salmon for food and refuge (Brannon et al. 1999). Risks associated with carrying capacity in the freshwater environment are most likely to occur when juvenile hatchery salmon have a longer spatiotemporal overlap with their wild counterparts, particularly with stream-type life histories (Flagg and Nash 1999). Some hatcheries can also produce larger juveniles to overcome the poorer smolt-to-adult survival of hatchery fish (Flagg and Nash 1999), leading to a larger appetite and overall competitive advantage. Larger hatchery juveniles can displace wild juveniles into marginal habitats with low survival potential if freshwater habitats are fully occupied (Tatara and Berejikian 2012). In the spawning phase, wild spawners can have limited spawning site options, especially if broodstock practices select for early spawning migration timing. In the nearshore environment, competition for prey resources during the critical period for early marine growth and survival may diminish the foraging capacity and growth potential for wild salmon (Davis et al. 2018). Habitat partitioning between hatchery and wild fish of different sizes may also reduce competition between the two types (Chandler and Bjornn 1988); however, the degree of trophic overlap between hatchery and wild Chinook Salmon is unknown.

The presence of hatchery salmon can increase the risk of intra and inter-specific predation. Hatchery smolts may consume wild juveniles if a significant size difference exists (Gardner et al. 2004), optimal food sources are not adequately abundant, or different year-classes of juveniles share the same nursery area. Hatchery salmon may attract larger aggregates of predators (Nickelson 2003), which could occur from concentrated hatchery releases, bottlenecks in migration, and environments with concentrated patches of optimal habitat. Predators can favour hatchery salmon as prey if a sufficient size differential exists. Conversely, hatchery salmon can be more susceptible to predation if they exhibit avoidance behavior deficits from rearing in an artificial environment (Olla et al. 1998).

Hatchery salmon may have a different pathogenic profile compared to wild conspecifics due to different exposure levels in the hatchery rearing environment. Infectious diseases can disrupt behaviours and physiological performance, feeding and growth, and immunological function. In severe cases, they can cause both direct and indirect mortality (Miller et al. 2014; Costello 2006). High rearing densities in hatchery environments increase the potential for enhanced transmission of pathogens, but efforts can be taken to minimize prevalence in hatchery fish and subsequent transmission to wild fish. For example, antibiotics, broodstock selection practices to minimize vertical transmission, and the use of ground rather than river water may all reduce susceptibility to infections of various pathogens to some extent. There has not been an extensive study of the infectious profiles between hatchery and wild fish between freshwater and marine environments nor is the variation between populations and hatchery practices known. However, wild and hatchery fish appear to be more divergent in agent profiles in freshwater with a lower agent diversity in hatchery-origin fish (Thakur et al. 2018).

Mixed stock fishery interactions can negatively affect wild salmon if they are overharvested in stocks mixed with enhanced salmon or if the abundance of enhanced salmon masks the declines of wild salmon stocks. Impacts can result from excessive fishing levels that develop in response to large abundances of salmon (of mixed hatchery and natural origins) that are not calibrated to Pacific Salmon produced in natural environment. However, wild fish are likely to be over-harvested in mixed stock fisheries where hatchery fish constitute a larger proportion, the ratio of which can be worsened by larger hatchery production or improved survival rates for hatchery fish. Mark selective fisheries can minimize these impacts; however, they are only suitable if a large proportion of fish have an obvious external mark, such as an adipose fin clip, and gear type and conditions produce low incidental mortality of wild fish. Previous fisheries management was historically concerned with the total abundance of salmon, which did not disentangle wild and enhanced production. In Canadian waters, some unmarked hatchery releases from the US have mixed with wild salmon and further inflated the apparent abundance of natural-origin fish. This, along with the lack of hatchery marking in systems in Canada, could have delayed harvest reductions to support the recovery of wild stocks, thus masking the decline of wild populations.

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. For the DUs covered in this report, only DU15 (LTh-1.2) has a population with an indicator stock (Nicola). Chilko River is under development as an indicator for DU13 (STh-1.3). 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. 2008). 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; there is some evidence that this was driven by size-selective fisheries (Lewis et al. 2015). Declining trends of older and larger 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).

It was recently estimated that across BC Chinook Salmon indicator stocks, productivity has declined by 25-40% since the early 1980s (DFO 2018c). 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 13). Xu et al. (2020) found that since the early 2000's all management units (ex. Sp 1.2, Sp 1.3, Sm 1.3, Sm 0.3, Fall) of Fraser River Chinook showed a decreasing size at age. The long term trend for Nicola, the CWT indicator stock for the Spring 1.2s, did not show a decline in the generation length generation time for this management unit is already at the lower end of the range for Chinook Salmon. The recent Chinook 5 Year Review found that there has been a decline in length-at-age at Albion for 1.3 fish, but not 1.2 fish (Dobson et al. 2020a). 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. 2020a). The trend in fecundity is currently unknown for all DUs.

Due to the lack of indicator stocks, current survival and absolute productivity data are not available at the DU level with the exception of DU15. Producing representative life history parameters is a known knowledge gap for the other DUs discussed in this RPA.

Table 12. Summary of life history parameters for SBCC 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 found in (Healey 1986). Average fork lengths were estimated for SBCC 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 (# of eggs/ female)	Fork Length by Age (mm)			
							Age-2	Age-3	Age-4	Age-5
DU1 SM-Boundary Bay	Samish	Ocean	Fall	4_1	3.8	2648-4462	NA	NA	NA	NA
DU6 LFR-Maria	Lower Shuswap	Ocean	Summer	4_1	3.8	2648-4462	636	777	828	NA
DU13 STh-Summer	Chilko	Stream	Summer	5_2	4.5	5388-9063	628	750	836	850
DU15 LTh-Spring	Nicola	Stream	Summer	4_2	4	4018	615	695	795	NA

Table 13. Summary of recent trends in characteristics for four BC management units (from DFO 2018b).

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 4_1	Lower Shuswap	-42%	-0.020	Declining, Age-3,-4,-5	Declining
Fraser Summer 5_2	Chilko	Unknown	Unknown	Declining, Age-5	Unknown

Table 14. CWT Smolt- to age-3 survival rates (%) for Nicola (NIC) (LTh-1.2), Shuswap (SHU) (Maria) and Samish River (SAM) (Boundary Bay) Chinook indicator stocks. No indicator stock is available for South Thompson Summer 1.3.

Brood Year	NIC	SHU	SAM
1991	5.50%	0.90%	0.98%
1992	0.10%	3.23%	0.87%
1993	0.77%	2.10%	1.67%
1994	1.07%	3.22%	2.38%
1995	5.82%	2.73%	0.32%
1996	4.62%	3.17%	0.31%
1997	6.25%	0.73%	0.49%
1998	12.51%	6.36%	3.91%
1999	6.31%	5.16%	1.65%
2000	0.82%	3.78%	0.61%
2001	1.36%	2.39%	0.98%
2002	1.27%	4.32%	1.18%
2003	0.22%	0.87%	2.76%
2004	1.97%	0.85%	1.09%
2005	0.41%	3.52%	3.61%
2006	3.87%	2.81%	0.69%
2007	1.14%	2.18%	3.19%
2008	1.26%	1.05%	1.05%
2009	1.88%	1.35%	2.76%
2010	0.49%	5.60%	1.55%
2011	1.84%	2.55%	2.97%
2012	1.16%	1.69%	0.56%
2013	1.48%	1.57%	0.38%
2014	1.38%	2.80%	1.96%
2015	2.00%	1.18%	NA

2.4. 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. 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 2018; Brown et al. 2019).

2.4.1. 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 15). 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 > 30cm and suitable substrate sizes for redd construction are between 1.3 and 10.2cm (Table 15). 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 $10.7m^2$ for females 700 to 1000mm in fork length. For specific examples from SBCC populations, average redd size for stream-type Chinook was $9.1\text{-}10m^2$ in the Nechako River (Neilson and Banford 1983) and $8.7m^2$ in the Nicola River[5] (n=124, CV=24%). Optimal spawning temperatures range from 3.3-13.9°C for Chinook in the Nicola River (Peatt and Peatt 2013).

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 and requires mixing to ensure sufficient oxygen without risk of freezing. Redd site selection in the Nicola River strongly correlates with groundwater-surface water interchange zone. In DU6, the majority of Chinook spawning occurs in four constructed riffles that were created by building a berm across the slough and leaving a narrow channel on the margin to concentrate flows. Water flowing into Maria Slough is largely from groundwater with the exception of Hicks Creek. In coastal systems, scouring from fall and winter flooding is a significant 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 (Richard Bailey, DFO, Kamloops, BC, pers. comm. 2021).

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. The Serpentine River (DU1) is a potential exception; a

[5] Chuck Parken, DFO, Kamloops, BC. Unpublished data.

preliminary assessment that concluded that the upper Serpentine River lacked spawning habitat and identified seven sites that would be suitable to supplement with gravel (City of Surrey 2015). The City of Surrey added gravel to five of the sites between 2013 and 2016; however, some of the supplemented reaches did not retain spawning gravel in subsequent years because increased discharge levels from moderate storms caused bank erosion and displace spawning gravel (Yuan 2018).

Some studies provide additional information about spawning habitat within the four DUs. In DU1, a Sensitive Habitat Inventory and Mapping project in the Little Campbell River found that the best spawning and rearing habitat exists in the lower reaches of the watershed. In DU13, aerial cover of Chinook spawning habitat in the Eagle River was measured by density categories and found that 13.85% (1064554m^2) of the Eagle River mainstem was used for spawning with 0.02% in high density areas and 10.22% in low density areas (Hawes et al. 2015). However, it is unclear how differences in Chinook escapement and habitat changes vary inter-annually. A Chinook habitat assessment conducted in the Salmon River found that 61000m^2 of spawning habitat exists and spawning capacities were estimated around 3000 Chinook pairs (Burt and Wallis 1997), although substantially more spawning habitat was estimated at a higher discharge (123000m^2) (Whelen and Olmsted 1982). However, the relevance of these estimates are unknown due to habitat changes, such as gravel displacement and groundwater profiles, from these assessments to present day.

2.4.2. 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 DU6 (Maria) tend to outmigrate 50-160 days after emergence (DFO 2007); however, their distribution during this period is unknown. Rearing habitat for DU1 juveniles is largely unknown, but they are thought to rear in the Boundary Bay estuary. 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 (DUs 13 and 15), 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 15). 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 16). It should be noted the reported limit of <25 NTUs (Nephelometric Turbidity Units) in Table 15 may be unreasonable for SBCC, 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 SBCC 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). SBCC 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 5000ha^{-1} (0.5m^{-2}) interior Columbia River tributaries (Thorson et al. 2014). During 2001 to 2006, Chinook fall fry stocks were evaluated in tributaries of the lower Thompson basin (Decker and Hagen 2007). Chinook fry density showed substantial spatiotemporal variation, but there was a consistent pattern of increasing fry densities from upstream to downstream reaches, both within individual streams and the study area. Fry abundance was greatest in relatively deep, lower velocity habitats and in lower gradient stream sections, while marginal habitats experienced greater interannual variation in fry abundance. Among tributary reaches, Chinook fry density in runs averaged 9.9 times (range=0.9 to 127.4) greater than riffles. In the Nicola River, the optimal range for juvenile rearing and growth is estimated between 10.0 and 15.5°C (Peatt and Peatt 2013). Additionally, Warkentin (2020) found that low summer flows in the Nicola River strongly decreases productivity and Chinook Salmon cohorts are predicted to be irreplaceable in years with average August discharge less than 10.83 m^3s^{-1} during the rearing summer.

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.

Access to ephemeral habitats is a critical component of fry and juvenile rearing, which plays an important role for both ocean and stream-type Chinook. Juvenile Chinook with genetic markers from the Lower Thompson and South Thompson stocks have been captured in seasonally flooded areas of the lower Fraser River near Hope (Murray Manson, DFO, Delta, BC, pers. comm. 2021). 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 SBCC-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 SBCC.

The amount of rearing habitat available to coastal and interior populations has significantly decreased (Finn et al. 2021) and has shown to be limiting (Thorson et al. 2014; David et al. 2016). In one population of DU13, 290000m^2 of rearing habitat in the Salmon River was estimated to be capable of supporting 73000 sub-yearling Chinook and was proposed to be more limiting than spawning habitat (Burt and Wallis 1997). However, interannual variation and habitat changes from 1997 to present day likely limit the generalization of these estimates. While not SBCC 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).

2.4.3. Juvenile Freshwater Outmigration Habitat

Ocean-type Chinook from populations from the lower Fraser 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 DUs.

2.4.4. 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 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). Marsh habitat was the main habitat used by both sub-yearling and yearling Chinook Salmon in the lower Fraser River estuary (Chalifour et al. 2020) 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 200-400km 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 sub-yearlings from the South Thompson DU tend to exit the Salish Sea earlier (first fall and winter at sea) than sub-yearlings 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 sub-yearlings 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 sub-yearlings. In contrast to sub-yearling 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 vary over time and location but fish (primarily herring and sandlance) dominate the diet with crab larvae, squid and large zooplankton also contributing. During their early marine residence in Puget Sound, Chinook diets are composed of euphausiids, crab larvae, hyperiid and gammarid amphipods, large copepods, and small fish (Daly et al. 2009; Duffy et al. 2010). In nearshore habitats, terrestrial insects may significantly contribute to juvenile Chinook diets (Gamble 2016; Davis et al. 2018). Individuals found at depths greater than 30m in offshore areas of Puget Sound consume more fish and decapod larvae (Duffy et al. 2010) and appear have a higher growth rate than those in estuarine or nearshore habitats (Gamble et al. 2018). In the Strait of Georgia, Chinook juveniles feed on larger zooplankton, such as amphipods, larval decapods, euphasiids and juvenile fish (Neville and Beamish 1999; Daly et al. 2010). The marine survival of some Chinook stocks strongly correlated with the biomass of certain prey items, although the persistence of these relationships require a longer time series (Keister and Herrmann 2019). The importance of herring in the diet of juvenile Salish Sea Chinook appear less important in recent years than in the 1970s (Healey 1980, Duguid et al. 2021), although this appears strongly related to juvenile Chinook size (Chamberlin et al. 2021; Duguid et al. 2021). Chinook juveniles heavily rely on invertebrates in Puget Sound where they feed on larval crab in the spring, gammarid or hyperiid amphipods through the summer, and herring and sandlance in the fall (Beauchamp et al. 2020).

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). Marine distributions inferred from CWT recoveries are shown for each DU in Element 5.

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 SBCC DUs differently and may be complex.

2.4.5. 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. Upstream migration rates are highly dependent on abiotic conditions such as flow, temperature dissolved oxygen and sediment. In the Fraser River, returning adults are known to hold near the mouths of cleaner tributaries to seek cooler water and clean sediment from their gills while they await lower discharge conditions.

Environmental thresholds identified by Hague and Patterson (2009) were used to assess the encounter rates of Fraser Chinook populations to adverse upstream migration conditions and were taken from other systems, such as the Columbia River basin where migration studies suggest optimal temperatures for swimming are 16.3°C and lethal temperatures are > 21°C. Hague and Patterson (2009) reconstructed thermal and flow histories of five Fraser River Chinook Salmon populations and evaluated the historical temperatures, flows encountered, and the likelihood of exceeding identified thresholds.

Migrating salmon can encounter warm conditions during summer months in the Fraser River. Water temperatures above 18°C are known to impair migration or lead to en-route mortality (Fenkes et al. 2016) and durations when Fraser River temperatures exceed 18°C have increased over last 50 years (Martins et al. 2011). SBCC are unlikely to encounter temperatures above the assumed lethal limit of 21°C in the Fraser River itself; water temperatures in Maria Slough and the Nicola and Salmon rivers, however, are known to surpass this limit while Chinook spawners are present. Chinook rely on groundwater upwelling zones to compensate for unfavourable water temperatures, which create thermally stabilized local habitats that significantly cool local water temperature from ambient stream temperature. For example, maximum daily temperatures in the Nicola River were on average 11.5°C cooler in groundwater upwelling areas than in adjacent areas (McGrath and Walsh 2012). The availability of groundwater upwellings and thermal refugia was mapped in the Nicola River (Willms and Whitworth 2016), although similar studies have not been conducted for other temperature-sensitive areas. Unfavorable water temperatures are unlikely to occur in DU1, Eagle River, Seymour River, Scotch Creek and Louis Creek for Chinook spawners due to their geographic locations and local environmental conditions.

Returning adults can be restricted by low flows along their upstream migration route. In DU15, Chinook Salmon from the Coldwater River and Spius Creek arrive at the lower areas of their natal streams during spring freshet to gain access to spawning habitats that would be otherwise inaccessible during lower water levels. Spawning habitat in Maka Creek, a tributary of Spius Creek, is only used opportunistically when water levels allow upstream passage. Upon ascending these systems, the fish remain in deep holding habitats for an extended period and only emerge from those habitats to spawn one to two months later (Richard Bailey, DFO, Kamloops, BC, pers. comm. 2021). The later-arriving Nicola Chinook Salmon hold at the confluence of the Nicola and Thompson Rivers if their return-timing coincides with low summer flows. The productivity of Nicola Chinook is impaired during low flows (Warkentin 2020). Optimal instream flows vary between reaches of the Nicola River (Lewis et al. 2009) and are summarized in Table 18. Similarly, Chinook adults returning to Maria Slough and the Salmon River can hold in the Fraser River and Shuswap Lake, respectively, until water levels allow passage.

Table 15. 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). Population-specific adaptations can alter the range of attributes.

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.

[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
			Coastal: near-shore sheltered habitats, abundance of kelp and other shoreline vegetation. 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 16. 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 present 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 17. Summary of freshwater migration distances and timing for four Southern British Columbian Chinook DUs.

<table>
<tr><th>DU</th><th>Population</th><th>Net Freshwater Migration Distance (km)</th><th>Enter Freshwater</th><th>Peak Spawn</th><th>Enter Ocean</th></tr>
<tr><td rowspan="3">DU1</td><td>Serpentine R</td><td rowspan="3"><50</td><td rowspan="2">September-November</td><td rowspan="3">October-November</td><td rowspan="3">March-June</td></tr>
<tr><td>Nicomekl R</td></tr>
<tr><td>Little Campbell R</td><td>Mid September-End October</td></tr>
<tr><td>DU6</td><td>Maria Slough</td><td>145</td><td>August-September</td><td>Mid-End October</td><td>May-June</td></tr>
<tr><td rowspan="4">DU13</td><td>Seymour River</td><td>585</td><td rowspan="2">Unknown</td><td>End-September</td><td rowspan="4">April-May</td></tr>
<tr><td>Scotch Cr</td><td>510</td><td>Mid-October</td></tr>
<tr><td>Salmon R</td><td>670</td><td rowspan="2">June-July</td><td>Early-Mid September</td></tr>
<tr><td>Eagle R</td><td>605</td><td>Mid-End September</td></tr>
<tr><td rowspan="6">DU15</td><td>Bonaparte R</td><td>450</td><td rowspan="3">April-June</td><td rowspan="2">Early-Mid September</td><td rowspan="6">April-June</td></tr>
<tr><td>Deadman R</td><td>420</td></tr>
<tr><td>Louis Cr</td><td>530</td><td rowspan="2">End August</td></tr>
<tr><td>Spius Cr</td><td>380</td><td rowspan="2">April-July</td></tr>
<tr><td>Coldwater R</td><td>405</td><td>Mid-End August</td></tr>
<tr><td>Nicola R</td><td>375</td><td>May-July</td><td>Mid-September</td></tr>
</table>

Table 18. Optimal instream flows in the Nicola River mainstem for different life history stages of Chinook (Lewis et al. 2009).

Life-History Stage	Thompson River confluence to Spius Creek Confluence	Spius Creek confluence to Coldwater River confluence	Coldwater River confluence to Nicola Lake dam
In-migration and Spawning	Optimal: 10.9m^3s^{-1}(Lewis et al. 2009)	Optimal: 11.0m^3s^{-1} (Lewis et al. 2009) for Aug-Sep and 3.12m^3s^{-1} for Oct-Dec	Optimal: 3.4m^3s^{-1} (Bruce and Hatfield 2003)
		Optimal: 6.8m^3s^{-1} (Bruce and Hatfield 2003)	Optimal: 1.7m^3s^{-1} (Kosakoski and Hamilton 1982)
		Optimal: 4.25m^3s^{-1}(Kosakoski and Hamilton 1982)	-
Incubation (eggs)	Unknown	Unknown	Unknown
Emergence	Unknown	Unknown	Unknown
Rearing (0+) young of year (fry)	Optimal: 2.8m^3s^{-1}(Lewis et al. 2009)	Optimal: 1.1 m^3s^{-1} (Lewis et al. 2009)	Unknown
		Optimal: 3.5m^3s^{-1} (Bruce and Hatfield 2003)	
		Optimal: 1.42m^3s^{-1} (Kosakoski and Hamilton 1982)	
Rearing (1+) (parr)	Optimal: 6.4m^3s^{-1}(Lewis et al. 2009)	Optimal: 3.5m^3s^{-1}(Lewis et al. 2009)	Optimal: 1.4m^3s^{-1} (Lewis et al. 2009)

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

2.5.1. Freshwater Habitat Distribution

SBCC are widespread throughout the Fraser River and many of its tributaries while DU1 is distributed in three drainages flowing into Boundary Bay, south of Vancouver. The known distributions of each DU are presented in the following maps and further described where there is additional information for freshwater life history stages. 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. Knowledge of the distribution of Chinook fry, especially for stream-type DUs (13 and 15), is limited because that life history stage is not extensively surveyed. However, they exhibit three rearing strategies in the freshwater environment: remaining near their natal streams, occupying downstream habitat within the basin of their respective second-order tributaries, and migrating to the lower Fraser River. The following changes have been made to the COSEWIC maps to better reflect the freshwater distribution of SBCC DUs covered in this RPA:

- DU1
- DU6
- DU13

- DU15

2.5.1.1 DU1 – Boundary Bay Ocean Fall

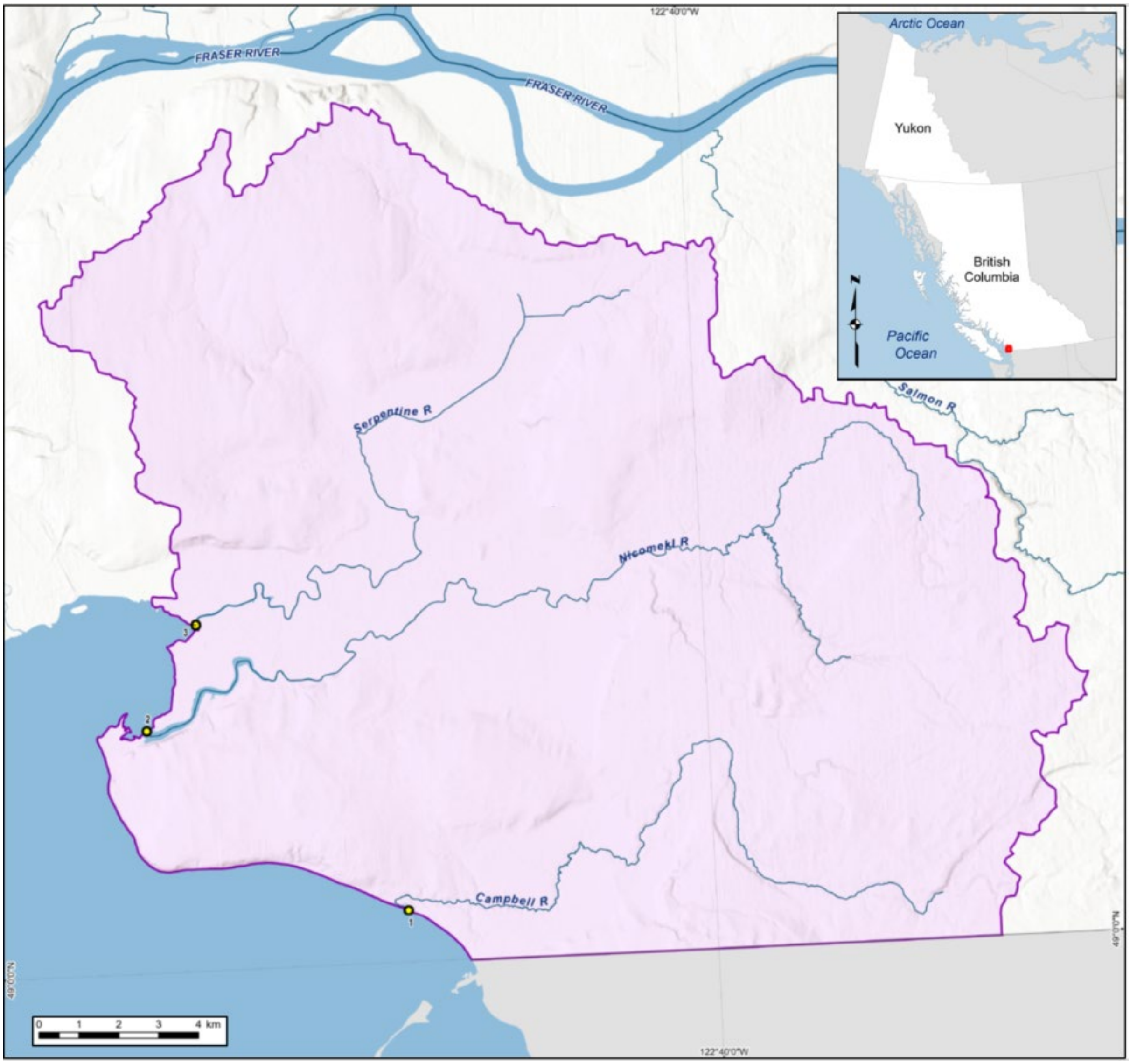

Figure 9. Map of DU1 – Boundary Bay Ocean Fall. Produced by Coastal Resource Mapping Ltd. for Fisheries and Oceans Canada. Note that Campbell R refers to the Little Campbell R.

Chinook Salmon are present in the Serpentine, Nicomekl and Little Campbell rivers; however, little information is known about the spatial extent of spawning and rearing locations within those systems. Tributaries of the Little Campbell River extend into the US, but all spawning is thought to occur in Canadian waters.

2.5.1.2 DU6 – Lower Fraser River Ocean Summer (Maria)

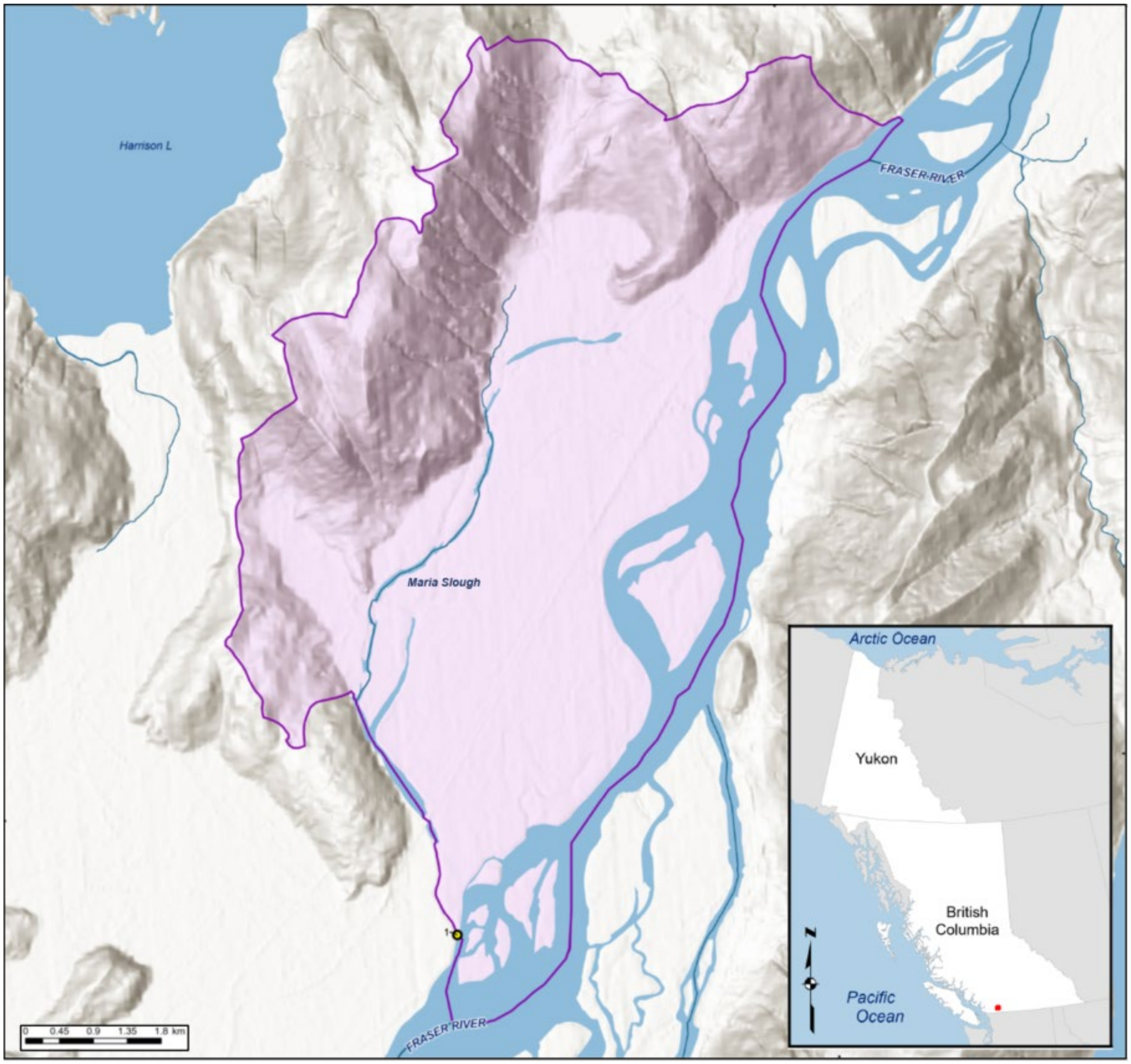

Figure 10. Map of DU6 – Lower Fraser River Ocean Summer (Maria). Produced by Coastal Resource Mapping Ltd for Fisheries and Oceans Canada.

Chinook Salmon migrate to Maria Slough, the only known spawning site of DU6, from July 16 to August 31 and spawn in October. Hatchery-reared Maria Slough origin Chinook Salmon have also been released in the nearby Camp and Hope Sloughs, but it is unknown if any naturally sustaining populations persist in these areas because they are not surveyed for escapement. In years with low flows that have restricted access to the slough, Chinook have been observed spawning in the Fraser River immediately downstream of the Maria Slough confluence. The distribution of fry is unknown during their 50-160 days of freshwater occupancy (DFO 2007), although it is likely that the fry would utilize habitats within the lower Fraser River floodplain and the Fraser estuary before moving into the marine environment.

2.5.1.3 DU13 – South Thompson Stream Summer

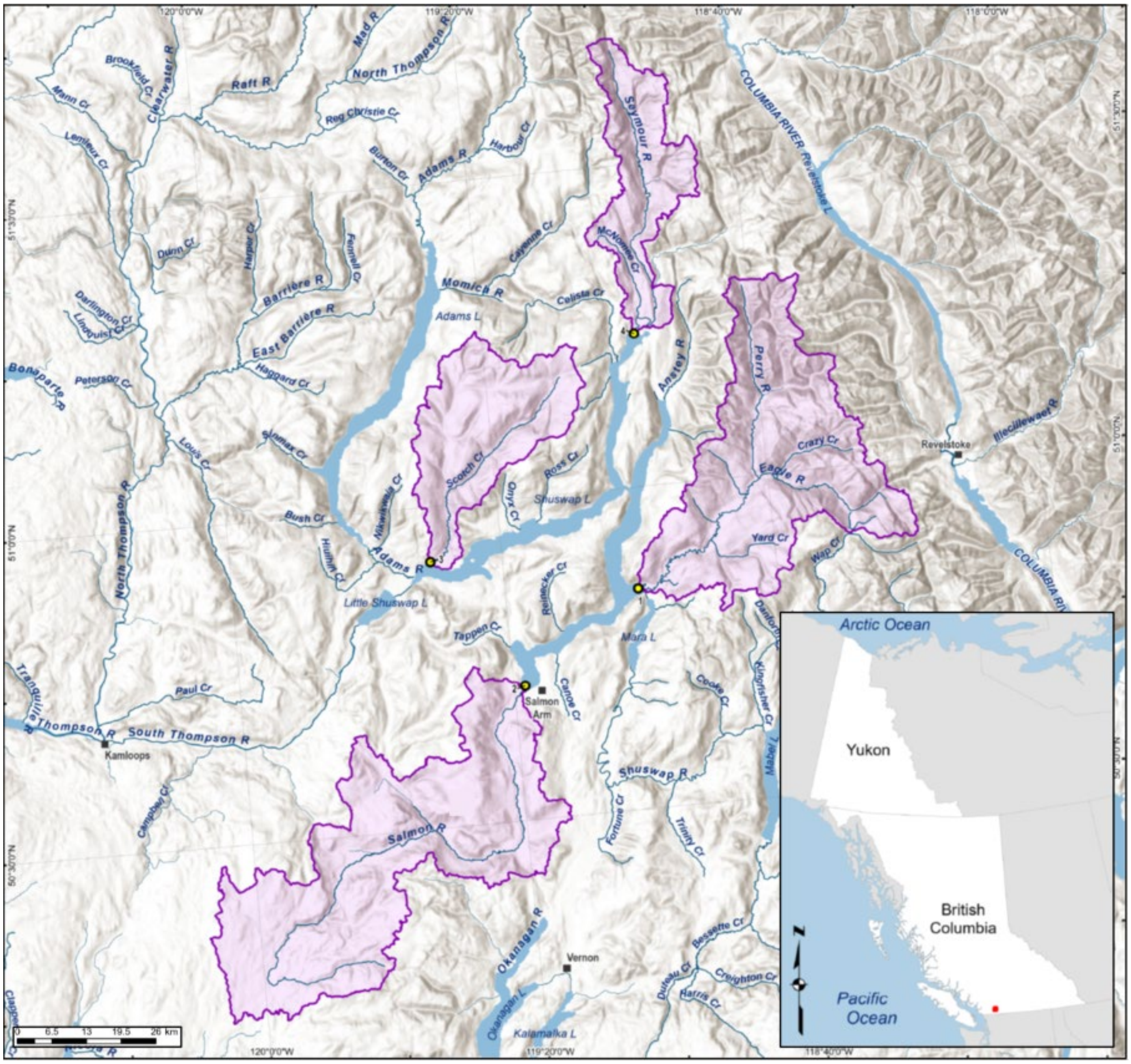

Figure 11. Map of DU13 – South Thompson Stream Summer. Produced by Coastal Resource Mapping Ltd for Fisheries and Oceans Canada.

The majority of Chinook Salmon from this DU are thought to spawn in the Salmon, Eagle and Perry rivers (Perry River is a tributary to the Eagle) with a lower proportion in the Seymour River and Scotch Creek. Spawners in the Eagle River system have been observed from approximately 10km downstream of the Perry River, upstream to Griffin Lake. Spawner distribution in the Perry River is not documented; however, redds have been observed in the lower two kilometres of the river. Within the Salmon and Seymour rivers and Scotch Creek, the distribution of spawning Chinook is not well known, although it is likely that the presence of enumeration fences in Salmon and Scotch may have influenced the distribution of spawners.

The distribution of Chinook juveniles is largely unknown; however, those that rear in the Eagle basin have been observed in Owlhead Creek. It is likely that the juveniles from this DU behave in a similar manner to those of other yearling Chinook in the Fraser. Typically, there are three strategies with broad overlaps among the three. The first strategy is that juveniles emerge from the redd and move passively and actively downstream, exiting the natal river and rearing in Shuswap Lake and downstream into the South Thompson. Overwintering likely occurs in the Lower Thompson and Lower Fraser before smolting in April or May in their second spring. Juveniles in the second strategy remain in the natal stream through the first summer after emergence and then move downstream into Shuswap Lake. Overwintering may occur in Shuswap Lake but more likely in the South Thompson and Lower Thompson rivers from where they would smolt and go to sea in April and May. The third juvenile life history strategy is for juveniles to remain resident within the natal stream throughout their first year after emergence, smolting from the natal stream in the following spring.

2.5.1.4 DU15 – Lower Thompson Stream Spring

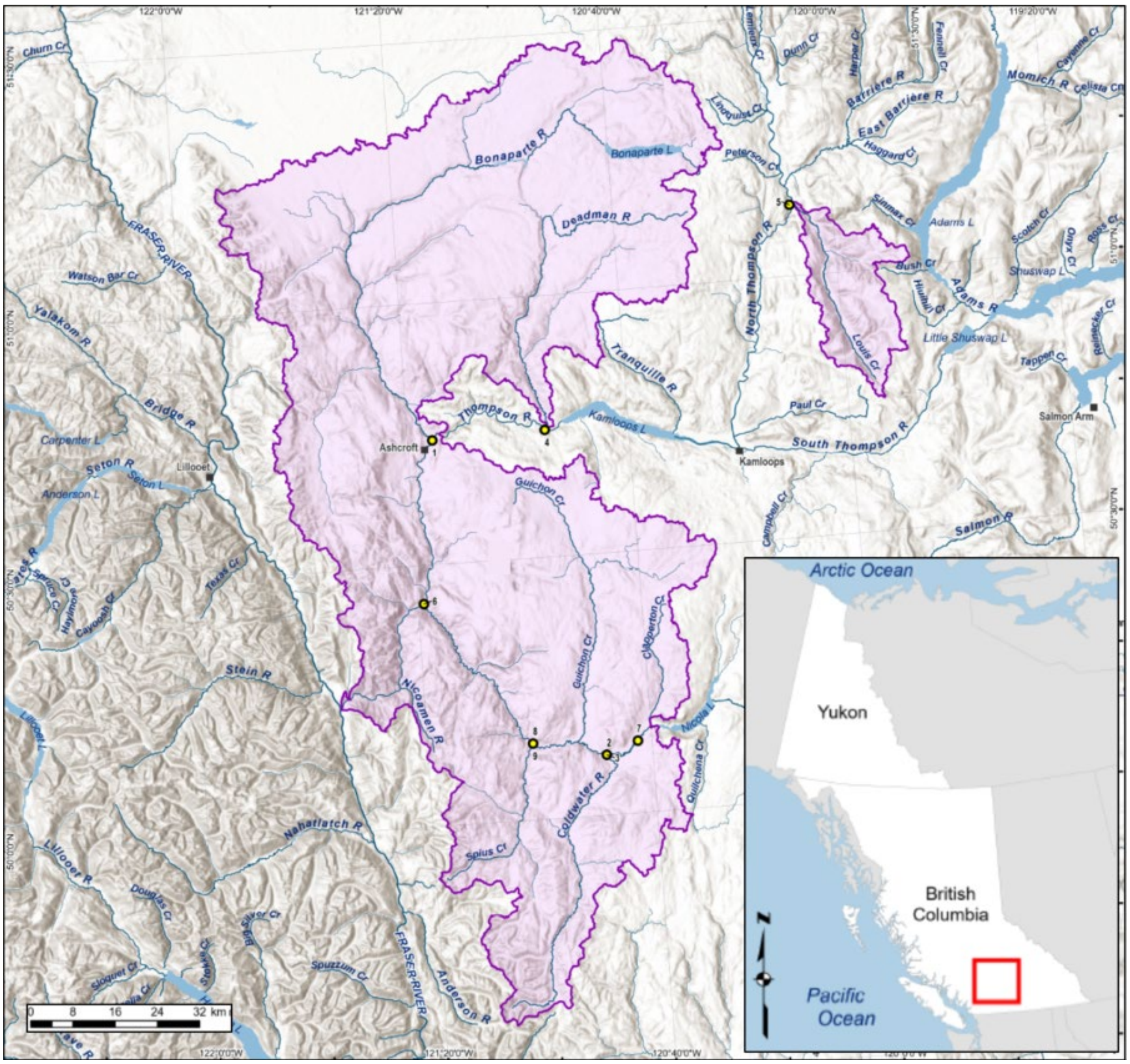

Figure 12. Map of DU15 – Lower Thompson Stream Spring. Produced by Coastal Resource Mapping Ltd for Fisheries and Oceans Canada.

Chinook Salmon are present in Deadman River and Criss Creek, Bonaparte River, and Louis Creek, while four Chinook stocks are found within the Nicola basin. The earliest-arriving Chinook Salmon spawn the Coldwater River and Spius Creek; they will also occupy Maka

Creek if water levels permit passage. The majority of Nicola Chinook spawn between the Coldwater and Spius confluences. A remnant population in the Upper Nicola River and Spahomin Creek could exist. Chinook juveniles that rear in the Nicola basin have been found in Clapperton and Guichon Creeks. In the Bonaparte, Chinook spawn both below the fishway, and above the fishway upstream to the outlet of Youngs Lake. In the Deadman, spawning occurs in the mainstem and in Criss Creek, the principal tributary. In Louis Creek, spawning occurs upstream, at least to Whitecroft.

Similar to DU13, there are three juvenile rearing strategies with broad overlaps among the three. The first strategy is that juveniles emerge from the redd and move passively and actively downstream, exiting the natal river and rearing in the Lower Thompson and downstream into the Lower Fraser. Overwintering for this group likely mostly occurs in the Lower Fraser before smolting in April or May in their second spring. Juveniles in the second strategy remain in the natal stream through the first summer after emergence and then move downstream into the Lower Thompson. Overwintering likely occurs in the Lower Thompson River from where they would smolt and go to sea in April and May. The third juvenile life history strategy is for juveniles to remain resident within the natal stream throughout their first year after emergence, smolting from the natal stream in the following spring. The exception would be Louis Creek where downstream migrants may take up residence in the North Thompson River and move downstream through Kamloops Lake into the Lower Thompson River.

2.5.2. 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 between 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). Ultimately, juveniles from DU6 migrate to the north and rear on the continental shelf, mostly between the northern tip of Vancouver Island and Prince William Sound, similar to other, far-north migrating ocean-types. Stream-type Chinook Salmon of DU13 and 15 also appear to spend their first summer in the marine environment in the Salish Sea but then migrate north along the continental shelf through and across the Gulf of Alaska, and toward the Aleutian Islands. They differ from ocean-type Chinook Salmon in their early distribution in that they are thought to exit the Salish Sea through both the Strait of Juan de Fuca and Johnstone Strait.

While the full extent of SBCC marine distribution is unknown at the DU level due to insufficient sampling to adequately characterize all rearing locations in the North Pacific, there is some evidence available from CWT recoveries (1970s to present) that can be used for inference. High seas fisheries CWT recovery data are illustrated in figures 9 to 13. CWT recovery data from Samish River Chinook Salmon were used to infer marine distribution for DU1, which lack both a CWT program and a genetic baseline. The Samish River is thought to be the most suitable comparison because they have similar run timings, average generation times, and share glacial ancestries. The majority of CWTs recovered from Samish River Chinook Salmon were from fisheries around Haida Gwaii, the Salish Sea, and the Washington coast, surmising that DU1 has a relatively local coastal shelf distribution. CWT recoveries for DU6, Maria Slough were indicative of marine residence on the central and north coast of BC and into the Gulf of Alaska, with the majority of recoveries occurring in those areas. Some recoveries of maturing fish did occur in the Strait of Juan de Fuca and the San Juan Islands, as well as the Strait of Georgia and Johnstone Strait, indicating that the return to the Fraser may occur through both the northern and southern entrances. CWT recovery data exist for most populations within DUs 13 and 15, except Seymour River and Scotch Creek in DU13 and Louis Creek in DU15. As previously mentioned, juveniles from DUs 13 and 15 migrate northward along the continental shelf to the Gulf of Alaska and then to Kodiak Island and the Aleutian Islands. There have been recoveries of DU15 adults in the Bering Sea Pollock fishery, indicating that some Chinook from DU15 enter the Bering Sea during summers. The return migration routes for both DU13 and 15 are thought to directly cross the Pacific ocean from the Aleutian Islands to the continental shelf margin in the vicinity of Juan de Fuca Strait. CWT recoveries for DU13 and DU15 are mostly from fisheries near the entrances to the Salish Sea and in freshwater fisheries occurring during the upriver migrations.

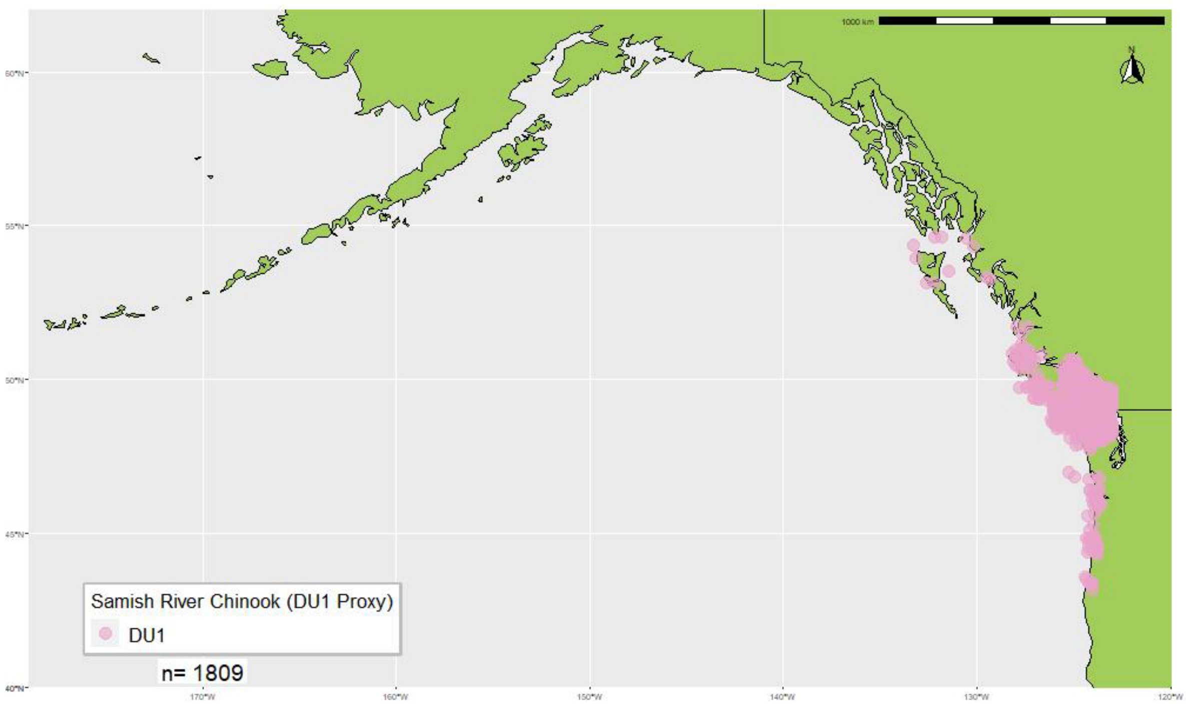

Figure 13. High seas fisheries CWT recoveries for fall-return ocean-type using Samish River Chinook Salmon as the proxy for Boundary Bay Chinook Salmon (DU1).

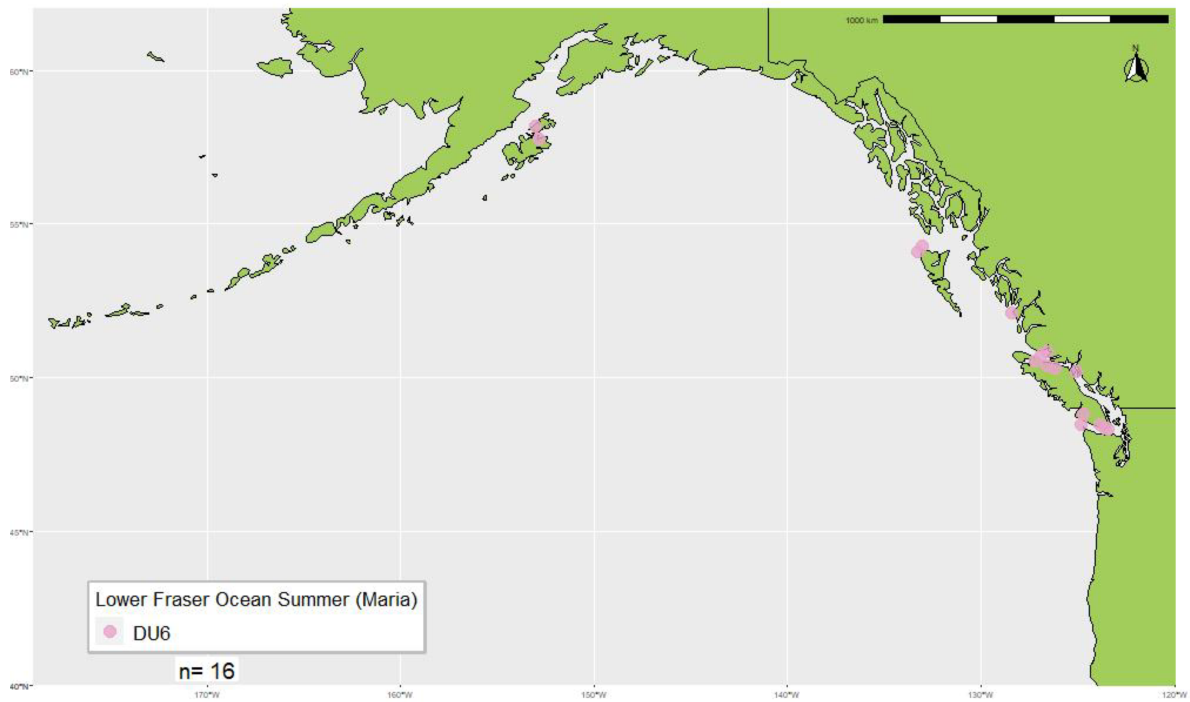

Figure 14. High seas fisheries CWT recoveries for summer-return ocean-type Maria Slough Chinook Salmon (DU6).

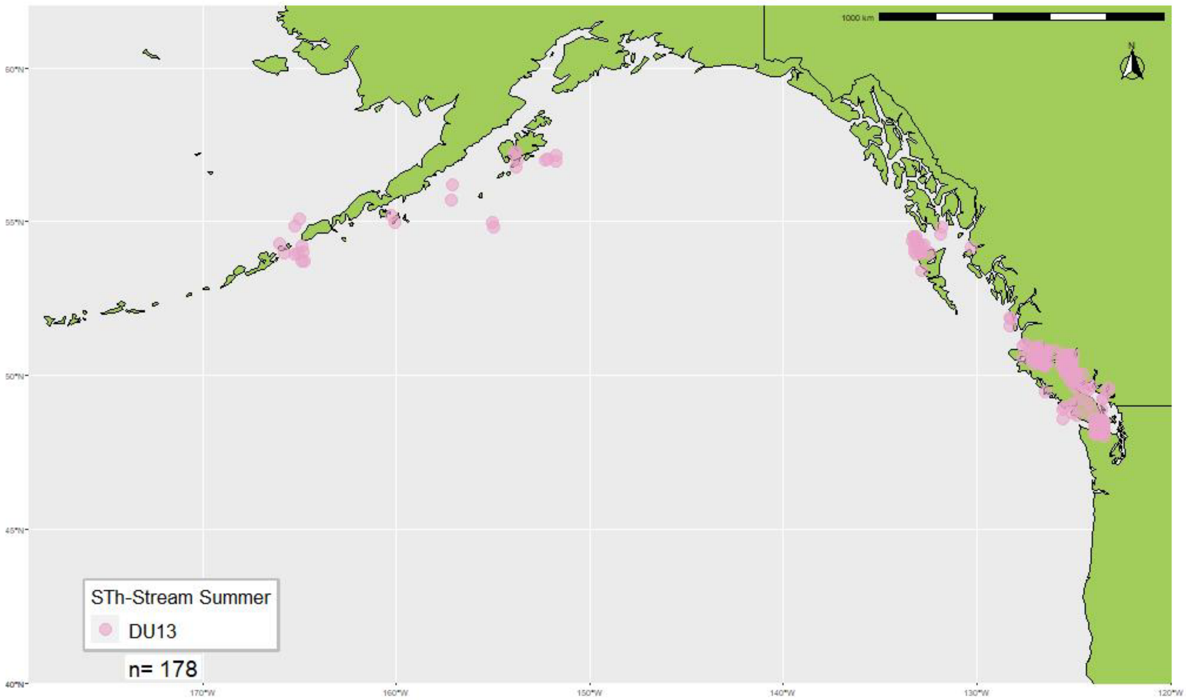

Figure 15. High seas fisheries CWT recoveries for summer-return stream-type South Thompson Chinook Salmon (DU13).

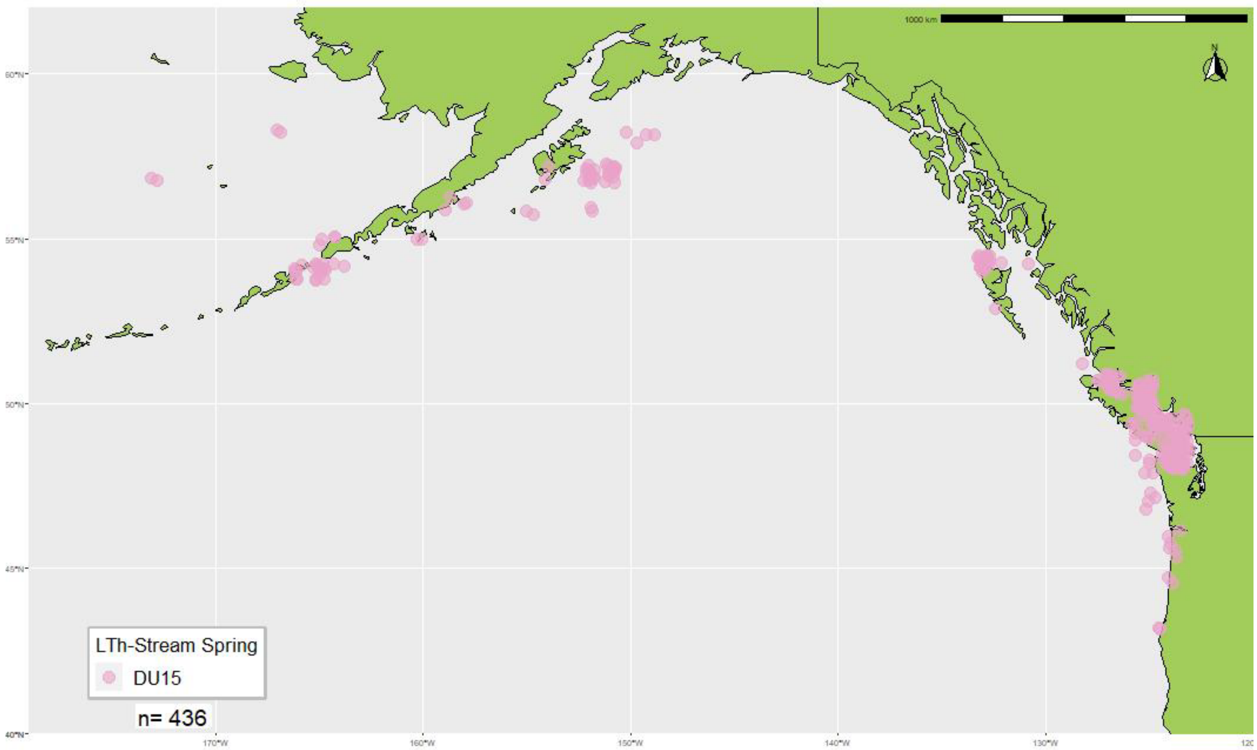

Figure 16. High seas fisheries CWT recoveries for spring-return stream-type Lower Thompson Chinook Salmon (DU15).

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

2.6.1. Dams

Dams within these four DUs vary in the degree to which they restrict Chinook Salmon. In DU1, sea dams exist along King George Boulevard near the mouths of the Serpentine and Nicomekl rivers. The sea dams were constructed to prevent salt water from permeating agricultural fields and provide fresh water for irrigation. There are hydraulically-controlled gates that open passively when pressure from the upstream side is greater than the opposing pressure at the downstream side (i.e. low tide or rain events); conversely, gates close during high tide when the pressure is greater on the downstream side. Anadromous fish passage is limited to the low tide outflow period and can be problematic during late summer and early fall when levels of tidal water remains greater than the river level for extended periods, which is concurrent with the upstream migration of Chinook spawners. Additionally, these periods of closure may also create osmoregulatory barriers to which sub-yearling juveniles may be most susceptible. The degree to which the Serpentine and Nicomekl sea dams affect the upstream migration of spawners and downstream migration of smolts has not been quantified. In early 2020, the replacements of both sea dams were announced to mitigate coastal flooding in Surrey, Semiahmoo First Nation and Delta communities. These new designs are intended to potentially alleviate fish passage concerns by installing slots of adequate size for adult Chinook to pass (City of Surrey 2019). The Serpentine River sea dam replacement is expected to be completed in the fall of 2022.

Small impoundment dams have been constructed on agricultural property for irrigation or livestock watering. One such feature is located on Jenkins Creek near 192nd St and 3a Ave which is a tributary to the Little Campbell River. It is known to prevent the upstream migration of coho to upstream spawning habitat. Although this dam is most likely above the upstream limit of DU1 Chinook migration, its potential impact is unknown.

Hydroelectric development has not occurred on the Fraser River mainstem, but dams have been constructed throughout its tributaries for irrigation purposes. In DU15, dams exist at the outflows of Nicola Lake, Mowich Lake, Mamit Lake. The Nicola Dam has a fishway that allows for the passage of Chinook spawners. However, the dam has been rebuilt multiple times and fishway access might not have been consistent between years (Chuck Parken, DFO, Kamloops, BC, pers. comm. 2021). It has been used to strategically release water during periods of low flow and hot temperatures to alleviate thermal stress for fish and maintain suitable rearing flows. The Mowich Lake dam was constructed to store water for irrigation and provide maintenance flows for fish; it is considered to be a full barrier for adult Chinook Salmon. No known dams exist for DUs 6 and 13.

2.6.2. Natural Blockages

Landslides that have culminated into impassable rapids or waterfalls have hindered Chinook migration for DUs 13 and 15. Since 1914, Hells Gate has continued to delay Chinook migration during high flows, particularly for smaller individuals. Fishways have been installed to alleviate passage issues, but the degree to which Chinook Salmon utilize this fishway is unknown. However, the relationship between migration delay at Hells Gate and spawning success for these DUs is not believed to be problematic. In DU13, anadromous fish are restricted to the lower 14.6km of the Seymour River due to a fully impassable 6m waterfall. South Pass Creek and Crazy Creek, tributaries to the Eagle River, both have waterfalls that are impassable to adult Chinook Salmon. In DU15, a 7m waterfall on the Bonaparte River historically limited Salmon habitat to the lower 2.6km. A fish ladder was constructed in 1988 to allow anadromous fish to access 140km of suitable upstream habitat. During Chinook spawning migration in the fall of 2020, Passive Integrated Transponder (PIT) array and a resistivity counter were used the quantify the proportion of Chinook Salmon that cycled through the fishway. Of the 141 fish whose movement patterns were analyzed, 105 moved upstream and 6 of those cycled through the fishway (Michael Arbeider, DFO, Kamloops, BC. pers. comm. 2021). Additionally, falls impassable to adult Chinook exist in Chasm and Clinton Creek, tributaries of the Bonaparte River, and Mow Creek, a tributary of the Deadman River.

2.6.3. 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 (Fraser River Action Plan (FRAP) 1998; Langer et al. 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). Finn et al. (2021) quantified the amount of stream and floodplain salmon habitat lost due to anthropogenic barriers in the Lower Fraser River by comparing historical and current habitat extents. The authors found that approximately 102km^2 of a historical 659km^2 of floodplain fish habitat remains in the Lower Fraser. More specifically, 4.3km^2 of 91.9km^2 (5%) remains for Boundary Bay Chinook (DU1) and 71.4km^2 of 467.4km^2 (15%) remains for Maria Slough Chinook (DU6). It is estimated that DU1 can access 28% of their historical stream habitat (184km of 660km) with 177km rendered inaccessible, 116km channelized, and 182km lost. DU6 can access 38% of their historical stream habitat (21km of 55km) with 21km rendered inaccessible and 13km lost.

2.6.4. Low Water Levels

Chinook Salmon are restricted in migration and spawning when reaches are rendered inaccessible due to low water levels. Low water levels naturally occur through the late summer to the winter in snowmelt-driven hydrographs (DUs 13 and 15) with the timing of these low water events occurring when Chinook Salmon are spawning. In rain-driven hydrographs (DU1 and 6), low water levels typically occur in spring and summer months when juvenile Chinook Salmon are outmigrating. While this typically does not cause issues for migrating and spawning Chinook Salmon, it can become a barrier in years of unusually low water especially when coupled with increased pressure on rivers due to agricultural withdrawals. Although withdrawals are unlikely to lower flows to create a physical barrier, a thermal barrier may be created due to low water levels and high summer temperatures. This is particularly an issue within DUs 13 and 15 where summers tend to be hot and dry and agricultural pressures have increased in recent years. This is likely to become a more common issue with climate change.

Low water levels possess additional challenges for migrating Chinook when they need to pass through culverts to access habitat. Poorly designed culverts have a large entrance height restriction or the shape and position are not suited to provide adequate water depths during periods of low flow which pose problems for fish passage. Chinook from DU1 are particularly affected by low water and culverts due to the highly urbanized landscape in this DU. A culvert at 104 Avenue on the Serpentine River (DU1) was determined to be a consistent barrier to passage under the criteria for *Field Assessment for Determining Fish Passage Status* (BC Ministry of Environment (MOE) 2011). Historically, Chinook spawners had been observed upstream of the culvert while anadromous fish are not currently observed upstream of it[7]. Another perched culvert on Jacobsen Creek (tributary to the Little Campbell River, is known to restrict Coho migration to upstream spawning habitat. It is unknown if DU1 Chinook would migrate this far upstream, but a project is underway to restore access through this barrier in 2022.

A concrete box culvert at km26 on the Canadian Pacific Railway (CPR) on the Eagle River (DU13) is a barrier to fish migration during low flow periods and blocks high quality upstream spawning and rearing habitat. The barrier is thought to have been occurring for decades but went undetected due to its remote location. Several studies were conducted and mitigation options were explored after CPR was advised of the barrier in 2002; however, the complexity of the situation and costs of mitigation have delayed the pursuance of a solution. At km25, a sub-surface diversion of the Eagle River through the railway grade can result in dewatering the main stem and cause fish kills. Additionally, the Perry River (a tributary of the Eagle River) has a partial obstruction at 6km that may restrict fish passage at certain water levels and is known to be Chinook spawning habitat. On the Salmon River (DU13), a nearly 13km portion in the middle reach of the flows underground until it resurfaces at the community of Westwold for most of the year. An irrigation weir, located west of Falkland near the Highway 97 crossing, can also be a

[7] Backman, D.C. and Simonson, T.L. 1985. The Serpentine River watershed salmonid resource studies, 1984-85. Unpublished report prepared for the Tynehead Zoological Park.

barrier to fish passage at low water levels. In 1998, prior to installing a perched culvert on Rumball Creek between Salmon River and Foothills Road, juvenile Chinook Salmon were found to be rearing upstream of it.

Maria Slough spawning habitat is primarily comprised of four constructed spawning channels that rely on berms to concentrate flow through areas of appropriate gradient and substrate composition. These spawning channels are at risk of low flow through blockage by beaver activity or berm failure which could result in flow bypassing the spawning habitat. An overflow culvert that had been leaking was repaired in 2021, to maximize flow through the spawning channels.

2.6.5. Anticipated Barriers

In DU13, there is concern that there could be a channel avulsion on the Seymour River and restrict the lower reaches of the present channel where a significant portion of Chinook spawning occurs. There is also the potential for future flood protection infrastructure to be constructed at Maria Slough, which would force upstream migration through flood gates and potentially impact outmigrating juveniles through the pumps.

2.7. 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). Redds, i.e. spawning nests constructed by Pacific Salmon and other fish species, are considered residences because they meet the following criteria:

- individuals (not a population) make an investment (e.g., energy, time, defense) in the redd and/or invest in the protection of it;
- the location and features of the redd contribute to the success of a life history function (i.e., breeding and rearing);
- 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). 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).

3. THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF SBCC SALMON

3.1. 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 2014b). 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 negatively consequential behavioural changes to SBCC, 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 SBCC 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.

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 Guidance on Assessing Threats (DFO 2014b), Ecological Risk and Ecological Impacts for Species at Risk, to the extent possible in the context of limited data and information on threats to SBCC within Canadian waters (DFO 2014b). For these four DUs, a working group made up of biologists from DFO, academia, and First Nations assessed threats using the IUCN-CMP threat assessment method used by COSEWIC during a three-day workshop led by a COSEWIC facilitator that took place virtually October 12-14, 2021 (Appendix E). 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. If conflicting opinions divided the expert group, the threat was scored with an unknown impact. Otherwise, no threats were scored without group consensus. The threat assessments determined during the workshop were subsequently converted to the DFO standardized assessment method (DFO 2014b).

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 2014b). 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 E. In some cases, a threat risk category was omitted if it was not deemed to be a threat to SBCC. Any category omitted was identified at the top of the section.

Table 19. Definitions for the Levels of Impact (a), Likelihood of Occurrence (b), and Causal Certainty (c) that may be assigned to each threat category. Definitions were modified from DFO (2014b) 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.

a)

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.
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.

b)

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.

c)

Causal Certainty	Definition
Very High (1)	Very strong evidence that threat is occurring and the magnitude of the impact to the population can be quantified.
High (2)	Substantial evidence of a causal link between threat and population decline or jeopardy to survival or recovery.
Medium (3)	There is some evidence linking the threat to population decline or jeopardy to survival or recovery.
Low (4)	There is a theoretical link with limited evidence that threat is leading to a population decline or jeopardy to survival or recovery.
Very Low (5)	There is a plausible link with no evidence that the threat is leading to a population decline or jeopardy to survival or recovery.

3.1.1. Residential and Commercial Development

3.1.1.1 Housing and 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 3.1.9 Pollution and Contaminants (IUCN-CMP threat category 9.1).

The lower Fraser Valley and Southern Mainland are 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 new development that may encroach on SBCC habitat. Development upstream of the lower mainland will continue through time, although significant in-river impacts beyond those in the lower Fraser River and Boundary Bay are unlikely due to reduced density in these areas.

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]. In the lower Nicomekl River (DU1), there is an anchorage of around 15 boats inhabited year-round; however, the type of boats and number of inhabitants are unknown. As the price of land in the lower mainland continues to increase, it is possible that the number of boats and houseboats in the area will increase. Houseboats are present in Shuswap Lake (DU13) during summer months; however, their impact is likely minimal due to their seasonality and low density. The overall impact of houseboats is unknown but is not expected to be positive.

The scope of this threat is pervasive for all four DUs because all juvenile and adult salmon migrate through rivers in the Lower Mainland where they will likely encounter any new development or houseboats. Ephemeral habitat used by Chinook juveniles in DU1 is at risk from the growing pressure to increase housing supply in the Lower Mainland. Stream-type Chinook (DUs 13 and 15) and ocean-type Chinook (DU6) are at risk of new urban development between Hope and Mission, as stream-type juveniles overwinter in these areas and ocean-type Chinook rear in these areas, and removal of this habitat could lead to increased competition,

[8] Peace Arch News. 2017. Homeless count records people living on South Surrey River. Peace Arch News. [Accessed November 17, 2021]

overcrowding of other areas and a reduction in habitat capacity for Chinook Salmon production. Future urban development likely poses some threat to all SBCC DUs, yet the level of impact is currently unknown.

3.1.1.2 Commercial and 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 and lower Mainland around Boundary Bay are highly developed and multiple commercial and industrial expansion projects have been proposed. There are a number of industrial developments on the banks of the Fraser River and Boundary Bay rivers, some of which are encroaching on critical foreshore habitat. One such development is Roberts Banks, an 8000ha 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, including SBCC before their seaward migration; 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 3.1.9 Pollution and Contaminants*).* 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). The Metro 2050 Regional Growth Strategy initiative also proposes urban expansion in the lower mainland, including along the lower Fraser River (Metro Vancouver 2021), although the specific footprints and impacts are unknown. The Little Campbell River is the least developed drainage in DU1 because a large proportion of it is currently bordered by ALR. However, the City of Surrey endorsed the South Campbell Heights Land Use Plan in 2017, which proposes the expansion of its urban containment boundary by 600 acres to support industrial development. The Plan Area is bisected by the Little Campbell River, includes areas of floodplain associated with the river, and overlays the Brookswood aquifer, which is an unconfined aquifer that provides the base flow source for the Little Campbell River. Additionally, a 77 acre truck parking lot has been proposed adjacent to the Little Campbell River[10], which would allow parking, truck washing, oil change and tire services, and washroom facilities. While it is currently unknown whether the aforementioned proposed expansions will proceed, these developments are anticipated to cause net losses in habitat and have an overall negative impact on all SBCC DUs.

This threat is pervasive in scope because all DUs migrate through rivers in the lower mainland and will be similarly impacted by the encroachment of new industrial areas. Though the impacts from industrial development on SBCC have not been quantified, expert opinion from the Threats Calculator workshop concurred that there is likely a low level of impact for DUs in the lower Fraser River (DU6-Maria, DU13-STh-1.3, and DU15-LTh-1.2) and an unknown impact for DU1 (Boundary Bay) because some of their habitat is concentrated within areas experiencing

[9] Raincoast Conservation Foundation. 2016. Roberts Bank Terminal 2 Assessment - Sufficiency and Technical Merit Review. [Accessed March 14, 2022]

[10] Peace Arch News. 2015. Truck Park Planned near Little Campbell River. [Accessed November 24, 2021]

ongoing pressure for development. It is important to note that this is only the impact from new activities; the impact that has occurred from past encroachment of development into SBCC habitat was not considered in the assessment of this threat's risk level.

3.1.1.3 Tourism and 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 the lower Nicomekl River, with increasing urban densification in the lower mainland that may lead to growing pressure for development in an already highly degraded habitat. There is not currently enough information to predict the amount of tourism and recreation development that will occur in any of the DUs, but marina upgrades and expansions will likely happen. Overwater structures, such as marinas, reduce natural lumens below and adjacent to them, causing reduced growth and density of aquatic plants; in some cases, inadequate light from overwater structures 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, do 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. In DU13, Shuswap Lake has considerable tourist traffic and infrastructure, including overwater structures, all of which have the potential to increase.

The impacts from tourism development, specifically marinas, on Chinook Salmon are not known with certainty. The scope of this threat is pervasive for all SBCC DUs, as all juvenile and adult salmon migrating through or rearing in the lower Fraser River or Boundary Bay rivers are likely to encounter any new developments. Tourism development may also occur in nearshore marine environments, most likely near populated areas such as Vancouver, the Sunshine Coast, and southeastern Vancouver Island; however, impacts to SBCC are likely negligible.

Table 20. DFO threats assessment calculator results for impacts from Housing and 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 and Urban Areas	DU1	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 21. DFO threats assessment calculator results for impacts from Commercial and 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 (2014) 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 and Industrial Areas	DU1	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 22. DFO threats assessment calculator results for impacts from Tourism and 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 and Recreation	DU1	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive

3.1.2. Agriculture and 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 SBCC DUs discussed in this report.

3.1.2.1 Annual and 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 3.1.9.3Agricultural and Forestry Effluents Agricultural and Forestry Effluents (IUCN-CMP threat category 9.3).

There is significant land use adjacent to the lower Fraser River and Boundary Bay rivers with much of the existing development behind dikes. 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% (37,669ha) 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% (9,943ha) consists of relatively small areas and provides limited opportunity for further agricultural development. This includes construction of greenhouses on existing fields, which can limit 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 400,000m^2 (Fraser Valley Regional District 2017). Intensification or conversion of existing agricultural land in the lower Fraser River is therefore a possible threat to SBCC in future years.

Significant agricultural footprints exist within certain areas of all four DUs. However, this threat was not scored for DUs 1 and 15 because the growth of agricultural footprints is not expected. The majority of the Serpentine, Nicomekl and Little Campbell rivers are currently bordered by agriculture, with the exception of urban development along the south bank of the lower Nicomekl River. However, agriculture is unlikely to increase in DU1 because any undeveloped land is instead expected to support housing or industrial development. This threat was scored to be low in scope for DUs 6 and 13 with slight impacts. In DU13, extensive agriculture occurs in the lower Eagle River and is expected to increase in the upper reaches of the Salmon River. The conversion of forest to agricultural land may also result in a significant loss of overwintering habitat throughout freshwater habitat, particularly at high water levels. Limited riparian area remains 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 impact FRC. Predicting the magnitude of impacts from future development is difficult, but some negative impacts for DUs 6 and 13 are anticipated.

3.1.2.2 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 SBCC through disturbance, alteration, damage, or destruction of redds when crossing or standing within streams. Although it is possible for livestock (primarily cattle) to enter SBCC habitat for all DUs, the impacts from this threat are thought to be negligible or non-existent due to the location of cattle ranching operations. Livestock typically only enter low gradient river sections and riparian buffers and fencing are thought to deter them from entering or crossing, thus limiting 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 and livestock currently enter the stream and riparian area in DU15.

This threat was deemed small in scope for DU13, restricted in scope for DU15 and was not scored for DUs 1 and 6. Cattle have been observed within the Salmon River (DU13) and the Nicola, Deadman, and Bonaparte rivers and Louis Creek (DU15). Cattle could possibly enter streambeds in shallow parts of Maria Slough, Bonaparte River, Coldwater River, and Spius Creek. In the Nicola basin, however, cattle typically occupy higher-elevation range when Chinook spawners are present. In systems where cattle are present, their impact is likely negligible. This is supported by a study in Oregon that found that cattle contacted the redds less than 0.01% of the time when near active spring Chinook Salmon redds (Ballard and Krueger 2005). 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 3.1.9.3 Agricultural and Forestry Effluents.

3.1.2.3 Marine and 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 3.1.5.2 Fishing and Harvesting Aquatic Resources, and threats from disease transmission and introduced genetics are discussed in section 3.1.8 Invasive and Other Problematic Species and Genes.

Fish aquaculture is pervasive in the Fraser River and Boundary Bay river basins and nearshore rearing habitats, so it is probable that all SBCC 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 the footprint of open net pens and they were not considered to be a threat to SBCC. There are, however, concerns surrounding competitive interactions between SBCC and hatchery-origin fish, which can impact wild populations through competition for food and spatial resources if hatchery-origin fish occupy preferred feeding areas and displace wild fish to less productive feeding areas. Hatchery fish comprise around 40% of salmon in the ocean (Ruggerone and Irvine 2018), the interactions with which could produce significant effects. Overall, ecological interactions between SBCC and hatchery-origin fish are largely unknown. Inter-specific competition with other Pacific Salmon species is generally 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). However, density-dependent survival of hatchery Chinook Salmon released into the central and southern parts of the Salish Sea was negatively associated with the abundance of juvenile Pink Salmon and hatchery Chinook release numbers in even-numbered sea-entry years (Kendall et al. 2020). Ecological interactions between SBCC and hatchery-origin Chinook Salmon represent a knowledge gap in this assessment.

Competitive interactions between wild SBCC and hatchery-origin Chinook Salmon represent a major threat from aquaculture because their life-histories and ecological niches significantly overlap. 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, Boundary Bay rivers and all associated estuaries 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 reduced carrying capacity for Chinook juveniles and the number of fish may exceed this capacity due to the high degree of hatchery supplementation in the Boundary Bay, Fraser River and nearby drainages into Puget Sound. The critical size and period hypothesis suggests that the ability for Chinook to forage and grow in nearshore and offshore estuarine habitats may largely influence their early marine survival and cohort abundance (Beamish and Mahnken 2001). While not SBCC-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, substantial early natural mortality can occur in marine environments, mostly from predation (e.g. river lampreys) (Beamish and Neville 1995) when juvenile Chinook do 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), 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.

In addition to increased Fraser hatchery salmon production, the State of Washington created the Southern Resident Orca Task Force (SROTF) in 2018 in response to declines in the endangered population; it mandates to identify, prioritize, and support the implementation of a long-term action plan for the recovery of Southern Resident Killer Whales (SRKW), including Chinook hatchery production (SROTF 2018). The Task Force recommended that Chinook hatchery production for SRKW-preferred stocks should increase by approximately 50 million smolts beyond 2018 levels to augment the diet of SRKW with 30 million of those proposed for Puget Sound (Washington Department of Fish and Wildlife 2019).

This threat was considered pervasive for all DUs because wild SBCC interact with hatchery-origin fish throughout their lifecycles. This threat was deemed to have a serious-moderate impact for DUs 1 and 6 as all populations within DUs are enhanced, although there is high uncertainty surrounding these scores due to insufficient information. Wild populations in these DUs have relatively low abundances and low PNIs, which could exacerbate the impact of competitive interactions with hatchery-origin fish. Maria (DU6) and Boundary Bay (DU1) Chinook are likely to encounter relatively more hatchery stocks during their occupancy along the coastal shelf. Freshwater competition during juvenile life stages is likely lower for ocean-type Chinook Salmon due to shorter freshwater life histories and most hatchery-fish are released as smolts instead of fry. This threat was deemed to have a moderate to slight impact on DUs 13 and 15 because Salmon River Chinook are the only population currently enhanced in DU13 and Nicola, Coldwater and Spius are the only enhanced populations in DU15. 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 SBCC DUs, as ocean-type variants make up the majority of overall numbers in the Fraser River and other SBCC drainages (Figure 17). 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).

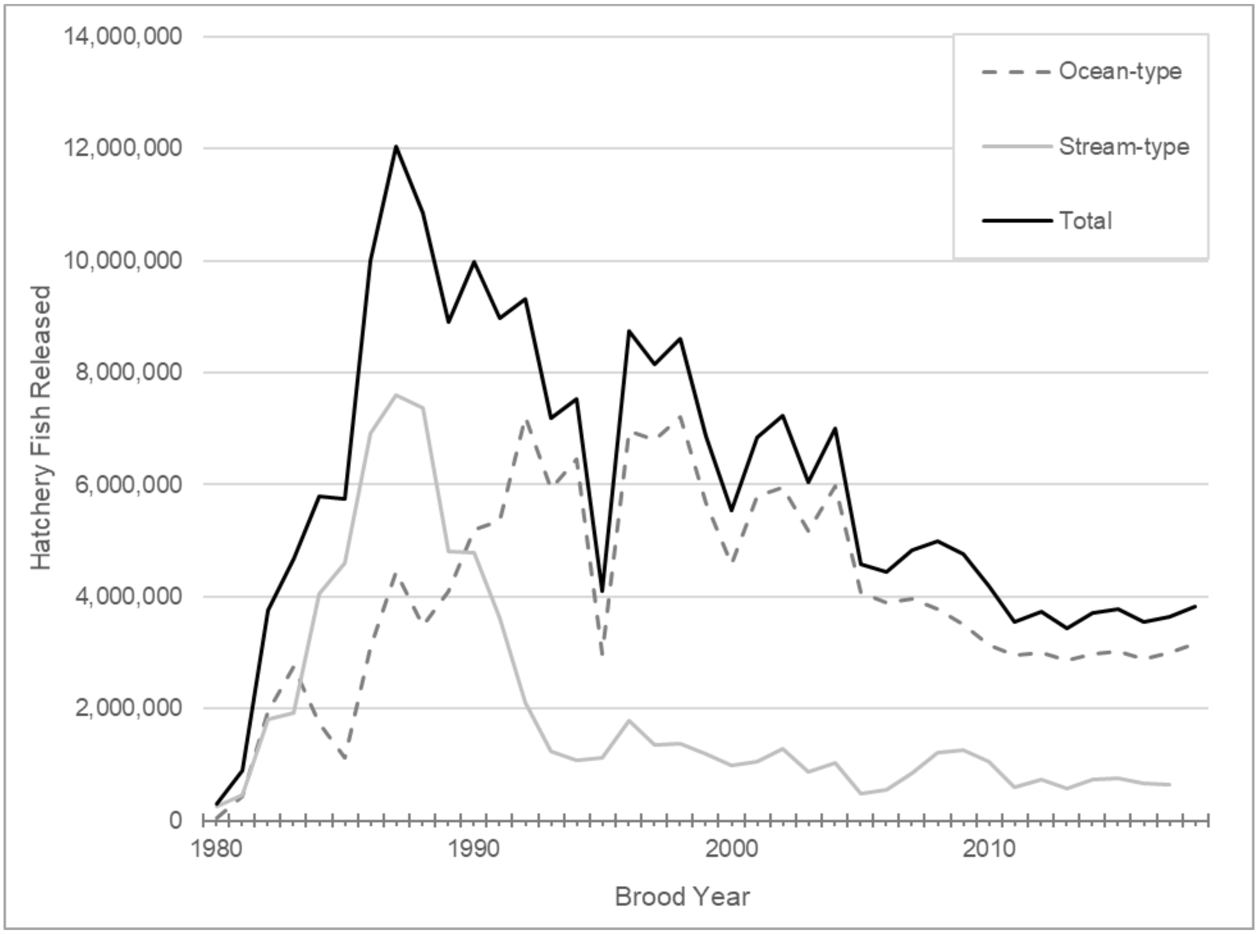

Figure 17. Ocean and stream-type hatchery releases of Chinook Salmon in the Fraser River Basin from 1980 to 2020.

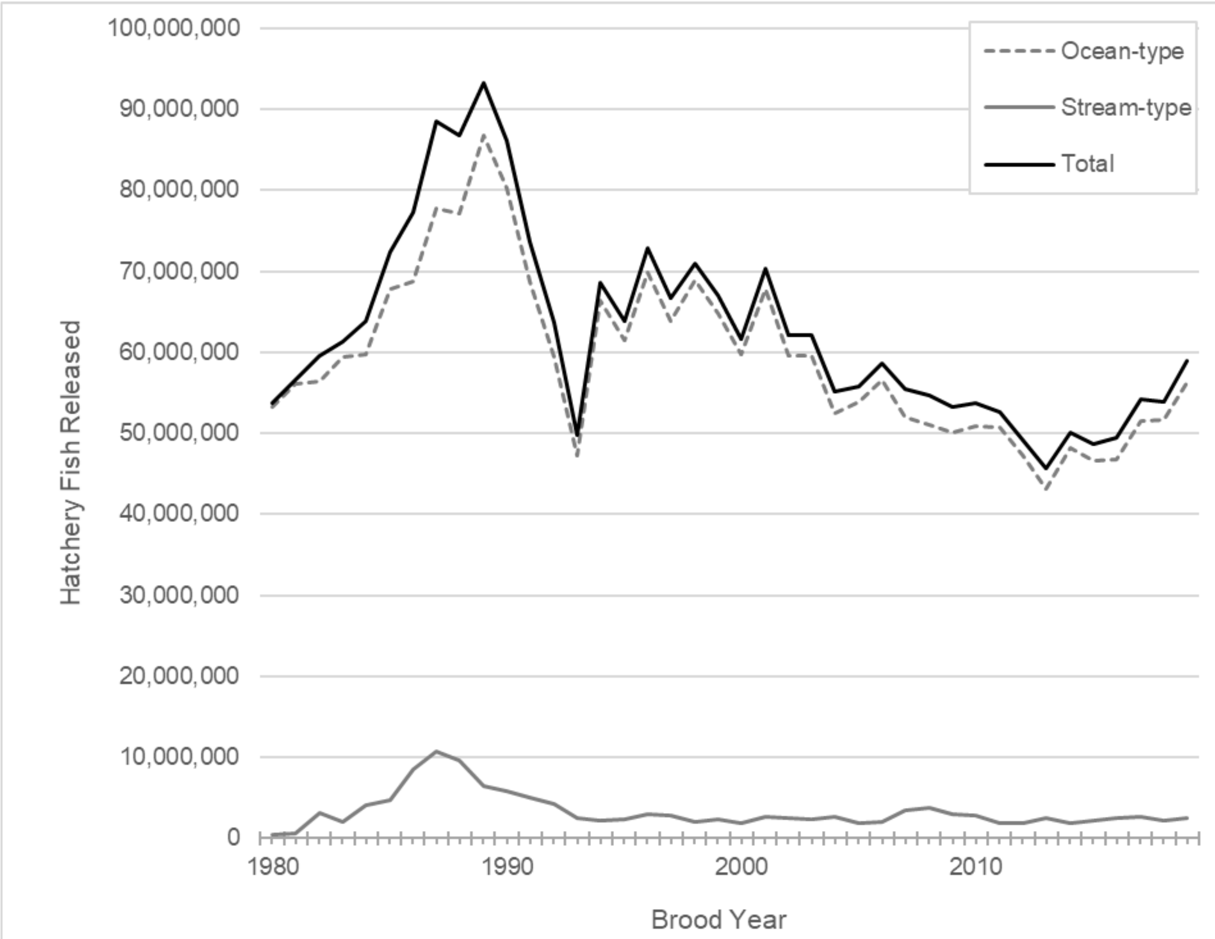

Figure 18. Ocean and stream-type hatchery releases of Chinook Salmon in the Salish Sea from 1980 to 2020.

Table 23. DFO threats assessment calculator results for impacts from Annual and 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 and Perennial Non-Timber Crops	DU6	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Restricted
	DU13	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Restricted
	This is not anticipated to be a threat for DUs 1 and 15.							

Table 24. DFO threats assessment calculator results for impacts from Livestock Farming and 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 (2014) 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 and Ranching	DU13	Known	Low	Medium	Low (3)	Historical/Current/ Anticipatory	Continuous	Restricted
	DU15	Known	Low	Medium	Low (3)	Historical/Current/ Anticipatory	Continuous	Narrow
	This is not anticipated to be a threat for DUs 1 and 6.							

Table 25. DFO threats assessment calculator results for impacts from Marine and 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 and Freshwater Aquaculture	DU1	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive

3.1.3. Energy Production and Mining

IUCN-CMP threat category 3.1 Oil and Gas Drilling and 3.3 Renewable Energy are not included in this section, as to our knowledge, these activities are not occurring directly within C habitat. Hydroelectric facilities are considered under section 3.1.7.2 Dams and Water Management.

3.1.3.1 Mining and 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 3.1.9.2 Industrial and 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. 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 SBCC. There is some evidence that overwintering SBCC from upstream use the gravel bars and are impacted by gravel extraction (Bill Rublee, Triton Environmental, pers. comm. 2019). It is considered unlikely that extractions would have large impacts as there are other habitats that SBCC could utilize (but it adds to cumulative habitat impacts). Alterations through gravel extraction have immediate impacts on SBCC 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 setbacks. Impacts from future gravel removal was thought to be likely for DU6 (Maria) because of a known gravel extraction event in 2014 around Seabird Island. Additionally, out-migrating Maria 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. Historically, placer mining was pervasive in the Fraser River and there are lasting sediment effects in the lower Fraser River (Nelson and Church 2012). DU15 (LTh-1.2) was deemed to be at the greatest risk from this threat, as placer mining activities are ongoing in many of the streams, with some recreational permit holders using excavators to dig in the streambed (Paul Mozin, Scw'exmx Tribal Council, Merritt, BC, pers. comm. 2021). 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).

Several large open pit mines exist within the boundaries of DU15 (LTh-1.2) but the footprint does not exist within the river and any impacts are likely due to pollution and will be discussed later in the document. Both placer and open-pit mining activities have the potential to increase in the future and 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 26. DFO threats assessment calculator results for impacts from Mining and 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 and Quarrying	DU6	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	This is not anticipated to be a threat for DU1.							

3.1.4. Transportation and 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 SBCC DUs.

3.1.4.1 Roads and 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 3.1.9.1 Household Sewage and Urban Waste Water (IUCN CMP threat category 9.1). This threat ranking does not include impacts associated with general modifications to catchment surfaces caused by roads and railroads, see 3.1.7 Natural Systems Modifications.

The roads and railroads threat to SBCC addressed in this section is limited to the activities associated with new footprints, ongoing impacts of the immediate footprints currently in place and maintenance of stream crossings. The density of these infrastructures and their maintenance frequencies are expected to increase with human population density.

An old CPR line installation from the late 1800s infilled upstream and downstream access to an Eagle River bend above Griffin Lake with railway ballast. A new steeper, boulder lined channel was built alongside the rail line to provide passage past the blocked channel for both adult and juvenile fish. Over time this has proven to be an inadequate solution as there are ongoing issues with fish passage and fish mortality. Upstream movement is hampered due to increased velocities at higher water levels and both downstream and upstream movement can be cut off as this section of the Eagle River becomes intermittent during lower water events. The footprint of the railway ballast also serves as an ongoing mortality risk to fish. Water is still drawn through the coarse rock structure into the old channel which acts to sieve and strand juvenile fish. A number of remediation approaches have been considered including a bridge span, but to date, no actions have been taken.

Bridges are generally used to span Chinook spawning systems due to their larger size; however, cost considerations often lead to less expensive culvert installation on smaller streams potentially inhabited by juvenile Chinook life stages. Both culvert and bridge construction on smaller tributaries often requires that the stream be blocked or diverted during construction, which can temporarily affect fish behaviour and access. The relatively low frequency and small footprint of stream crossing construction and maintenance, as well as adherence to timing and mitigation measures should limit these specific impacts.

Longer term issues can develop, however, when culverts and bridges are not sized properly as culverts can become impassible and cut-off large sections of upstream habitat (Mount et al. 2011) and both can be washed out during high water events. Washouts will likely increase as climate change impacts hydrographs. Culverts can also sever the natural downstream gravel and LWD recruitment processes vital to rearing (House and Boehne 1986). Though spawning adults are unlikely to be impacted by culverts, juvenile rearing habitat access can be impeded. This is not always the case, however, as a poorly designed culvert in DU6 (Maria) has led to several years where passage into the spawning grounds has been almost impossible and resulted in extremely low escapements (near 0).

There is ongoing work in BC to replace old culverts with crossings built to higher standards though it is far outpaced by new culvert installations and it is not clear if culverts existing in the range of the DUs discussed here are in scope. Work to upgrade stream crossings may temporarily impact SBCC but the net effect is expected to be positive. 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.

Building, maintenance, and ongoing footprints of roads and railways are known to negatively impact salmonids during all life stages when impacts are not properly mitigated. DUs that were potentially threatened by roads and railways scored moderate to slight given that uncertainty exists in the efficacy of mitigations of building and maintaining transportation corridors. The doubling of the TransCanada highway (TCH) between the Alberta border and Chase, BC could be potentially harmful to DU13 (STh-1.3) as the highway crosses the mouth of the Salmon River and runs along the Eagle River. Additionally, there is concern that there will be an increase in salvage logging due to the extensive wildfires in DU15 which will lead to an increase in the number of forest service roads in the area. DU1 (BB) scored negligible for this threat as the geographic location within the Lower Mainland already has an extremely high density of roads and railways. While density is likely to increase further with the approval by the City of Surrey to build a new road through Bear Creek[11], it is unlikely that this will cause further declines in this DU.

3.1.4.2 Utility and 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 3.1.9.2 Industrial and Military Effluents (IUCN CMP threat category 9.2).

The TransMountain Expansion (TMX) Pipeline is the most extensive utility route near freshwater habitat used by SBCC and it crosses approximately 1000 fish bearing streams between Edmonton and Burnaby[12]. This pipeline crosses the South Thompson River (a DU13 migration corridor) and the Coldwater River (used for all freshwater stages of DU15)), and along the lower Fraser River (a migration corridor and potential rearing area for all upstream DUs and particularly DU6). The TransMountain Expansion Pipeline is currently being twinned. Efforts will be made to minimize impacts for stream crossings on the South Thompson River and Coldwater River through horizontal directional drilling; however, the expansion will impact the Coldwater River in particular as the water will need to be temporarily diverted.

A new neighbourhood is being built in Maria Slough (DU6) for which water and utility lines will be built and require servicing in the future. This work will occur in the vicinity of the spawning habitat and could have the potential to be harmful if not properly mitigated.

3.1.4.3 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 DUs covered in this report with the exception of DU1 (BB), 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 SBCC, which can affect survival (Gregory 1993; Gregory and Northcote 1993). An unknown proportion of SBCC juveniles rear and overwinter in the lower Fraser River so there

[11] CBC News, 2021. Surrey approves construction contracts for controversial road through Bear Creek Park [Accessed March 14, 2022]

[12] TransMountain. 2018. Watercourse Crossings in Burnaby. [Accessed March 14, 2022]

will likely be some impact to an unknown proportion of each of the DUs. Since most 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 et al. 2002). The DU level impacts, however, are currently unknown; therefore, this threat was not scored.

Table 27. DFO threats assessment calculator results for impacts from Roads and 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 and Railroads	DU1	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Broad
	DU13	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	This is not anticipated to be a threat for DU6.							

Table 28. DFO threats assessment calculator results for impacts from Utility and 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 and Service Lines	DU1	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Recurrent	Broad
	DU6	Likely	Low-Medium	Low	Low-Medium (4)	Historical/Current/ Anticipatory	Continuous	Narrow
	DU13	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Recurrent	Extensive
	DU15	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Recurrent	Extensive

Table 29. 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	DU6	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/Anticipatory	Continuous	Extensive
	This is not anticipated to be a threat for DU1.							

3.1.5. Biological Resource Use

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

3.1.5.1 Logging and 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 3.1.9 Pollution and Contaminants. Impacts from the reduction of forest cover is discussed in section 3.1.7 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):

> "Felling or modifying a tree that has been windthrown or has been damaged by fire, insects, disease or other causes, if the felling or modifying will not have a material adverse impact on the riparian reserve zone;"

The determination of adverse impacts is through a professional reliance model which has been criticized as unable to adequately protect for values other than timber harvesting[13].There are changes to the BC *Forest and Range Practices Act* underway as well as better professional association guidance to further the protection of the natural hydrological cycles of watersheds that may begin to address these shortcomings.

BC forests have suffered a massive mountain pine beetle outbreak and numerous catastrophic wildfires. In the recent past, this has prompted aggressive salvage logging operations to recover as much economic potential as possible (BC Ministry of Forestry 2004; BC Ministry of Forests and Range 2005; Schnorbus et al. 2010). However, current salvage logging practices are beginning to conform with the values of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) and there has been greater adoption of Indigenous Principles in harvest and salvage planning post wildfire. These principles are generally more holistic in their guidance and consider forests in the context of watersheds and multiple values, with emphasis on maintaining healthy hydrographs and riparian retention. Where salvage logging is still occurring next to streams there is likely to be some intrusion into SBCC habitat, either by machines or by felled trees.

Forest disturbances in the form of fire, 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 is particularly likely in DU15 (LTh-1.2) after the past several years of large forest fires and will likely occur in DU13 (STh-1.3) as more forest fires occur in the future.

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 in the Salmon Arm of Shuswap Lake which may impact Chinook from DU13 (STh-1.3); however, it likely only impacts migrating Chinook in the present location. Log storage in lakes can reduce dissolved oxygen and cause decreased

[13] Government of BC. Professional Reliance Review. [Accessed March 14, 2022]

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.

3.1.5.2 Fishing and Harvesting Aquatic Resources

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

Fisheries operating in both Canada and the US intercept SBCC 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. 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 specific US fisheries that intercept SBCC 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 SBCC stocks include the Chinook-targeted troll fisheries on the west coast of Vancouver Island (WCVI) and northern BC (NBC). There have also been seine and gill net demonstration fisheries (considered commercial fisheries) in Kamloops Lake, though these have been curtailed in recent years. 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. SBCC 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. DU1 (BB) is not impacted by most recreational fisheries in Freshwater Regions 2, 3, 5, 7, and 8 as this DU does not migrate into the Fraser River. However, the Region 2 recreational fisheries on the Serpentine River, Nicomekl River, and Little Campbell River impact this DU. DU6 (LFR-Maria) is impacted in recreational fisheries in Freshwater Region 2, but not by recreational fisheries in Freshwater Regions 3, 5, 7, and 8, which occur upstream of the spawning areas of this DU. DU13 (STh-1.3) is impacted in recreational fisheries in Freshwater Region 2 and 3, while DU15 (LTh-1.2) is impacted in recreational fisheries in Freshwater Region 2 and 5.

FSC fisheries in the South Coast marine waters often target local South Coast stocks near the river mouths, but there are also likely to be impacts to other co-migrating stocks, including Fraser stocks, especially for fisheries in the Salish Sea and WCVI. Chinook-targeted FSC fisheries in the Lower Fraser River from the mouth of the river to the confluence with Sawmill Creek impact all FRC stocks except DU1, which probably do not migrate into the Fraser River often. Further upstream, Chinook-targeted FSC fisheries occurring between the confluence with Sawmill Creek and the confluence with the Thompson River impact DU13 and DU15. DU6 (LFR-Maria) migration overlaps with the return of more-abundant South Thompson sub-yearling Chinook stocks and other salmon species, potentially leading to higher impacts compared to the other DUs. FSC fisheries in the Fraser River upstream of the confluence with the Thompson River can impact the LTh-1.2 stocks, based on Nicola River CWT recoveries as far upstream as the Stein River confluence, but the more distant, upstream fisheries are not believed to impact the DUs included in this RPA.

Several Canadian test fisheries operate along the migration corridor of SBCC. 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 SBCC 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 DU1, which does not enter the Fraser River. Catch at Albion is proportional to abundance in-river, and over the last 10 years (2012 to 2021) has averaged 1,547 Chinook. This typically accounts for 0.5% to 1.3% 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.

SBCC can 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, with some exceptions. Impacts are generally only estimated for salmon fisheries; at this time there are not enough data available to evaluate the impact of non-salmon fisheries on FRC. In the winters of 2019/2020 and 2020/21, coded-wire tags (CWT) were sampled from the Southern BC groundfish (hake) trawl fishery that originated from the DU15 (LTh-1.2) (Nicola River) and DU1 (BB) (Samish River; Will Duguid and Pat Zetterberg, pers. comm. 2019). Studies are being developed to quantify the impacts of these fisheries on DUs.

The impact of all fisheries on the individual 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 Pacific Salmon Treaty (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 CWT, catch, and escapement data. Nicola River is the indicator stock for the Spring 4_2 MU (DU15), Harrison River is the indicator stock for the Fall MU (DU2, not assessed in this RPA), and Lower Shuswap is the indicator stock for the Summer 4_1 MU (DU6 is a component of this MU). There are currently no indicator stocks for the Spring 5_2 and the Summer 5_2 MUs. There was an indicator stock for the 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 and the Lower Chilcotin River for the Spring 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, size-selective fisheries, 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 outlined 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 the 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-to-age-2 survival rate are also uncertain because they are CWT-based are rely on uncertain estimates of fishery harvests and releases and incomplete sampling. There are also several uncertainties associated 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. While there is 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, the CWT-based method was used to inform threat scores for all DUs except DU13, which does not currently have a CWT indicator stock. For that DU, expert knowledge about historical and current management of fisheries that impact this DU (based on known migration timing of the DU and DNA sampling in fisheries) was used to estimate the severity of future fishing activity. It is important to note that severity refers to the percent decline in the population, so for this threat severity is not directly measured by exploitation rate. One way to determine whether a percent decline can be expected from specific ER values is by comparing these values to a sustainable ER identified for that population. Unfortunately, this metric has not been determined for the populations examined in this RPA so inferences were made based on expert judgement of stock productivity and ER trends in recent years. CWT ERs described below are expressed in brood years (BYER) and catch (calendar) years (CYER). BYER is based on complete brood years and would be comparable to sustainable ERs if they are calculated in the future. CYER can be estimated for incomplete brood years and can provide an early indication of recent changes in exploitation if it differs from BYER; it is not directly comparable to BYERs or the sustainable ER.

There is no CWT indicator stock for DU1; the Samish River CWT indicator stock in Washington, USA was used as a proxy, but uncertainty exists regarding similarities in marine distribution and exposure to fisheries. The time series of BYER and CYER estimates for the Samish River CWT indicator stock are shown in Figure 19. The average total BYER across this time series is 44.5% (26.4% in Canadian fisheries, 18.1% in US fisheries). The average total CYER across this time series is 42.2% (24.6% in Canadian fisheries, 17.7% in US fisheries). Based on the Samish River CWT indicator stock, impacts are expected to occur primarily in recreational fisheries in SBC (West Coast Vancouver Island (WCVI), Strait of Georgia (GST) , Juan de Fuca (JdF)) and the USA. Lesser impacts occur in Washington, NBC, WCVI and Southeast Alaska (SEAK) troll fisheries. There may also be unaccounted mortality from incidental catch in the groundfish fishery. As outlined below for the other DUs, it is anticipated that exploitation rates are unlikely to increase as management actions are not expected to become less restrictive until the abundances of at-risk populations significantly improve in Canada. Within the DU1 spawning streams, a relatively high number of fish are taken for hatchery broodstock, which experts in the threats workshop suspected may be causing population-level impacts to the wild component; these impacts are included in this category. A threat risk of Medium to High with Medium causal certainty was assigned to this DU.

Quantitative data for DU6 (LFR-Maria) are limited, but CWT data for a co-migrating productive stock group (South Thompson under-yearling Chinook) suggest significant fishing activity may have occurred on DU6. The time series of BYER and CYER estimates are based on the Lower Shuswap River indicator stock (Figure 20). The average total BYER across this time series is 51.2% (34.0% in Canadian fisheries, 17.2% in US fisheries). The average total CYER across this time series is 48.0% (31.9% in Canadian fisheries, 16.1% in US fisheries). DU6 Chinook likely hold in the Fraser mainstem until favourable flow conditions occur in Maria Slough, which may also increase their exposure to fisheries that occur in the mainstem. In the marine waters, Area F troll has become less of a threat in recent years because the fishery has been delayed until mid-August. Given the potential for significant exposure to recreational, FSC, and unmonitored fisheries but high uncertainty around the direct impact to DU6, a threat risk of High with Medium causal certainty was assigned to this DU.

DU13 does not currently have a CWT indicator stock from which to estimate BYER and CYER; however, some quantitative information from a recent review of the management actions implemented to protect three Chinook MUs (Spring 4_2, Spring 5_2, Summer 5_2) can be used to estimate the threat risk. In 2012, the Department set a goal of reducing overall harvest rate on Spring 4_2, 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). The recent review of this management approach 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 stream-type populations (Spring 4_2, Spring 5_2, Summer 5_2) to near 5%; an analysis of the effectiveness of the management actions suggested this objective was likely met for 2019 and 2020 (DFO 2021a). These Chinook migrate before the main South Thompson sub-yearling population and therefore garner protection from the majority of fishing activity that targets the South Thompson sub-yearlings. Lower Fraser First Nations FSC fisheries are limited in effort and duration until mid-August, well after DU13 is expected to have migrated through that area. A threat risk of Low with Medium causal certainty was assigned to this DU with the assumption these management actions will remain in place for the foreseeable future until abundance improves.

Consistent time series of BYER and CYER estimates are available for DU15 and are based on the Nicola River indicator stock (Figure 21). The average total BYER across this time series is 26.5% (23.7% in Canadian fisheries, 2.7% in US fisheries). The average total CYER across this time series is 26.2% (23.0% in Canadian fisheries, 3.1% in US fisheries). CYERs have decreased in recent years since Canadian fisheries have been planned to avoid high impacts on this stock group, as noted above. FSC fishing with rod and reel can occur in upstream Fraser River areas, particularly at the confluence of the Lower Thompson and Nicola rivers, and can have significant impacts. In years with prolonged low water, Chinook accumulate at the mouth of the Nicola River and they can hold throughout the lower Thompson River and in the Fraser River near its confluence. Their holding behaviour increases their exposure to fisheries; which likely contributed to the high total CYER estimate in 2020 (very low CYERs were estimated in all other Canadian fisheries). In the Deadman River, a no-fishing FN community bylaw exists. In the Bonaparte River, fishing occurs near the confluence with the Fraser River using gillnets and rod and reel, and farther upstream at the fishway using dip nets. The recreational fishery targeting jack Chinook in the lower Thompson River starts in late August to avoid impacts to this stock group. While management actions intended to result in a low CYER are expected to persist going forward, given the uncertainties in the ER estimates and management implementation error, a threat risk of Low to Medium with High causal certainty was assigned to this DU.

Fishing dynamics in mixed-stock areas may change in the future with changes in hatchery production. The effects of salmon hatchery production and mixed-stock fisheries were 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. 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 et al. (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 SBCC-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). Objectives and appropriate protocols can be developed to ensure enhancement activities are aligned with the recovery of these DUs.

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 highly uncertain because sustainable levels are largely unknown for these DUs and also 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 for DU1, DU6, and potentially DU15, the current ERs are higher than what these populations can sustain at current productivity levels. Fishing activity is not likely the main factor driving recent declines in these DUs, though it is a contributing factor when ERs are above sustainable levels. Fishing activity is expected to continue, but the magnitude of the threat is highly uncertain.

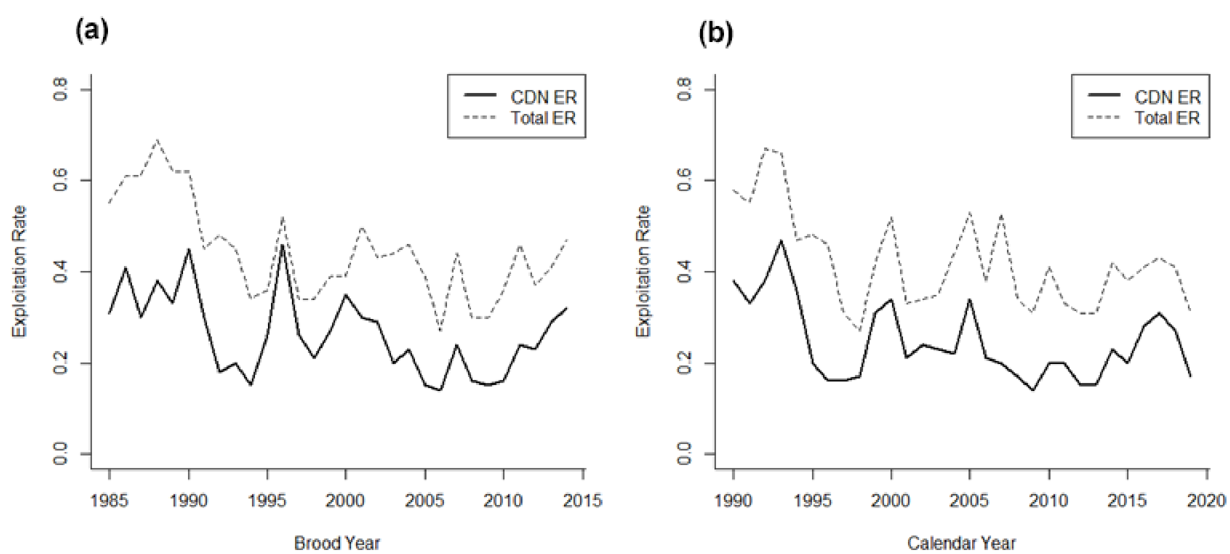

Figure 19. Exploitation rate (ER) summary for Samish River Chinook, proxy CWT indicator stock for DU1 – Boundary Bay Ocean Fall Chinook. (a) Brood year ER data from 1985 – 2014. (b) Calendar year ER data from 1990 – 2019. Data provided by the Pacific Salmon Treaty Chinook Technical Committee.

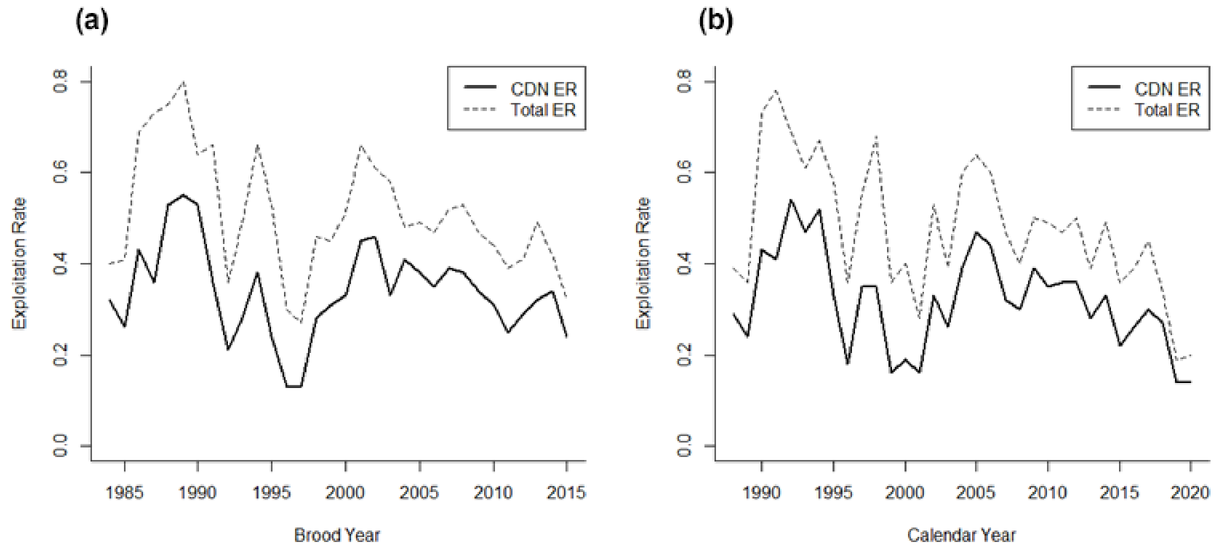

Figure 20. Exploitation rate (ER) summary for Lower Shuswap Chinook, proxy CWT indicator stock for DU6 – Lower Fraser Ocean Summer Chinook. (a) Brood year ER data from 1984 – 2015. (b) Calendar year ER data from 1988 – 2020. Data provided by the Pacific Salmon Treaty Chinook Technical Committee.

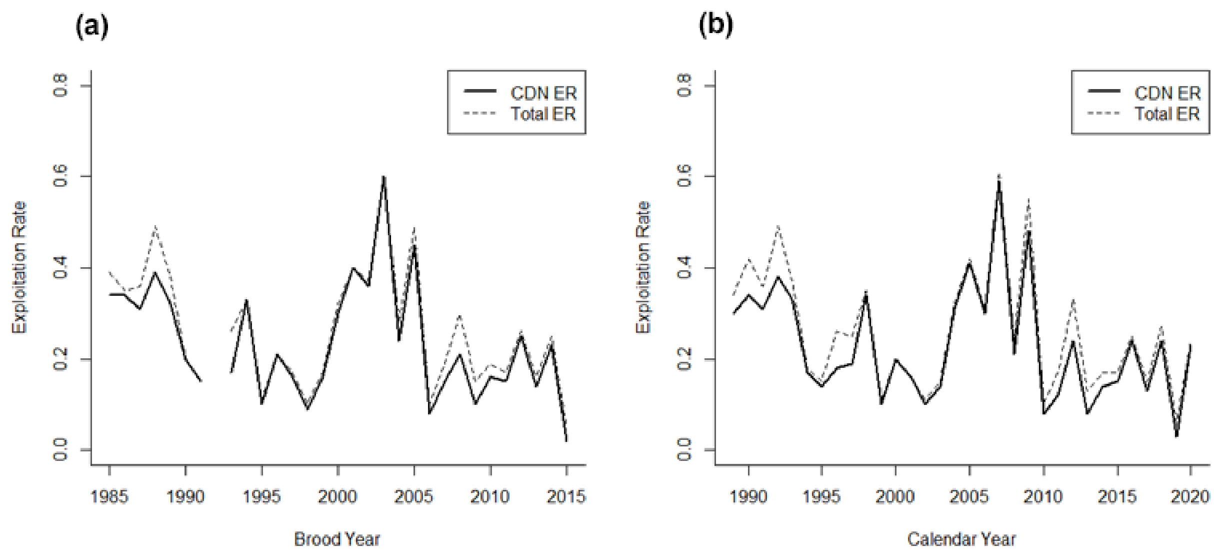

Figure 21. Exploitation rate (ER) summary for Nicola River Chinook, CWT indicator stock for DU15 – Lower Thompson Stream Spring Chinook. (a) Brood year ER data from 1985 – 2015. (b) Calendar year ER data from 1989 – 2020. Data provided by the Pacific Salmon Treaty Chinook Technical Committee.

Table 30. DFO threats assessment calculator results for impacts from Logging and 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 and Wood Harvest	DU13	Known	Low	High	Low (4)	Historical/Current/ Anticipatory	Continuous	Narrow
	DU15	Known	Low	High	Low (4)	Historical/Current/ Anticipatory	Continuous	Narrow-Broad
	This is not anticipated to be a threat for DUs 1 and 6.							

Table 31. DFO threats assessment calculator results for impacts from Fishing and 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 and Harvesting Aquatic Resources	DU1	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	High	Medium	High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low	Medium	Low (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	High	Low-Medium (2)	Historical/Current/ Anticipatory	Continuous	Extensive

3.1.6. Human Intrusions and Disturbance

3.1.6.1 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 SBCC habitat, or directly cause SBCC 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 as well as any boat activity occurring in SBCC habitat occupied by juvenile fish or eggs. Jet boats in particular can suck up fish or eggs causing direct mortality if they are driven through gravel beds or littoral habitat during critical periods. Additionally, boat wakes may strand juveniles along shorelines or in shallow habitats. The pressure fluctuations created under a passing jet in shallow water are 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 was 75% greater in a popular boating area of the Kenai River, Alaska when compared to areas where boating restrictions are in place. Reduced water clarity may also interfere with how fish use shallow water habitat, in addition to wildlife habitat along the water's edge (Laderoute and Bauer 2013).

This threat has a negligible scope and impact for DUs 6 and 13 and a small scope with a slight impact for DU15, while DU1 was not scored due to a lack of information. Certain rivers within these four DUs are more susceptible to impacts from jet boating. In DU1, there are boat launches on the Nicomekl and Serpentine rivers, which is a highly developed and popular area. No boat restrictions exist in the Serpentine River; however, the Nicomekl River imposes a 16km/h speed restriction and towing is prohibited in certain parts. Non-motorized boat traffic in the Nicomekl River is also common; however, the impacts are likely negligible. In DU13, jetboating occurs in the Eagle and Perry rivers, although there is a 5km/h speed restriction. Additionally, snowmobiling and off-roading are becoming increasingly popular in the Perry River area and throughout DU15; they are facilitated by a network of forestry roads and can degrade SBCC habitat or crush redds when entering streams. However, the proportion of DUs exposed to this threat is likely low. An annual summer music festival occurs near a section of Chinook spawning grounds within the Coldwater River (DU15); festival goers are known trample Coldwater River habitat and rearrange streambed to bathe in pools.

3.1.6.2 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 SBCC 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 Expansion pipeline could attract large protests, which could result in damage to equipment or the pipeline itself leading to accidental spills. The threat has unknown impacts for all DUs due to the amount of uncertainty with these events occurring; hence, no threat table is provided.

3.1.6.3 Work and 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 SBCC within this category is limited to scientific research. Stock assessment and scientific research are ongoing within many streams in SBCC 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 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. Fish are not captured 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. Among the DUs assessed in this RPA, broodstock collected from Spius Creek and the Salmon and Nicola Rivers could experience adverse water temperatures (>18°C) while other brood-take procedures are unlikely to have temperature-related impacts. The enumeration method during spawner surveys can also affect SBCC. In DU15, there is a long standing angling mark-recapture program on the Nicola River; however, effects from angling on this project are low with the immediate hooking mortality rate reported at 0.9% (Cowen et al. 2007). Roving surveys in Louis Creek, Seymour River, and Scotch Creek and jetboat surveys in the Eagle River could potentially depress redds, although surveyors attempt to avoid redd locations.

In the BC Interior, enumeration and hatchery brood stock capture fences were constructed in the 1980's on the Salmon River and the Eagle River in DU13 and on the Nicola River in DU15, as well as various locations in the vicinity of Prince George. Enumeration and capture fences were common in coastal systems at that time and were presumed to be the most efficient method to achieve both objectives. However, after the installation of conventional fences in interior systems, it was observed that Chinook often failed to enter the trap boxes, but instead re-distributed themselves into habitats downstream of the fences, and often spawned in areas previously unused for spawning. This phenomenon was observed in the Nicola and Eagle rivers and the operation of the Nicola fence was terminated after a single year. The Eagle River fence was operated for several years associated with the Eagle hatchery, but was discontinued in the early 1990's. Similar issues were also observed in the fences installed around Prince George, and for the most part the use of conventional counting fences was discontinued. An exception would be the Salmon River fence at Salmon Arm (DU13), which is a multi-purpose fence that has been used annually since 1986 to count Chinook and Coho returns and to facilitate brood stock capture. This fence has been located below any potential spawning gravels, and while there have been considerable issues surrounding unwillingness of fish to enter the trap, fish have been captured and enumerated annually. Fence operators have attempted many novel enhancements to attempt to attract fish into the trap box including shading the vicinity below the fence to provide cover and concentrating flows through the trap to provide stronger attraction flows.

Until recently, the Salmon River fence was the only fence in operation for capture and enumeration in the Interior Fraser. Following the Big Bar landslide, First Nations, community stewardship groups, and DFO responded with emergency enhancement activities in an attempt to mitigate impacts on escapement. Fences have been installed and operated on several systems the last three years including the Endako and Chilako rivers with similar results to those previously observed in terms of an unwillingness to pass. One exception was on the

Upper Chilcotin River where a novel design, involving a temporary fence with a very long, shallow angle to allow fish to ascend the stream alongside the fence without being obviously corralled was used instead of a barrier at 90 degrees to the flow. When fish were sufficiently far upstream and approaching the apex, a net was raised behind them to create a trap in the apex area of the fence. By further reducing the size of the apex area through manually moving the downstream net upstream, fish were penned and captured. This novel approach functioned well in its first year (2021), offering hope that alternate, labor intensive approaches can capture fish for hatchery brood stock when returns are poor, with less impact on the distribution of natural spawners. As populations decline, fish capture becomes more difficult at lower escapements, leading to greater interest in the use of fences or weirs to capture brood. Improperly installed and operated fences have the potential to further harm already depressed populations, particularly in the interior where there appears to be greater aversion to fences.

In addition to DFO, there are various other research groups and programs that are operating within these DUs and may be encountering or studying Chinook Salmon.

Table 32. 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	DU1	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Unknown
	DU6	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Negligible
	DU13	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Negligible
	DU15	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Continuous	Restricted

Table 33. DFO threats assessment calculator results for impacts from Work and 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 (2014) 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 and Other Activities	DU1	Known	Negligible	Very Low	Low (5)	Historical/Current/ Anticipatory	Continuous	Broad
	DU6	Known	Negligible	Very Low	Low (5)	Historical/Current/ Anticipatory	Continuous	Negligible
	DU13	Known	Negligible	Very Low	Low (5)	Historical/Current/ Anticipatory	Continuous	Broad
	DU15	Known	Negligible	Very Low	Low (5)	Historical/Current/ Anticipatory	Continuous	Broad

3.1.7. Natural Systems Modifications

3.1.7.1 Fire and 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 incidence 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 can increase 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 their locations 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. DU15-LTh-1.2) because areas may be excavated with machinery to create pools deep enough to submerge aerial buckets. In the summer, adult Chinook may enter these artificial pools, where they could potentially be removed by an aerial bucket if fire suppression was ongoing. In addition, equipment conducting this work may inadvertently destroy habitat or release suspended sediments into the water column, indirectly impacting fish downstream. Recent wildfires in DU15 during the summer of 2021 resulted in bucketing directly from the Coldwater, Deadman, and Nicola rivers. It is also possible, given the size and intensity of the fires, that altered conditions, such as increased water temperature and decreased dissolved oxygen, may have created thermal barriers or inhospitable conditions for juvenile Chinook. These effects are currently unknown.

The proportion of any DUs covered in this report that would encounter or be impacted from this threat is either unknown or negligible, and is therefore not considered to be a significant threat to SBCC. However, given the size, number, and intensity of the forest fires in the summer of 2021, the direct impact of fire and fire suppression on SBCC could be problematic in the future.

3.1.7.2 Dams and 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 SBCC through water management and utilization (for a variety of sectors) in the Fraser River Basin and Southern Mainland 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[14]. Some of these structures have cut off access to backchannels and sloughs that were historically inhabited by SBCC and there is currently very limited floodplain habitat left for overwintering juveniles in the lower Fraser River. Flood boxes and tide gates can have ongoing impacts by preventing access to ephemeral habitat and creating undesirable habitat for juvenile

[14] Fraser Basin Council 2019. Flood and the Fraser. [Accessed March 14, 2022]

Chinook (Gordon et al. 2015; Collins et al. 2016). Finn et al. (2021) quantified the amount of stream and floodplain salmon habitat lost due to anthropogenic barriers in the Lower Fraser River by comparing historical and current habitat extents. The authors found that approximately 102km^2 of a historical 659km^2 of floodplain fish habitat remains in the Lower Fraser. More specifically, 4.3km^2 of 91.9km^2 (5%) remains for Boundary Bay Chinook (DU1) and 71.4km^2 of 467.4km^2 (15%) remains for Maria Slough Chinook (DU6). It is estimated that DU1 can access 28% of their historical stream habitat (184km of 660km) with 177km rendered inaccessible, 116km channelized, and 182km lost. DU6 can access 38% of their historical stream habitat (21km of 55km) with 21km rendered inaccessible and 13km lost.

In general, salmonids are known to actively move into seasonal floodplain wetlands to avoid high main-channel flood flows, but reductions in connectivity and degradation of side-channels and tributaries have 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 of 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 SBCC-specific, Jeffres et al. (2008) report that off-channel floodplain habitats in the Cosumnes River provide significantly better rearing habitat than the intertidal river channel and support 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, floodplain restoration has been proposed as an important tool for enhancing salmon production (Sommer et al. 2005). Pump stations exert additional flood control impacts when water is evacuated from floodplains, potentially stranding fish that may have entered during high water or directly causing mortality to SBCC juveniles if fish are sucked into the pump.

DU1 (BB) and DU6 (Maria) were deemed to be threatened by flood control structures and activities. Dikes are extremely prevalent throughout DU1 as it is a highly urbanized landscape. Pressure controlled sea dams exist at the mouth of the Serpentine and Nicomekl rivers and there are many culverts at road crossing on these rivers as well as throughout the drainage of the Little Campbell River. It is not known how often or for how long these sea dams are closed during adult Chinook migration in the fall or juvenile migration in the spring, but the delay caused by sea dam closure has been known to increase pinniped predation on adult Chinook at these locations. Additionally, these sea dams can create sharp salinity gradients, which may impact osmoregulation, particularly for outmigrating smolts. It was discussed in the threats workshop that the city of Surrey is looking to replace these dams with fish passage issues in mind[15], but these dams will continue to pose a threat to Boundary Bay Chinook until fish passage is adequately addressed. Dredging on Seabird Island regularly occurs as a flood control measure, which has the potential to negatively impact Chinook in DU6 (Maria). A proposal was made in 2021 to continue this practice indefinitely. The addition of flood control structures at the downstream end of the slough is also being considered. Flood control was not determined to be a threat to either DU13 or 15 (STh-1.3 and LTh-1.2, respectively).

[15] City of Surrey. 2020. Award of Contract No. 6020-010 D1: Design of Serpentine River Sea Dam Replacement. [Accessed January 15, 2022]

Dams and 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). None of the DUs in this report are threatened by major dams.

There are numerous independent power projects, often built as run-of-river hydroelectric facilities within tributaries of the Fraser River, that may impact SBCC. 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 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 have not detected any large changes in resident salmonid abundances (DFO 2016). Ramping rates, the rate at which the facility changes water levels in the river, are likely the largest in-river threat from run-of-river facilities. 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 SBCC. A population-level impact from run-of-river facilities is not anticipated.

It should be noted that while unlikely, failure of fishways can have serious negative implications for SBCC that require passage above these structures. 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 (Figure 22). In the event of fishway structures failing, such as those at Hells Gate or Bonaparte, the migration of some or all fish from DUs 13 (STh-1.3) and 15 (LTh-1.2) would be potentially 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 SBCC. 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.

Figure 22. Bonaparte Fishway that facilitates upstream Chinook migration.

Water Extraction

Water extraction can impact SBCC 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 overall water availability.

DUs 13 and 15 (STh-1.3 and LTh-1.2) are both located in drought sensitive regions and are threatened by water extraction. In DU 13, parts of the Salmon River run dry for several months and restricts access to spawning habitat due to the high level of agricultural water withdrawals near the community of Westwold. Section 88 of the *Water Sustainability Act* (WSA) was invoked to restrict agricultural withdrawals in the Salmon River due to the extreme temperature and level 5 drought that occurred in the summer of 2021. When coupled with water extraction in the Salmon River, low levels in Shuswap Lake create distributaries at the mouth of the Salmon River and can result in fish stranding during their spawning migration. The Coldwater and Nicola rivers in DU15 are also subject to water management issues, particularly from agricultural withdrawals. Current evidence suggests that the volume of water in the Nicola River in August is associated with stock productivity and affects both juveniles and adults (Warkentin 2020). The DFO Fish and Fish Habitat Protection Program (FFHPP) have evidence of fish stranding events in the Nicola River when irrigator pumps are activated in low water situations. Voluntary restrictions are present on the Nicola and Coldwater rivers to reduce withdrawals.

Ranking

DU1 was scored at a high level threat from dams and water management/use due to extensive diking and the impacts of the flood control structures in this region. DU6 was scored medium as dredging was the only current potential impact and there is the possibility of an increased threat due to the proposed addition of flood control structures at the mouth of the slough. DU13 scored high-medium for this threat because, although the Salmon River is particularly affected by poor water management practices, the rest of the DU is largely unaffected. DU15 scored high as most streams are negatively affected by water management practices in the region.

3.1.7.3 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 3.1.9.3 Agricultural and 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 DUs 13 and 15 (STh-1.3 and LTh-1.2) and can impact flow and temperature regimes in a variety of ways. Forestry activities have been prevalent in the Southern BC Interior, impacting these DUs. 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 modifying 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 freshwater benthic invertebrate prey (Quigley and Hinch 2006; Richter and Kolmes 2005; Brett et al. 1982; Keefer et al. 2018; Shrimpton et al. 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 BC 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 3.1.5.1 Logging and Wood Harvest, 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 3.1.7.1 Fire and 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, 2018, and 2021 have led to the loss of over 4 million hectares of forest cover across the Province of BC.

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 873.1.7.1 Fire and 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, 2018, and 2021 resulted in the creation of areas of hydrophobic soils that are totally denuded of vegetation and prone to severe erosion, which has been shown to impact hydrology in the Coldwater River (DU15) in particular.

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, which is discussed in section 3.1.9.1 Household Sewage and 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 SBCC. 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 Boundary Bay rivers, 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 et al. 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 et al. 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 Chinook 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 SBCC use the corridors in the lower Fraser River and Boundary Bay rivers that are heavily linearized. The exact impacts of linearization and rip-rapping would require intensive research.

Invasive Species 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[16], though their population level impacts on SBCC 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). Invasive animals can also negatively impact SBCC through alteration of habitat and foodweb dynamics. For example, European Green Crabs (*Carcinus maenas*) are known to modify juvenile salmonid habitat through their consumption of Eelgrass (*Zostera marina*) in estuaries (Howard 2019). Pumpkinseed (*Lepomis gibbosus*) are not known to directly compete with or consume SBCC but they alter foodweb dynamics through their competition with native species such as sticklebacks. Relative to other threats, invasive species are likely having a low impact on SBCC, but their extent and effects should be monitored in the future.

Ranking

The threat from the aforementioned ecosystem modifications is pervasive for all SBCC DUs. Modifications to catchment surfaces and linear developments are most concentrated in the areas surrounding the lower Fraser River and Boundary Bay, which is the migratory corridor for the three Fraser River DUs and is the spawning and rearing habitat of DU1 (BB), respectively. Fire and fire suppression is an unlikely threat in DUs 1 and 6. Wildfires in DU13 have recently affected habitat and are expected to persist into the future. A low threat risk was assigned because the impacts of bucketing are likely to affect a small proportion of the DU. A low threat risk was assigned to DU13 because wildfires have recently affected habitat and are expected to persist into the future. An unknown threat risk was assigned to DU15 because the scope and intensity of anticipated and recent wildfires may have cause thermal migration barriers, reduced dissolved oxygen, and changed riparian habitats, but the actual impacts remain unknown. A medium level of causal certainty was assigned to DUs 1 and 6 for the dams and water management category and to all SBCC DUs for the other ecosystem modifications category because there is some evidence linking these threats with declines in productivity yet little research investigating the direct effects on SBCC. A high level of causal certainty was assigned to DUs 13 and 15 in the dams and water management category because declines in productivity from low water levels have been quantified.

All SBCC DUs will be impacted by the loss of off-channel habitat and a shifting hydrological regime due to modifications to catchment surfaces. The degree to which ecosystem modifications will impact SBCC Chinook is uncertain, but at the very least a low impact is anticipated.

DU1 (BB) and DU15 (LTh-1.2) were deemed to be the most impacted from this threat category. DU1 is highly impacted due to the degree of stream bank modification for dikes in addition to the flood control structures that exist at the mouth of two of the three rivers in the DU. However, DU15 scored high because of the level of habitat degradation due to the number and intensity of wildfires in the region in addition to water management issues in the Fraser River watershed and, as such, ecosystem modifications that alter these characteristics may have severe impacts on SBCC.

DU6 (Maria) and DU13 (STh-1.3) were categorized as having a high-medium threat from other ecosystem modifications. The degree of uncertainty for DU6 lies with the fact that invasive

[16] BC MOE. 2015. Status of Invasive Species in BC. [Accessed March 14, 2022]

species, such as Reed Canary Grass and Pumpkinseed, exist in this location, but their impacts have not been studied. The invasion of Reed Canary Grass is likely to be significant in Maria slough and is expected to lead to migration barriers if left unmanaged. For DU13, the severity of the impact of dams and water management/use had an uncertainty range from moderate to serious as the Salmon River is mainly affected while the other tributaries are not likely impacted. There was additional uncertainty regarding the impact of ecosystem modifications due to invasive species in the Lower Fraser on this DU.

Table 34. 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 and Fire Suppression	DU13	Known	Low	Low	Low (4)	Historical/Current/ Anticipatory	Recurrent	Broad
	DU15	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Recurrent	Broad
	This is not anticipated to be a threat for DUs 1 and 6.							

Table 35. 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 (2014) 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 and Water Management	DU1	Known	High	Medium	High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Medium-High	High	Medium-High (2)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	High	High	High (2)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 36. 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 Ecosystem Modifications	DU1	Known	High	Medium	High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	High	Medium	High (3)	Historical/Current/ Anticipatory	Continuous	Extensive

3.1.8. Invasive and Other Problematic Species and Genes

3.1.8.1 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 and riparian zone invasive species (IS) have been described as one of the most prevalent threats for Canadian at-risk freshwater fish species (Dextrase and Mandrak 2006), degrading the quality of stream and estuarine habitat for juvenile salmon (Klopfenstein 2016), and 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 IS that pose some level of threat to these DUs, in addition to our current knowledge of threats from non-native pathogens.

Freshwater Invasive Species

Thirteen non-native freshwater species have established populations within the Fraser River Basin (Brown et al. 2019), and some of these species compete with or prey on juvenile salmon and the impacts of species invasion can lag many years before they are detectable. 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 aquatic invasive species (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*), but there are several other species such as goldfish/koi, oriental weather fish, crayfish, etc. that have not been assessed but certainly could pose a risk. These species became established in British Columbia from unauthorized introductions, deliberate introductions by government agencies, and natural dispersal (Arbeider et al. 2019). Of greatest concern are three spiny-rayed fish (Largemouth Bass, Smallmouth Bass, and Yellow Perch) and the indirect effects of Reed Canary Grass (RCG) on aquatic stream and estuarine habitats.

The following three sections on the potential interactions between Chinook and Largemouth Bass, Smallmouth Bass, and Yellow Perch borrow heavily from Part I of the Pre-COSEWIC review of Southern BC Conservation Units (Brown et al. 2019) and the Recovery Potential Assessment for Fraser River Chinook (DFO 2020a).

Largemouth Bass, a voracious piscivore, eat juvenile salmon (Brown et al. 2009a). They have invaded much of the lower Fraser River and tributaries where juvenile Chinook rear and migrate, from Hope to Richmond, BC, and they are in the upper Serpentine River (DU1-Boundary Bay). A fish-wheel operating in the lower Fraser River near Mission BC in 2009-2010 caught 32 Largemouth Bass (Brown et al. 2019), and there are numerous reports and YouTube videos of anglers catching them. Since Largemouth Bass are widely distributed in the lower Fraser River, they likely eat large numbers of juvenile Chinook, particularly ocean-type Chinook rearing in tributaries and sloughs (Levings et al. 1995); however, no studies have quantified the predation or Chinook mortality rates.

Smallmouth Bass reside in the littoral zone of lakes and slower moving rivers (Brown et al. 2009b), and they can significantly impact juvenile Chinook Salmon abundance and survival in large rivers (Rieman et al. 1991; Vigg et al. 1991; Tabor et al. 1993; Zimmerman 1999), but the effect on salmonid abundance varies among years and locations (Brown et al. 2009b; Counihan et al. 2012). In 2006, Smallmouth Bass were found in Beaver Creek, a tributary of the Quesnel River, leading to control efforts by the Province of BC; despite these mitigation efforts, Smallmouth Bass have since been confirmed in several waterbodies within the Beaver Creek watershed (Martina Beck, Province of BC, pers. comm. 2021). Recently, Smallmouth Bass have been illegally introduced into Cultus Lake, near Chilliwack, B.C., and they have been captured at the DFO fish trap downstream of the lake in Sweltzer Creek. As the trap is only operated seasonally, it is very likely that Smallmouth Bass have dispersed into the Chilliwack and Fraser rivers. Subsequent sampling in Cultus Lake has found multiple age/size classes and nesting, confirming that there is a reproducing population (Wendy Margetts, Thompson Rivers University, pers. comm.). In the absence of successful control and suppression programs, the Smallmouth Bass will likely establish throughout the lower Fraser River, similar to the Largemouth Bass experience, and increase predation on Chinook further reducing their productivity.

Yellow Perch is a highly adaptable species that utilizes a wide range of habitats (Brown et al. 2009c). 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, invertebrates and fish (Brown et al. 2009c). 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. 2009c). Yellow Perch are present in drainages throughout southern British Columbia including the Columbia, Kootenay, Thompson, lower Fraser and Vancouver Island (Runciman and Leaf 2009). Twelve small interior lakes were rotenone treated between 2007-2017 to eradicate introduced populations of spiny rayed fish including yellow perch in the Thompson-Nicola drainage (Martina Beck, Province of BC, pers. comm.). Following the successful treatment of Windy Lake in 2017, Yellow Perch were confirmed downstream in Sanctuary Lake (2017), Douglas Lake (2018) and Nicola Lake (2020). There is much concern for the continued dispersal of Yellow Perch, and the lack of success with control and suppression programs to prevent them from spreading throughout the Fraser River. Yellow Perch are another invasive species that will reduce the productivity of Chinook Salmon via predation and competition for food resources in cohabitated areas.

Pumpkinseed have been intentionally stocked in B.C. for sport fishing and introduced by aquarium owners who can no longer care for them. Pumpkinseed are found within the Columbia River system, the upper Kootenay River, Pend d'Oreille, and Okanagan river systems as well as southeastern Vancouver Island and the lower Fraser River. They have been in the lower Fraser River for several decades and they have distributed to most of the sloughs, tributaries and backchannels from Hope to Richmond, BC and they are in the upper Serpentine River. Pumpkinseed are typically found in shallow waters within quiet, slow moving streams, small lakes and ponds, and their populations can grow rapidly as females lay from 600 to 14,000 eggs at a time.

Pumpkinseed may affect juvenile salmon through competitive interactions and indirect effects at different trophic levels. A study by Bonar et al. (2005) found that Pumpkinseed did not consume Coho Salmon in several shallow lakes in the Washington State, however to the best of our knowledge, no studies have examined Pumpkinseed diets in shallow sloughs or slow moving riverine habitats when Chinook fry emerge and occupy shallow waters in spring to determine their predation on Chinook fry. Bradford et al. (2008b) assessed the ecological risk for pumpkinseeds as very high in small warm lakes and moderate for large lakes because they only use a small portion of the habitat and are less likely to cause resource depletion. Recently, they have been caught in shallow water habitat in Maria Slough at the same time (and trap) as juvenile Chinook, during minnow trapping for Oregon Spotted Frogs, a species with SARA protection (Aleesha Switzer, Fraser Valley Conservancy, pers. comm.). In the spring, the waters of Maria Slough, off-channel sloughs and backwaters connected to the Fraser River, and the rivers in the Boundary Bay DU warm rapidly and reach the warmer water temperatures favored by Pumpkinseed (e.g. Maria Slough was 14°C on April 26, 2001; Shaun Spenard, DFO, pers. comm.). Although the diets of the Pumpkinseed in Maria Slough have not been sampled yet, Pumpkinseed likely prey on the Chinook fry (and the Oregon Spotted Frog tadpoles), and compete with Chinook fry for insects and other prey in these habitats (Levings et al. 1995). Predation by Pumpkinseed and competition for food with juvenile Chinook will reduce Chinook productivity.

While not a current threat to these DUs, Northern Pike will become a significant threat when they invade to these DUs. Northern Pike are ambush predators with a generalist diet (Parken 1996; Cathcart et al. 2019) and they are substrate- oriented, selecting cover to ambush prey (Savino and Stein 1989; Chapman and McKay 1990). Since juvenile Chinook must rear in shallow stream habitats, estuaries (Levings et al. 1991, 1995), and lake shorelines (Brown and Winchell 2004), their preferred habitats overlap completely with those of Northern Pike. Northern Pike preferentially prey on juvenile salmon (Rutz 1999), regardless of whether salmon are abundant or rare (Sepulveda et al. 2013), and invasive populations in Southcentral Alaska have caused significant declines in once abundant Chinook Salmon populations in rivers and shallow lakes (Haught and von Hippel 2011; Sepulveda et al. 2014; Dunker et al. 2018). Coexistence of Chinook and invasive Northern Pike is unlikely without management actions to reduce Northern Pike abundance and avoid the collapse of Chinook stocks (Sepulveda et al. 2013, 2014; Dunker et al. 2018). While Northern Pike are native to the Peace River watershed (northern, BC), they are not native to the Fraser, Columbia, or any of the coastal watersheds in British Columbia. Northern Pike have been introduced into the lower Columbia River and they have recently dispersed to the reach between the Hugh L. Keenleyside Dam near Castlegar, BC, Cristina Lake, BC, and Lake Roosevelt which is impounded by Grand Coulee Dam, WA. Northern Pike are within 10 miles of the Grand Coulee Dam indicating their potential to spread downstream in the Columbia River[17]. When Northern Pike move beyond the Grand Coulee Dam they will likely spread into systems such as the Okanagan River system and further into BC, either via illegal introductions or natural dispersal. They can naturally disperse throughout river estuaries and short distances through salt water, as found in Alaska (Dunker et al. 2018). In low-relief watersheds, invasive Northern Pike thrive and depress Chinook escapement to low levels, with escapements declining to 5% of long-term average at Alexander Creek, Alaska after fisheries were closed completely (Dunker et al. 2018). See Doutaz (2019) for a detailed synthesis of Northern 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 many areas of BC with suitable conditions (DFO 2013). 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.

[17] Francovich, E. 2018. "Invasive northern pike found 10 miles from Grand Coulee Dam, Spokane Tribe catches 45-inch fish". The Spokesman Review. [Accessed March 14, 2022]

Estuarine and Marine Invasive Species

The European Green Crab (*Carcinus maenas*) was introduced to coastal ecosystems around the globe, including the Pacific Coast of North America, where they have negative impacts on eelgrass habitats (Howard 2019). They have been assessed as having a moderate to high risk because of their influence on biodiversity and habitat which could have trophic consequences (Therriault et al. 2008). 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, causing rapid degradation of eelgrass meadows with high crab densities (Howard et al. 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 now considered an established IS along the entire West Coast of Vancouver Island from Barkley Sound to Winter Harbour and the Central Coast[18]. 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 et al. 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 (DFO 2020a). Eelgrass meadows in the Fraser and Boundary Bay estuaries have already been highly impacted from historical activities, and further loss of these habitats through invasion of Green Crabs could exacerbate impacts on juvenile Chinook rearing in these habitats (i.e. Chinook from DU1-BB, DU6-Maria).

Reed Canary Grass occurs in the riparian areas and tidal marshes along the lower Fraser River, Maria Slough and Boundary Bay rivers, where juvenile Chinook, particularly ocean-types, rear during the spring (Levings et al. 1995). The RCG is a highly invasive species in southern BC coastal rivers and estuaries (Levings et al. 1995; Townsend and Hebda 2013), and it simplifies habitats and reduces native plant diversity in riparian areas—it may provide habitat that is less suitable for Chinook Salmon (Klopfenstein 2016). The small Chinook fry rear and feed in the nearshore environments of the Fraser River and Boundary Bay estuaries 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*, cladocerans, copepods, and fish larvae (Levings et al. 1991; 1995). Klopfenstein (2016) reported slower growth rates for hatchery Chinook placed into net pens in RCG dominated riparian areas than naturally vegetated areas in the Lower Columbia River estuary in 2015 and 2016. 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 Mahnken 2001). Since the RCG adversely modifies the riparian zone, shallow water habitats and their ecosystem function for native species, it is often targeted by salmon habitat restoration programs (Silver and Eyestone 2012; Garthwaite et al. 2014; Diefenderfer et al. 2016; Sinks et al. 2021).

[18] DFO. 2019. European Green Crab. [Accessed March 14, 2022]

Introduced Pathogens and 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 SBCC.

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; Polinski et al. 2020). DFO[19] noted that Kibenge et al. (2013) proposed that PRV first arrived in BC from Norway sometime around 2007 based on an analysis of genetic differences. However, recent testing of archived samples held by DFO has revealed that PRV has been present in salmonids on the Pacific coast of North America salmon since 1987 and possibly as early as 1977 (Marty et al. 2015; Siah et al. 2015). There are three distinct genotypic groups of PRV, but only PRV-1 has been observed in BC (Polinski et al. 2020). 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). Modelling associations between infection from dozens of infective agents and early marine survival over a decade show that PRV infection has consistent and powerful associations with fish condition (relative weight) and survival during the fall and winter period, which coincides with strong indications of pathology associated with PRV infection (Bass et al. 2022). 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). Additionally, laboratory exposure of Chinook Salmon, Coho Salmon and Rainbow Trout revealed all three species are susceptible to PRV-1 infection, but in no case did infection cause notable disease (Purcell et al. 2020). Therefore, PRV is likely to pose a threat to wild populations of these enhanced DUs.

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. Open net-pen aquaculture is slated to be phased out by 2025[20] so the impact of this potential threat on wild Chinook should be largely mitigated in the future. However, this action may be delayed or overturned due to a recent court ruling in which a Federal Court judge set aside the Department of Fisheries order to phase out fish farming in the Discovery Islands[21].

The risk of introducing an exotic pathogen into the Canadian aquatic environment is mitigated by DFO and Canadian Food Inspection Agency through permitting procedures and testing. The

[19] DFO. 2018. Piscine Orthoreovirus (PRV) and Heart and Skeletal Muscle Inflammation (HSMI). [Accessed March 13, 2022]

[20] CBC. 2020. B.C.'s open-net salmon farms on the way out, but replacement systems may differ by region [Accessed May 2, 2022]

[21] The Globe and Mail. 2022. Federal Court sets aside Department of Fisheries order to phase out B.C fish farms [Accessed June 9, 2022]

CFIA assumed regulatory authority under the *Health of Animals Act* and Regulations for all imports into Canada in 2015. Prior to the regulatory authority for import of salmonids into BC shifting to the CFIA, import control was the responsibility of the DFO under the Fish Health Protection Regulations, which had strict testing and quarantine measures in place for any imports of eggs from outside of BC and Canada. There have been no imports of Atlantic Salmon eggs into British Columbia since 2009.

Ranking

This threat risk was scored as low to medium for all four DUs because IS are present throughout all habitats. There is high potential for new invasive species to be introduced and established in the lower mainland and for current invasive species to extend their range. The timing of IS establishment and subsequent impact on Chinook has been identified as a significant knowledge gap for all DUs and should be considered for future mitigation planning. Due to the different life history strategies employed by ocean-type and stream-type Chinook Salmon, the threat to DU1 (BB) and DU6 (Maria) are largely from AIS within estuarine and marine habitat. There are many invasive species in the lower Fraser River that can have impacts 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 DU1 and DU6 is the potential future colonization of Green Crab in the Fraser River and Boundary Bay estuaries. The threat of Green Crab invasion to these enhanced DUs is highly probable, but one cannot predict when or if it will occur, or what the level and timing of impacts will be.

DUs 13 and 15 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 DU6 (Maria Slough), as all habitat lies within the lower Fraser River. All fish from these DUs will likely encounter some of the invasive species within the lower Fraser River or Boundary Bay rivers. There are Pumpkinseed (*Lepomis gibbosus*) throughout DU6 (Maria), and predation on Chinook Salmon fry is likely since both species have overlapping habitat use in shallow water during the spring. The impacts of AIS were therefore deemed to be low to medium with some uncertainty.

There are likely some impacts on these enhanced DUs from disease transmission between contained salmon and wild Chinook Salmon, yet a definitive cause and effect relationship has not been shown.

3.1.8.2 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 rely 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 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 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 the amount of Chinook Salmon eaten by resident killer whales (RKWs) (RKWs discussed in section 3.3 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 correlations of seal density and hatchery smolt releases, in the Chinook Salmon ocean entry year, on the density-independent component of productivity for 20 ocean-type type Chinook populations originating near the Salish Sea and coastal Washington. The study reported significant negative correlation between Chinook productivity and Harbour Seal density in 14 of the 20 populations. However, the reliability of the study's inference is uncertain because the smolt-to-age_2 survival covariate, which represented most of the density-independent variation in Chinook Salmon productivity for the nearby Harrison and Cowichan stocks (Tompkins et al. 2005; Brown et al. 2001) and many other Chinook stocks (Parken et al. 2006), was not represented and the factors that affect variation in Chinook survival may also affect variation in seal density. The threat of pinniped predation can be particularly important for significantly depressed DUs and for DUs where adult Chinook have extended exposure to pinniped predation while staging in the ocean and estuaries until the fall rains increase river flows sufficiently for river entry and upstream migration.

Parasites and 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 opportunistic parasites or those previously at a carrier state (Miller et al. 2014). Immunosuppression in multiple species of sub-adult salmon sampled in the Gulf of Alaska has also been associated with reduced prey availability and increased infection burden (Deeg et al., In Review).

Juvenile salmon transitioning to saltwater are especially vulnerable to negative impacts of infection as they are making physiologically demanding adjustments to higher salinity and faced with a new suite of pathogens upon ocean-entry (Miller et al. 2014). Through climate change, salmon are also experiencing higher water temperatures and lower availability of quality prey during this period. The early marine period has also increasingly been recognized as an important influence on year-class abundance (Beamish and Mahnken 2001), with survival of Pacific Northwest Chinook co-varying on a spatial scale of 350–450km (Sharma et al. 2013). The Strategic Salmon Health Initiative (SSHI) was a program designed to examine the role of infectious disease in salmon declines, with specific focus on the early marine phase. Studies undertaken included a broad-based survey of infective agents detected in Chinook Salmon from southern BC stocks during their migration from freshwater hatcheries and natal rearing areas through their first year at sea, with a dataset that surveyed over 50 infectious agents in juvenile Chinook Salmon over a decade. Genetic stock identification (GSI) was performed on individual fish so that infection status could be linked back to individual stocks.

GSI and CWT data on juvenile Chinook Salmon reveals that most sub-yearling stocks in BC remain within 200 km of their river estuary of origin for their first marine year (Trudel et al. 2009). Indeed, GSI data on the juvenile salmon collected for analyses of pathogens reveals that all four of the enhanced DUs use the Strait of Georgia in the summer months through early fall (Appendix A). There is a pattern of northward movement of fish from DU13 and DU15 in the fall. However, without catch per unit effort data, there is not enough granularity in the data to determine precisely when the majority of fish have left the Strait of Georgia and CWT recoveries representing DU1 has a pattern of rearing in the Salish Sea, coastal Washington and Vancouver Island year-round and for all ages. Detections of a small number of fish from the DU15 (LTh-1.2) were observed in two years over the first winter at sea, and CWT recoveries from age 3 fish in the groundfish trawl fishery provide evidence that at least part of the DU resides within the strait until their second year at sea. As fish move northward through the Discovery Islands and Johnstone Strait in the fall/winter period, they will have come into contact with high density salmon farms, culturing Atlantic Salmon in this region of the coast. Hence, all of these DUs may also experience risks associated with pathogen spillover effects from farms.

Application of spatial resampling simulations via SatScan[22] applied over detection data for 38 of the most commonly detected infective agents in juvenile Chinook Salmon from stocks throughout southern BC revealed that the Strait of Georgia is a hotspot for infectious agents in the summer months (Bass et al., In Prep; Table 62). Specifically, all Fraser River stocks are at a high risk of infection by freshwater bacterium *Flavobacterium psychrophilum*, and freshwater parasites *Myxobolus arcticus, Tetracapsuloides bryosalmonae* and *Ichthyoptherius multifiliis*, observed at highest levels for “marine” samples in fish sampled at the confluence of the Fraser River Estuary. Within the Strait of Georgia, infections with bacterium *Candidatus* syngnamydia salmonis, and microparasites *Loma salmonae*, *Paranucleospora theridion*, *Parvicapsula pseudobranchicola*, and viruses Erythrocitic necrosis virus (ENV), salmon pescarenavirus-1 (SPAV-1), and viral hemorrhagic septicemia virus (VHSV) were elevated during summer

[22] SatScan. Available from SaTScan - Software for the spatial, temporal, and space-time scan statistics [Accessed March 21, 2022]

months. DU15 (LTh-1.2) and DU1 (BB) observed reaching the Discovery Islands in the summer would also carry an elevated risk of exposure to *Ichthyophonus hoferi*, and if they passed Johnstone Strait, they would also be at an elevated risk of *Tenacibaculum maritimum* infection, which is strongly associated with farm activity (Shea et al. 2020; Bass et al. In Prep). Hotspots of many infective agents shift during the fall/winter period. In this period, the DUs for which data are available appear to be moving northward, through the highest density salmon aquaculture region in BC, although fish are still detected in the Strait of Georgia. Fish still residing in the Strait of Georgia will have new increased risk of exposure to bacteria *Piscirickettsia salmonis* and a Rickettsia-like organism (RLO), and parasites *Ceratonova shasta*, and *Parvicapsula minibicornis*. Several agents elevated in the Discovery Islands and Johnstone Strait in the fall/winter would also pose new exposure risks to migratory salmon, including bacterium *Candidatus* Piscichlamydia salmonis, parasite *Parvicapsula kabatai*, and virus piscine orthoreovirus (PRV). In all, the these enhanced DUs are at an elevated risk of exposure to 21 of the 38 most common agents assessed, seven of which dominate in the environments in which they live from spring through fall (Appendix B).

Exposure to a salmon pathogen does not mean that a fish will become diseased, and it is notably difficult to study disease development of fish in nature, especially in the marine environment where mortality is not directly observable. There were four approaches used in the SSHI to assess pathogenic potential, or disease risk, of agents carried by migratory Chinook Salmon. First was traditional histopathology, where microscopic lesions associated with cellular damage can be observed. This method is considered a gold standard, or at least the normal means with which disease is demonstrated, but requires fish to be at a fairly advanced stage of disease. Capturing fish at late stages of disease through random sampling may be rare, as many agents impact performance traits like swimming or vision and increase risk of predation at early stages of disease (reviewed in Miller et al. 2014; also see Furey et al. 2021). To localize infective agents potentially associated with cellular damage, SSHI researchers often employed a molecular staining procedure, *in-situ* hybridization, to fluorescently label the agent in question (see Di Cicco et al. 2018; Mordecai et al. 2019, 2020). Researchers also utilized knowledge of pathological effects from controlled laboratories for well-studied agents. Of the agents that these enhanced DUs were at an elevated risk of exposure, several were well-studied known pathogens of Chinook Salmon, including freshwater agents *F. psychrophilum* (Loch et al. 2012), *T. bryosalmonae* (Foott et al. 2007), *C. shasta* (Hurst and Bartholomew 2015), *Renibacterium salmoninarum* (Kent et al. 2013), *Nanophyetes salmonicola* (Roon et al. 2015), *I. multifiliis* (Foott 2002), and IHNV (Garver et al. 2005), and saltwater agents *Aeromonas salmonicida* (Kent et al. 2013), *P. salmonis* (Brocklebank et al. 1993), *Vibrio anguilarum* (Arkoosh et al. 1998), *Ichthyophonus hoferi* (Kocan et al. 2004) and VHSV (Emmenegger et al. 2013). L. salmonae is an opportunistic pathogen (Shaw et al. 2000) and pathological investigations on free-ranging fish confirmed lesions in gill tissue in some fish (Wang 2018). Within the SSHI, pathology in juvenile free-ranging BC Chinook was also demonstrated for *C. shasta*, *P. minibicornis*, *Ca. B. cisticola*, *I. hoferi*, *P. theridion*, PRV (Wang 2018), and SPAV-1 (Mordecai et al. 2019), although it is important to note that not all agents were assessed.

Increasingly, gene expression profiling has been used to document and diagnose disease, especially in human medicine (Zaas et al. 2009; Andres-Terre et al. 2015). Given the increased sensitivity to detect early stages of disease development (Andres-Terre et al. 2015), the SSHI researchers followed suit and developed and validated a panel of genes that could identify salmon in a viral disease state (Miller et al. 2017). This “viral disease development” (VDD) panel was applied to identify fish with activated anti-viral activity indicative of disease and differentiate them from fish either not infected with a virus or only in a viral carrier state. The VDD biomarker panel was applied to discover previously uncharacterized viruses in BC salmon (Mordecai et al. 2019, 2020), to study disease development processes associated with PRV infection (Di Cicco et al. 2018), and to identify fish in the wild experiencing disease associated with specific viruses (Wang 2018; Mordecai et al. 2019). Activation of the VDD panel confirmed that many farmed and wild Chinook Salmon with high levels of PRV during the fall/winter period were in an active disease state, and pathology confirmed that when this panel was activated, the virus was invading new tissues which would ultimately become damaged (Di Cicco et al. 2018; Wang 2018). A new similar biomarker panel has recently been developed in Norway to identify bacterial disease responses in salmon, and will be applied in a similar way in BC salmon in the future.

As juvenile salmon infection data were generated using fish sampled over a decade, the SSHI was able to apply these data in models to explore relationships between infection with specific agents and CWT-based estimates of smolt-to-youngest age of recruitment survival (Smolt to Adult Ratio (SAR)[23]). This approach revealed agents that carried a potential for population-level impacts, and despite being association-based, was considered the most compelling means to identify pathogens of importance to free-ranging salmon. This is the same approach that has been used to elucidate other factors associated with year-class abundance—such as ocean regime shifts (Pacific Decadal Oscillation (PDO)/El Niño Southern Oscilliation (ENSO)), sea surface temperature (SST), early marine growth, prey availability, predator impacts, or others (e.g. Mueter et al. 2002; Duffy and Beauchamp 2011; Sharma et al. 2013). Models were also developed to assess associations between agent loads (abundance) and body condition, specifically weight relative to length (mass deviations[24]). Given that pathogen profiles shift considerably between warm spring/summer and cool fall/winter periods, separate models were developed for each. Agents detected in the spring/summer period showing the strongest associations with Chinook Salmon survival include (in order of impact) *Ca*. S. salmonis, RLO, *I. multifiliis*, *T. maritimum*, Pacific Salmon nidovirus (PsNV), SPAV-1, and *M. arcticus* (Table 62). *T. maritimum* and *M. arcticus* also showed strong negative associations with mass deviation in the summer period, along with PRV, C. shasta, and ENV. In the fall/winter period, *M, arcticus*, *P. psuedobranchicola*, and PRV showed the strongest negative associations with survival, followed by the two freshwater agents *I. multifiliis* and *F. psychrophilum*. Agents showing negative associations with mass deviations in the winter included *L. salmonae*, PRV, *Ca* B. cisticola, *I. hoferi*, *T. maritimum*, and *I. multifiliis*.

Temperature is known to be a major driver of infection and disease susceptibility for a wide array of pathogens (reviewed in Miller et al. 2014), but is also associated with productivity shifts in the ocean (Sharma et al. 2013). Ocean temperatures are also associated with marine regime shifts, such as ENSO and PDO, established factors associated SAR across multiple salmon species (ibid). The SAR models for infection from Bass et al. (In Review) incorporated a sea surface temperature (SST) anomaly to account for temperature mediated influences and found that localized SST was not negatively associated with Chinook survival over the 10 year study, but was positively associated with mass deviation, especially during the fall/winter period (i.e. warmer winters = fatter fish). Thus, in our short time-series, we found that infectious agents were more strongly associated with SAR than the well-established SST anomaly indicator.

In summary, the early marine habitats utilized by these enhanced DUs show elevated infection risk for many of the agents strongly associated with pathogenic potential. Three of the four agents with higher than normal prevalence in the Fraser River Estuary are associated with

[23] Bass, A.L., Bateman, A.W., Kaukinen, K.H., Li, S., Ming, T., Patterson, D.A., Hinch, S.G., and Miller, K.M. *In Review*. The spatial distribution of infectious agents in wild Pacific salmon along the British Columbia coast. Scientific Reports.

[24] Ibid.

negative impacts on Chinook Salmon condition and survival. While most may represent carryover effects from freshwater (i.e. years when freshwater conditions were suboptimal and fish entered the ocean in a more compromised state), others, such as the brain parasite *M. arcticus*, may impact performance. In Alaskan sockeye, this parasite is associated with severe reductions in swimming speed (Moles and Heifetz 1998), which could compromise both feeding and predator avoidance. In the Strait of Georgia, five of the saltwater transmitted agents with elevated risk of infection were also negatively associated with survival, and another was a well-established virulent viral pathogen (VHSV). In the Discovery Island and Johnstone Strait, elevated risk of infection by *T. maritimum* and PRV, two agents known to pose risk of transmission from farmed to wild salmon (Shea et al. 2020; Bateman et al. 2021; Mordecai et al. 2021) show consistent negative associations with survival and mass deviations across multiple salmon species (Chinook, Coho and Sockeye for *Tenacibaculum* and Chinook and Coho for PRV; Bass et al. In Review; Amy Teffer, University of British Columbia, pers. comm.).

Taken together, it is clear that pathogen infection of juvenile salmon during their first year at sea is a factor contributing to annual variations in survival of Chinook Salmon stocks in southern BC. The habitats utilized by these enhanced DUs carry abnormally high levels of infectious agents associated with poor condition and survival, which likely increase infection-related risks and impacts on them. We expect that these risks are exacerbated by climate-driven impacts on thermal exposure – both directly causing stress to salmon (Akbarzadeh et al. 2018; Houde et al. 2019) but also impacting the prey field (Sharma et al. 2013), as well as impacts of increased predation – due both to higher predator numbers and more compromised fish that are easier to capture. New genomics-based research will provide further understanding of the cumulative and synergistic interplay between stress and disease by elucidating the stressors salmon are responding to – like thermal stress, low oxygen stress, salinity stress, and viral disease, and identify fish that show signs of morbidity (natural death within 72 hours) (Houde et al. 2019; Akbarzadeh et al. 2020). Application of this technology in Fraser River Sockeye Salmon, which take the same route through the Strait of Georgia as the enhanced DUs with a northern ocean distribution but do so in a short period of time in the summer, has identified high levels of thermal stress as fish migrate out of the Fraser River and throughout their migration in the Strait of Georgia, peaking in the northern areas before fish move into the Discovery Islands where they will be exposed to an even higher concentration of some pathogens (Kristi Miller, DFO, Nanaimo, BC, unpublished data.; Shea et al. 2020). Both laboratory and field data show, however, that it is osmotic stress that appears most directly associated with survival (Houde et al. 2019; Kristi Miller, DFO, Nanaimo, BC, unpublished data). Hence, fish that are poorly prepared for ocean entry will be less able to withstand additional stress (Houde et al. 2019) or able to fight off infection. It is thus imperative that hatchery releases are released as free of pathogens and disease as possible to minimize risks of infection and disease in the ocean. Osmotic stress can also arise from infection and open wounds. The bacterial agent *T. maritimum*, many fungal infections, sea lice burdens, lamprey wounds and predator bites are among the biological factors that can increase risk of osmotic stress. *T. maritimum* and sea lice may be mitigated through reductions in farm exposure, while other factors are more difficult to control. Studies are ongoing to identify the most common mechanisms by which juvenile salmon are experiencing osmotic stress, and where these stressors are most commonly observed so that mitigation strategies can be developed, where possible.

Ranking

This threat is pervasive for all DUs, with a medium risk for DU1 and low to medium risk for DUs 6, 13, and 15. Pinniped predation is pervasive for all enhanced DUs, as all Chinook from these populations transit habitat occupied by pinnipeds. Both DU1 (BB) and DU6 (Maria) 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 and near the mouth of the Fraser River 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. The extent of seal predation is currently unknown; however, it is thought to be problematic for DU1 (Serpentine and Nicomekl rivers) because seals have been observed eating returning Chinook adults that are restricted by sea dam closures. During low water years, Chinook in DU6 could have a longer exposure period to pinnipeds if they are waiting for favourable flows to enter Maria Slough. Northern Pike minnow have a significant population in Maria Slough, but their impact on Chinook is not well-defined.

While not mentioned previously in this section, DU13 is at additional risk of predation from native species, including large Northern Pike minnow, Rainbow Trout and Bull Trout present in Shuswap and Little Shuswap Lake, and several avian predators.

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 for these enhanced DUs, 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 SBCC encounter and are host to a variety of agents that can lead to infection and disease. Infections and disease affect all SBCC DUs to some degree, yet there is currently a large amount of uncertainty surrounding the direct impacts on productivity and survival for Chinook Salmon.

3.1.8.3 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 the enhanced DUs from introduced genetic material involves hatchery activities. 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). The introduction of genetic material to the gene pool of a wild DU happens through a process called genetic introgression (Utter 2001; Muhlfeld et al. 2009). Introgression can occur when there is species hybridization, when fish from a DU stray to and reproduce with fish in a different DU, and introgression can occur within a single DU when genes and genetic material from hatchery origin fish are transmitted to the wild, indigenous population (Utter 1998). Both wild and hatchery origin salmon can stray from one DU to another, but some hatchery practices lead to higher stray rates than other practices (Candy and Beacham 2000). When stray salmon reproduce with wild indigenous salmon, survival can increase in the next generation via heterosis, or survival can decrease via outbreeding depression (Emlen 1991). Outbreeding depression is a threat to wild, indigenous populations when it reduces survival in the next generation (F1) and the subsequent generation (F2) either by producing intermediate phenotypes that are maladapted to the wild population or by epistasis in co-adapted complexes of genes (Gilk et al. 2004).

Hatchery-origin fish, whether from the same DU or another, can interbreed with wild stocks, leading to a decrease in fitness for fish living outside the hatchery, and limiting wild population adaptability in future generations due to the reduction of genetic diversity (Waples 1991;

Gardner et al. 2004). The relative fitness of hatchery salmon compared to wild salmon can be measured by the adult-to-adult reproductive success in the natural environment, and this relative reproductive success is often less than one for hatchery salmon (Christie et al. 2014b; Withler 2018). Using a quantitative genetic model, Ford (2002) reported that selection in captivity could theoretically reduce the fitness of wild populations, and there is growing evidence of progressive, intergenerational declines in fitness in wild populations when hatchery origin fish interbreed with wild origin fish on the spawning grounds (Fleming 2002; Berejikian and Ford 2003; Gardner et al. 2004; Araki et al. 2007, 2008; Grant 2012; Christie et al. 2014a; Withler et al. 2018; DFO 2018a). There are multiple mechanisms contributing to the reduced fitness of hatchery fish and their offspring, including artificial selection and epigenetic effects caused by the hatchery rearing environment which can be transgenerational (Le Luyer et al. 2017; Larsen et al. 2019; Venney 2020). Waples (1999) outlines how risks posed by hatcheries can never be fully avoided, even with best management practices.

The introduction of genetic material is a threat for enhanced DUs, and Withler et al. (2018) and DFO (2018a) advised that Canadian Chinook enhancement programs should be managed such that strays from out-of-basin hatchery programs are less than 3% of spawners in the wild population per year in order to have little long-term genetic consequences on the receiving population. Stray Chinook Salmon from hatcheries can be monitored by marking and sampling using techniques such as CWTs, thermal otolith marks, and genetic Parentage Based Tags (Candy and Beacham 2000; Vander Haegen et al. 2011; Brenner et al. 2012; Sattherwaite et al. 2015). The degree of marking and sampling for hatchery origin Chinook on the spawning grounds varies greatly among the spawning sites for these enhanced DUs, and others that could stray to these DUs. Both marking and sampling have been insufficient to measure the percentage of hatchery origin spawners on the spawning grounds for all the sites in the enhanced DUs, thus it is uncertain if the DFO (2018a) proposed guidelines are being met. These enhancement marking and spawning ground monitoring programs have not been designed for the objectives proposed by Withler et al. (2018), except at the Exploitation Rate Indicator Stocks (ERIS; i.e. Nicola population in DU15). This situation makes it difficult to accurately evaluate if the proportion of hatchery origin spawners in the wild population is less or more than the guidelines proposed by DFO (2018a) and the US Hatchery Scientific Review Group (Mobrand et al. 2005).

DU1 (BB) likely has experienced considerable genetic introgression based on observations. First, Chilliwack Chinook were released in large numbers (around 50,000 fish annually) into DU1 from 1990 to 2003, but none since then (Appendix C). Second, a high frequency of adipose fin clipped Chinook have been counted in the Little Campbell River recently, ranging from 4% to 49% over 2012-2020, but none have been released there since 2004 which identifies Chinook straying from at least one other DU. A similar pattern of straying likely occurs at the other sites, but data were not collected, recorded or managed, and we speculate that out-of-basin strays exceed the guidelines proposed by DFO (2018a). Third, one Chinook from the Cowichan River was identified in the Little Campbell River in 1997 based on the reading of a single CWT, however no other fish have been sampled for CWTs, despite numerous observations of AFC fish. Within about 60km of the DU1 estuaries, there are several large hatchery programs (e.g. Sandy Cove, Burrard Inlet, Orcus Island-East Bay, etc.) that use out-estuary displacement rearing strategies, which Candy and Beacham (2000) found had the highest stray rates and were suspected to have the least successful imprinting on the home stream for Chinook Salmon. Since Candy and Beacham (2000) reported that the Chemainus and Cowichan Chinook stocks had the highest stray rates for Southern BC stocks to US locations, we speculate stocks have also strayed to DU1 based on its proximity to the US and one observed Cowichan fish. To better understand and mitigate genetic risk, a marking and sampling program for the Little Campbell River Hatchery Chinook stock is planned for 2022.

These marking and subsequent sampling activities will improve the data and information to better understand the sources and degree of hatchery fish originating from outside and within DU; however, additional marking is needed from nearby hatchery production programs in the Salish Sea region of Canada and the United States to measure the out-of-basin stray rate.

There is no evidence of strays or genetic introgression from another DU at DU6 (Maria). No hatchery Chinook from outside the DU have been released directly into this DU. Since 1998, 21 of the 23 years had fish examined for adipose fin clips; however, 4 years had relatively few fish examined (i.e. <15; Appendix C). Among 304 adipose fin clipped fish sampled for CWTs, none was from outside the DU and all tags originated from Maria Slough. There is some evidence of strays and likely genetic introgression from other DUs at DU15 (LTh-1.2); however, no hatchery Chinook from outside the DU have been released directly into this DU. At the Eagle River, Chinook were examined for adipose fin clips from 1986 to 1996 and each year since 2015, whereas at the Salmon River Chinook have been examined for adipose fin clips from since 1986 with a few exceptions (2007-08, 2015-16, and 2018-2020; Appendix C). Among all of the fish sampled for CWTs at Eagle (1105) and Salmon (388) rivers, only two fish were identified outside the DU (Deadman River, Fraser Spring 1.2 DU, and Middle Shuswap River, South Thompson Summer Age 0.3 DU). We speculate that the percentage of out-of-basin strays is less than 3%, but measurements are not reliable due to insufficient marking to represent all out-of-basin hatchery production and insufficient sampling on the spawning grounds—both are critical for an evaluation of these rates.

There is some evidence of strays and likely genetic introgression from other DUs at DU13 (STh-1.3); however, no hatchery Chinook from outside the DU have been released directly into this DU. Escapements have been sampled for adipose fin clips and CWTs at the Bonaparte (1983-1996), Coldwater (1982-2004, 2010-2015 and 2017), Nicola (1981-2021), and Spius (1987-2004, 2010-2015 and 2017; Appendix C). Among 10,489 fish with CWTs, 6 Chinook have been identified as strays from other DUs (i.e. Middle Fraser Spring 1.3, North Thompson Summer 1.3, Shuswap River Summer 0.3, South Thompson Summer 1.3, and one from the Capilano River (ECVI Fall DU) and another from the Upper Bulkley DU). We speculate that the percentage of out-of-basin strays is less than 3%, but measurements are not reliable due to insufficient marking to represent all out-of-basin hatchery production and insufficient sampling on the spawning grounds.

This threat is deemed pervasive for DUs 1, 6, and 13, and large for DU15. A serious-moderate impact level with a high level of uncertainty was assigned to DUs 1 and 15. In DU1, hatchery releases from outside the DU have occurred; the genetic impacts on the wild population are unknown but expected to be negative. Enhancement currently exists in three of the six populations within DU15, although five have histories of within-DU enhancement. Hatchery-origin fish now comprise the majority of the Nicola population and an unknown degree of genetic diversity has likely been lost within the wild population. The genetic effects of hatchery enhancement have an unknown effect on Maria Chinook (DU6) because conflicting opinions existed on the impacts to this small, integrated population. In DU13, hatchery enhancement has only occurred in the Eagle River (end 1993) and Salmon River (continuing) with Chinook Salmon are inspected at the Salmon River fence for external marks.

Table 37. DFO threats assessment calculator results for impacts from Invasive Non-Native and 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 and Alien Species	DU1	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 38. 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	DU1	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 39. 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	DU1	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Unknown	Medium	Unknown (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low	Medium	Low (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Broad

3.1.9. Pollution and Contaminants

Much of the information in the following sections on pollution were summarized in Arbeider et al. (2020) for Interior Fraser Coho Salmon and in DFO (2020a) for Fraser Chinook. The information provided in their reports are highly relevant to SBCC due to the considerable habitat overlap.

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 and Boundary Bay drainages; therefore, pollution is separated into categories, including Household Sewage and Urban Waste Water; Industrial and Military Effluents; Agriculture and Forestry Effluents; Garbage and Solid Waste; and Airborne Pollutants. Contaminants in 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 SBCC are extremely difficult to disentangle. In this section, the potential effects of contaminant exposure on SBCC are first discussed, followed by known sources of pollution from individual categories and their predicted threat to SBCC.

Many contaminants are persistent in the environment, can 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 prior to 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). POPs have been detected in the Nechako River 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 Nechako 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). Long range atmospheric transport and deposition, coupled with the release of historic contaminant deposits from melting glaciers and permanent snow fields, are the likely source of these POPs at higher elevations. 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, glacial deposits release contaminants into headwaters, which may increase and expose younger more vulnerable stages of SBCC to POPs. Additionally, PCBs and other POPs are still present in consumer products; even though they are produced at much lower rates, their persistent nature allows them to accumulate in environments.

SBCC 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). SBCC spend most of their life in the pelagic marine environment where bioaccumulation of contaminants may be greatest (Healey 1991; Ross et al. 2013; COSEWIC 2017) and they undergo the majority of their growth (95%). 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 return 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), 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). Fish responses to these toxic chemicals are 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 salmon 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 on SBCC; however, considerable research has been conducted on ocean-type Chinook Salmon in nearby Puget Sound (O’Neill et al. 2020). 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, measurements of blood chemistry, condition factor, and total lipid content suggest this metabolic response was indeed contaminant-induced. While not SBCC specific, the results of these studies suggest that similar effects may occur for SBCC as these DUs migrate twice in their lifetime through either the Lower Fraser River and estuary or the Boundary Bay rivers and estuary. These effects may be particularly pronounced for DU1 because their freshwater habitat exists in a highly developed area and their rearing grounds in Semiahmoo and Mud Bays support an industrial footprint. Further, many of the Chinook from DU1 are thought to disperse into and rear 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 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 (DU2) 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). Accumulation of PCBs in seaward-migrating juvenile Chinook appears to be related to the type of land cover in their natal rivers, with watersheds with more than 25% impervious surface cover correlated to the highest accumulations in Chinook than less developed watersheds[25], and rearing in habitats in the vicinity of wastewater inputs (O’Neill et al. 2020). Future research on the many sources of pollution in the Fraser River and Boundary Bay

[25] PSP. 2021. Available from Vital Signs | Toxics in Fish [Accessed March 22, 2022]

drainages is needed to mitigate the effects of contaminants and to reduce their introduction into the environment; this has been identified as a major knowledge gap that needs attention for future recovery planning.

3.1.9.1 Household Sewage and 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 areas surrounding the lower Fraser River and Boundary Bay drainages are highly concentrated with urban development, leading to considerable sewage and wastewater discharge into these watersheds. The highly impermeable urban landscape of the Greater Vancouver mainland 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. Although some of these facilities have been upgraded to reduce the amount of contaminants in discharge and increase capacity to accommodate the human population in Metro Vancouver, these effluents will bypass treatment plants through CSOs and directly enter rivers if wastewater volume exceeds working capacity. In 2016, Metro Vancouver released over 30,000,000m^3 of untreated sewage into the Fraser River, ranking BC as the province with the consistently highest outflow volume in Canada[26,27]. Other sources of urban contaminants include street stormwater systems that bypass wastewater treatment plants, which can have adverse effects on smaller systems and result in die-offs of juvenile Chinook (Darryl Hussey, DFO, Kamloops, BC, pers. comm. 2019) and affected the sensory physiology and predator avoidance behaviours of Coho Salmon (Sandhal et al. 2007). Within FRC DU habitat, septic fields serve most rural properties where effluents leach into adjacent streams and treated sewage from the City of Merritt flows into the Nicola River. Heavy metals, such as copper from vehicles (Sandhal et al. 2007), and other toxic compounds, such as a globally ubiquitous tire rubber compound, 6PPD-quinone, that causes acute toxicity for adult salmon at around 1 microgram per liter (Tian et al. 2021), accumulate on roads and then enter waterways via CSOs. Dust from roads and highly trafficked areas can also act as a vector for fine sediments and contaminants (e.g. PAHs and heavy metals) to aquatic systems (Gjessing et al. 1984). Although traffic may be highest in urban areas, roads that are closer to spawning areas may have relatively larger impacts because embryos are at a more sensitive life stage. Multiple busy roads intersect the three drainages in DU1. In DU13, the Trans-Canada highway parallels the Eagle River for multiple kilometers and the Salmon River road follows the Salmon River along its lower reach and Highway 97 follows the river for 35km. Large transport trucks and other vehicles often crash into the Eagle River due to unsafe conditions on the TransCanada highway. In DU15, Highway 8 parallels the Nicola River while the Coquihalla highway follows and intersects the Coldwater River. Additionally, many kilometers of busy highways are in close proximity to SBCC migration routes and rearing habitats.

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

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[26] Cruickshank 2018 – News article for The Star Vancouver: Available from: "Untreated Sewage Pollutes Water Across the Country" [Accessed Jan 15 2022].

[27] Li and Cruickshank 2018 – News article for StarMetro: Available from: "Sewage problems must be fixed if Vancouver wants to be a global role model, say advocates". Fraser River Keeper - Sewage Problems Must Be Fixed [Accessed Jan 15 2022].

contaminants depends on every city's 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 SBCC DUs, as DU1 habitat is located within highly developed urban areas and DUs 6, 13 and 15 must 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 SBCC. While there is some evidence suggesting adverse effects of contaminant exposure from contaminants such as pharmaceuticals, home and personal care products, it is difficult to separate these effects from other cofactors that may be acting on SBCC. This threat is predicted to have a low-medium range of impact on all FRC DUs and a medium-high range of impact for DU1 with a medium level of causal certainty. Boundary Bay Chinook (DU1) are likely exposed to household sewage and urban wastewater during their entire freshwater occupancy.

3.1.9.2 Industrial and 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, WWTPs, 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). Historical seepage of creosote into soil at historic operations resulted in significant underground reservoirs of contaminants that are slowly infiltrating systems through groundwater in the lower Fraser River, near Coquitlam, BC (Bieber 2003).

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 Stellako 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). The Highland Valley mine occurs along the migration route and near possible rearing habitat for DUs 13 and 15, while other mines are located upstream of the distribution of the FRC DUs in this RPA. Intentional and unintentional releases 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 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).

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, conveyor belts, rail cars), and train derailments. While not SBCC-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[28]. 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 Point Roberts (5-10km) 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; Johnson and Bustin 2006) indicating significant air-borne transfer into the surrounding environment. The impacts of coal dust at the DU level are unclear, but an overall negative effect is anticipated and could be greater for DU1 due its proximity to urban areas.

The transport of diluted bitumen (dilbit) through pipelines may have impacts when leaks or spills occur within SBCC 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 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 Expansion pipeline runs through the upper Fraser, the length of North Thompson (DU15), part of the Lower Thompson (DU15), and along the lower Fraser River (DU6). Spills over land may also pose an unknown threat if dilbit or its constituents seep into groundwater and are transported into streams and the hyporheic incubation environment in low concentrations but over a long period of time. Dilbit is also

[28] Westshore 2019. Premier Mover of Coal. [Accessed March 14, 2022]

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. There are multiple reported instances of industrial effluents entering DU1 habitat. In the Nicomekl River, discharge from a cement plant triggered a mass-die off of fish and crayfish in September 2018[29] and a large diesel spill, worsened by heavy rainfall, occurred in May 2020[30]. In the Serpentine River, the City of Surrey reported that detergent dumped into Guildford Brook foamed the Serpentine River and caused known fish kills[31].

The scope of this threat was deemed pervasive for all SBCC DUs, as DU1 occurs in a highly developed area and DUs 6, 13, and 15 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.); however, to the best of our knowledge, there is no research directly linking these effects to population-level declines in SBCC. Research conducted on Chinook Salmon in Puget Sound reported sufficiently high 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 DU1 is likely at the highest level of risk compared to other DUs due to the increased amount of time spent in a highly developed area and their distribution in Puget Sound. Given the above, it is predicted there is medium impact for DU1 and a low to medium range of impact on all FRC DUs with a medium level of causal certainty.

3.1.9.3 Agricultural and 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. Forest fires are also included in this category, which can introduce toxic chemicals into aquatic ecosystems through forest fire retardants and exacerbate the impacts of effluents from the agricultural and forestry sectors.

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

[29] Soapy water in Surrey's Tynehead Park raises eyebrows | Surrey Now-Leader [Accessed December 15, 2021]

[30] Fuel oil contaminates Langley salmon-bearing stream | Today In BC [Accessed December 15, 2021]

[31] Huge fish kill near Langley hatchery another blow to conservation group | CBC News [Accessed December 15, 2021]

to streams through bank destabilization and increased surface erosion (Rhodes et al. 1994), which occurs in the Salmon River, Nicola basin, Louis Creek, Deadman River, and Little Campbell River. Landslide events have deposited significant amounts of sediment into DU15 and are discussed in 3.1.10.3 Avalanches and Landslides. Sediments and their effects can be broadly separated into fine and coarse sediments. Finer sediments have more direct impact, primarily by reducing egg survival through decreasing oxygen circulation, intrusion of fine sediments into interstitial spaces 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 have variable impacts 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.

Climate change is expected to increase the frequency of wildfires, 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 un-ionized (NH_3^0) forms when dissolved in surface water, and the former does not easily cross fish gills and is less bioavailable than the un-ionized 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 (United States Environmental Protection Agency [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 both the acute mortality immediately following misapplication and delayed mortality after ocean exposure (Dietrich et al. 2013). While not SBCC-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).

LWDs are a complicated aspect of forestry effluents because they can provide complex and beneficial habitat for juvenile salmon by creating lower-velocity zones in which fish can rest and forage for prey. Drift-feeding fish, such as SBCC, 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). Less LWD recruitment is a chronic impact of logging, which decreases habitat complexity (Meehan 1991). However, landslides may move large amounts of LWD into streams and modify habitats, create sediment traps, or impact connectivity when stumps and LWD are left in piles at harvest locations (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 how forestry practices impact LWD inventory in the Fraser River basin or the biological influences on SBCC.

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), which may be particularly problematic in Maria Slough due to little flow. There is little evidence of this 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, in Chilqua Creek (lower Fraser River) the biological oxygen demand (BOD) from agricultural fecal waste and sewage-fungus growth has decreased O_2 levels to less than 1.5 ppm in late October, creating an oxygen barrier for salmon passage and in the past also leading to multiple fish kills of adult Chum Salmon (Dave Nanson, DFO, Delta, BC. pers. comm. 2019). Conversely, nutrients may also affect primary and secondary productivity in beneficial ways. Nutrient additions have been used to enhance stocks in lakes and streams, 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.

Numerous 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 of organochlorines (e.g. DDT, endosulfan, cyclodienes), organophosphates (e.g. glyphosate (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 are known to use (Wan et al. 2005). Glyphosate is used in both agriculture and forestry. Laws prevent its use near aquatic systems, but it can be transported in rain-eroded soils and enter streams; however, it 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 SBCC (Mitchell et al. 1987). Rainwater transports chlorophenoxy herbicides and triazenes into streams, which may persist for longer periods than organophosphates and accumulate in sediments (Hill et al. 1990; Solomon et al. 2008). Atrazine may affect Chinook Salmon immune systems, but there is little evidence of lethal or sublethal effects at environmental concentrations (Solomon et al. 2008). The above contaminants (and more) have been observed in the interior and lower Fraser River watersheds (Gray and Tuominen 1999) as well as Boundary Bay watersheds, but more consistent and intensive surveys are required to understand their impacts on SBCC.

The scope of this threat was deemed pervasive for all DUs because agricultural and forestry effluents exist throughout their freshwater habitats with moderate impacts for DUs 1, 6, and 13 and a serious impact for DU15. Agricultural land reserve borders significant portions of the Little Campbell River (DU1), Maria Slough (DU6), Salmon River (DU13) and all DU15 watersheds. In Maria Slough, there is concern that runoff from manure spraying could affect water quality and nutrient loading, which is likely emphasized due to relatively stagnant water. Forestry occurs in DUs 6, 13, and 15, the effects of which have caused significant erosion and siltation in DU15. Fine grain sedimentation can be particularly problematic in DU15 if it fills the interstitial spaces of thermal refugia. Recent wildfires have emblazed significant portions of the Salmon River watershed and all of DU15 and they are expected to cause significant sedimentation in future years. In DU1, agricultural effluents exist in all three rivers, while forestry effluents are unlikely.

3.1.9.4 Garbage and 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, microplastics (IUCN-CMP threat category 9.4).

Microplastics are small fragments, fibers, and granules of barely visible plastic particulate matter 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 SBCC because plastics can block the intestinal tract leading to mortality and excrete harmful compounds causing physiological consequences. Microplastics also pose a threat to planktonic prey species of SBCC, 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 may be at particular risk because they might mistake microplastics for natural food items of the same size (Desforges et al. 2015). Suspension and filter feeding zooplankton are highly exposed to microplastics because their feeding modes concentrate food from large volumes of water (Kaposi et al. 2014; Moore 2008). Recent research conducted in the Strait of Georgia provided an ecological context for transmission of microplastics to higher trophic level organisms, including Chinook Salmon and other Pacific Salmon species (Desforges et al. 2015). This study demonstrated two types of zooplankton critically important to juvenile SBCC, copepods and euphausiids, ingest microplastics in the open ocean, leading to the subsequent accumulation of these contaminants in fish that prey upon 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 are 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 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[32]. Surveys in Puget Sound have identified Chinook Salmon mortalities among more than 32,000 animals sampled from derelict fishing nets (Good et al. 2010), and derelict fishing nets are regularly observed in large rivers with salmon fisheries, like the Columbia River (Kappenman and Parker 2007). For SBCC, considerable uncertainty exists about the impact of this threat, since the quantity and effects of derelict fishing gear is not comprehensively monitored in the Canadian Salish Sea nor the rivers used by the Chinook in the DUs within this RPA. Thus, the propensity for SBCC to become entangled in ghost gear is also unknown. However, observations and retrievals of derelict fishing nets with both live and dead salmon are

[32] Emerald Sea Protection Society 2019. Lost Fishing Gear - A Global Challenge. Available from: What We Do — Emerald Sea Protection Society [Accessed March 14, 2022]

common in the Fraser River by DFO, First Nations, and communities near the end of salmon fishing season in late September[33].

This threat is pervasive for all DUs because microplastics exist throughout their marine habitat, although the degree to which SBCC consume microplastics or become entangled in fishing gear is unknown. However, threats workshop participants agreed that garbage and solid waste are a threat to SBCC.

3.1.9.5 Airborne 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 solar 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 effective scavengers of aerial contaminants (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 matures, while those compounds with higher water solubilities 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 SBCC 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 SBCC. Air-borne pollutants are expected to exert a low to medium level of impact with a low level of causal uncertainty due to lack of information.

3.1.9.6 Excess Energy

Light pollution is a lesser studied aspect of pollution with respect to SBCC, but considerable research has been conducted for salmon in the nearby Puget Sound and drainages (Tabor et al. 2004, 2021). In general, artificial light can affect the migration timing behaviour for a diversity of organisms (Gaston et al. 2017), and the 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 SBCC-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

[33] Nlaka'pamux, St'at'imc, and DFO. Nlaka'pamux, St'át'imc and Department of Fisheries and Oceans Annual Ghost Net Removal Program (frafs.ca) [Accessed January 22, 2022]

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 indirectly affect SBCC as it is an important cue for both predator avoidance and feeding in freshwater systems. It may alter 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). Additionally, light pollution along streams, estuaries and nearshore areas of the Salish Sea attracts Chinook Salmon and may increase their exposure to visual predators (Tabor et al. 2004; 2017), which may highly affect DU1 because of the urbanized landscape surrounding these rivers and the estuaries. The effects of light pollution on SBCC, particularly at the DU level, are currently unknown. In the freshwater environment, however, light pollution occurs in the lower Fraser River and estuary throughout DU1, and near populated nearshore environments.

This threat has an unknown scope and impact on all four DUs, although it is expected to be most pertinent in DU1 due to light pollution adjacent to streams and refracted and reflected light from the urban areas of greater Vancouver and the lower mainland.

Table 40. 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 and Urban Wastewater	DU1	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 41. DFO threats assessment calculator results for impacts from Industrial and 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 and Military Effluents	DU1	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 42. DFO threats assessment calculator results for impacts from Agriculture and 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 and Forestry Effluents	DU1	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	High	Medium	High (3)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 43. DFO threats assessment calculator results for impacts from Garbage and 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 and Solid Waste	DU1	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 44. DFO threats assessment calculator results for impacts from Airborne 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
Airborne Pollution	DU1	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-Medium	Low	Low-Medium (4)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 45. DFO threats assessment calculator results for impacts from Excess Energy 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
Excess Energy	DU1	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Unknown
	DU6	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Unknown
	DU13	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Unknown
	DU15	Known	Unknown	Low	Unknown (4)	Historical/Current/ Anticipatory	Continuous	Unknown

3.1.10. Geological Events

3.1.10.1 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)[34]. 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 SBCC.

3.1.10.2 Earthquakes and 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 et al. 2003). As with the threat of volcanic activity, it cannot be accurately predicted when these activities will occur, therefore the level of impact on SBCC could not be scored.

3.1.10.3 Avalanches and 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 SBCC 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. Slope destabilization is further exacerbated by forest fires where slopes are denuded of vegetation which in turn increases the frequency 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 (2019) represent the worst case scenario of a slide.

In the fall of 2021, several landslide events occurred along the Coquihalla Highway and within the Fraser Canyon after historic rain events destabilized the slopes in these river valleys. This

[34] Natural Resources Canada. 2019. Where are Canada’s volcanoes? Available from: [Where are Canada's volcanoes? (nrcan.gc.ca)](#) [Accessed March 14, 2022]

unprecedented weather event occurred after several large and intense fires burned these areas in the summer of 2021. Although none of the landslides generated a blockage to any rivers, the likelihood of another catastrophic landslide similar to the one in Big Bar in 2019 will increase due to the interaction between bank destabilization caused by future forest fires and increasing frequency of fall heavy rain events fueled by climate change.

Table 46. DFO threats assessment calculator results for impacts from Volcanoes 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
Volcanoes	DU1	Unknown	Unknown	Very Low	Unknown (5)	Anticipatory	Single	Extensive
	DU6	Unknown	Unknown	Very Low	Unknown (5)	Anticipatory	Single	Extensive
	This is not anticipated to be a threat for DUs 13 and 15.							

Table 47. DFO threats assessment calculator results for impacts from Earthquakes and Tsunamis 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
Earthquakes/ tsunamis	DU1	Unknown	Unknown	Very Low	Unknown (5)	Anticipatory	Single	Extensive
	DU6	Unknown	Unknown	Very Low	Unknown (5)	Anticipatory	Single	Unknown
	This is not anticipated to be a threat for DUs 13 and 15.							

Table 48. 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 and Landslides	DU13	Known	Low	Medium	Low (3)	Historical/Current/ Anticipatory	Recurrent	Restricted
	DU15	Unknown	Unknown	Medium	Unknown (3)	Historical/Current/ Anticipatory	Recurrent	Unknown
	This is not anticipated to be a threat for DUs 1 and 6.							

3.1.11. Climate Change

3.1.11.1 Habitat Shifting and 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 SBCC. As SBCC 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 SBCC.

Marine Habitat

In a recent report evaluating threats to SBCC 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 SBCC, 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 et al. 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 organisms' abilities 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 SBCC 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 SBCC 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 et al. 2019). During this event ocean surface temperatures were 3-5°C above seasonal averages, extending down to depths of 100m (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 et al. 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 may 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 likely 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"[35], 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. It is currently unknown how this anomaly will develop and what the impacts on Pacific Salmon will be; however, this highlights the ongoing threat of shifting ocean conditions for SBCC.

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 SBCC 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). 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 SBCC DUs, and in some streams, inhibit conditions necessary to achieve successful spawning and rearing (Nelitz and Porter 2009).

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

[35] NOAA Fisheries. 2019. New Marine Heatwave Emerges off West Coast, Resembles “the Blob.” Available from: New Marine Heatwave Emerges off West Coast, Resembles "the Blob" | NOAA Fisheries [Accessed March 14, 2022]

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). Projected sea level rise is likely to impact the low elevation coastal rivers, such as those in DU1 (BB); however, these impacts are expected to occur past the time frame (ten years) with which these threats were assessed.

Ranking

The threat from habitat shifting and alteration is pervasive for all Chinook DUs. DU15 (LTh-1.2) was deemed to be the most threatened from habitat shifting and alteration due to the number and intensity of wildfires that have occurred in recent years and will continue to be worsened by climate change. DU1 (BB) was also likely to be affected by this threat as the loss of intertidal marshes utilized by juvenile Chinook in Boundary Bay would be exacerbated by climate change. The severity of the threat was scored slight to high as there is a great deal of uncertainty as to how much habitat shifting and alteration under climate change will affect SBCC.

3.1.11.2 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 SBCC (DUs 13 and 15) due to their extended residence time in freshwater, and in particular, spring-run stream-type SBCC (DU15) as they generally inhabit and spawn in streams that are dependent on winter precipitation and buffering from groundwater inputs. Drought can create migration barriers to salmon, lead to direct mortality of eggs and juvenile SBCC, reduce habitat availability through over-crowding, increase predation, and increase the prevalence of disease and transmission of pathogens. While not SBCC-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). *Cryptobia* was partly responsible for pre-spawn die offs observed in the South Thompson mainstem in the late 1990's (Richard Bailey, DFO, Kamloops, BC, pers. comm. 2019).

DUs 1 and 6 (BB and Maria) scored medium-low for the risk of drought. Both DUs are in the Lower Mainland and exhibit rain dominated hydrographs. The impact at the population level for DU1 (BB) is uncertain as there are known problems with the Little Campbell River but it is unclear if these issues are due to drought or improper water management. DU6 (Maria) can be vulnerable to drought in the fall due to limited water storage in the small catchment of Maria Slough but this is not usually an issue as fall is typically a time of high precipitation in the region. However, DUs 13 and 15 (STh-1.3 and LTh-1.2) both scored as high risk. In DU13 (STh-1.3), the Salmon River is at the greatest current and future risk from drought as it has already experienced drought levels of 3, 4, and 5 (very dry, extremely dry and exceptionally dry respectively; BC MOE 2021) and is subject to high levels of agricultural water withdrawals. The migratory corridor of the South Thompson River has also experienced increasing levels of drought over recent years but is headed by Little Shuswap and Shuswap Lake and impacts of drought are likely to be less on migrating adult and juvenile Chinook. The remaining systems in DU13 (Eagle, Seymour, and Scotch Creek) are all not considered to be at risk of drought. The Coldwater River in DU15 has most been impacted by droughts in recent years, but all systems within DU15 are vulnerable due to the semi-arid environment in the region. The dry conditions in DU15 are coupled with increasing agriculture in the region and consequently further water use pressures from agricultural expansion.

In both 2015 and 2017, the South Thompson basin experienced repeated weeks of Level 4 drought conditions (extremely dry)[36]. 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 River 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.

3.1.11.3 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 SBCC. 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 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 3.3 Natural Limiting Factors for a detailed description of the thermal limits of Chinook Salmon. Fraser Chinook Salmon-specific thermal limits during migration have not been determined 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 E-Watch) and the duration of these above average temperature events are predicted to increase (Morrison et al. 2002).

In June 2021, an unprecedented heat dome generated record breaking temperatures across Southern British Columbia. Temperatures in the Southern Interior of BC reached the mid to high 40’s. Lytton broke temperature records for Canada three consecutive days in a row and the majority of the village was lost in a subsequent wildfire. This heat dome event resulted in the

[36] BC Ministry of Environment. Drought Portal. Available from British Columbia Drought Information Portal (arcgis.com) [Accessed March 22, 2022]

death of billions of intertidal animals on the coast of BC[37], but the impacts on salmon in the marine environment are currently unknown. In the Nicola River, water temperatures near the dam reached over 30°C in late June 2021 and 22°C on July 1[38], which is more consistent with temperatures in August. Chinook mortality was observed around this time in the Coldwater River. There were no other noted mortality events for salmon in other freshwater environments. The impacts of this event will be further understood in coming years but for now they are uncertain.

DUs 1 and 6 (BB and Maria) were scored medium low risk for the threat of temperature extremes. DU1 was scored in this manner as these Chinook spend so little time in freshwater and marine temperature extremes are considered in habitat shifting and alteration. DU6 has the potential to be impacted by temperature extremes due to the standing water in Maria Slough. However, Maria Slough Chinook are unable to enter the slough in low water conditions, so they are likely spared from the worst of the temperature extremes that would occur at this locale.

DUs 13 and 15 both scored high-medium for the temperature extremes threat. Similar to the threat of drought, the Salmon River faces the largest threat from temperature extremes among DU13 streams. Fish kills have already occurred in this stream and are exacerbated by drought and worsening conditions under climate change projections. The Eagle River, however, is well buffered to handle temperature extremes. While the lakes at the headwaters of the Eagle River can act as heat sinks and release warm water when stratification occurs, the glacial influence coming from the Perry River will likely provide adequate protection to downstream habitats during such an event. Temperature extremes are less likely to impact the Seymour River and Scotch Creek due to the lush riparian vegetation consisting of mosses and cedars that exist along these systems. All systems within DU15 are known to be temperature sensitive. Thermal barriers already exist in the Nicola River during Chinook spawning migration but these are moderated by groundwater upwelling. Stream temperatures are expected to continue to rise above critical levels based on current climate change projections (Porter et al., 2013) and will affect the entire DU. However, the severity of the impact of this threat is currently uncertain due to limited data (Riddell et al., 2013); however, studies are currently underway within the Nicola River system to monitor temperatures, groundwater influences and associated salmon behavior.

3.1.11.4 Storms and 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 are experiencing more extreme conditions, reflecting the greater variability in climate conditions (Grant et al. 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). The recent series of ‘atmospheric rivers’ which resulted in unprecedented flooding in the Fraser Valley, Merritt and Princeton are further evidence that these events do indeed pose

[37] CBC. 2021. More than a billion seashore animals may have cooked to death in B.C. heat wave, says UBC researcher | CBC News [Accessed January 22, 2022]

[38] Water Survey of Canada. 2021. Available from Real-Time Hydrometric Data Graph for THOMPSON RIVER NEAR SPENCES BRIDGE (08LF051) [BC] - Water Level and Flow - Environment Canada (ec.gc.ca) [Accessed March 22, 2022]

considerable threats to some of the DUs, through habitat alterations, and increased mortality during incubation and rearing.

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). Warming air temperature associated with climate change leads to increased frequency and intensity of storm activity (Meehl et al. 2000). Temperature increases have also impacted the accumulation and duration of seasonal snowpacks, resulting in 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), which has led to 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 et al. 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 2018). Flash flooding may occur as a result of intense rainstorms, particularly affecting small to moderate sized streams throughout the province, and the flood intensity may be increased if heavy rainfall occurs on accumulated snows (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; Association of Professional Engineers and Geoscientists of British Columbia [APEGBC] 2016).

DU1 scored a medium threat risk because high water events cause significant bank erosion and remove gravels as they are confined to the main channel due to urban flood control. This threat is anticipated to be a low risk for DU6 (Maria) because it is not prone to scour events due to large marshy areas that absorb rain events and high flows. A low to medium threat risk was initially assigned to DU 13 (STh-1.3) and 15 (LTh-1.2). The Eagle and Salmon rivers are prone to scouring, especially from large snowpacks and warm spells. Rain on snow events may also potentially impact the Eagle River (DU13) and Spius Creek and Coldwater River (DU15) due to their mountainous headwaters. These threats were scored prior to the extreme flooding in November 2021 and the threat risk was increased to medium for DU15 as a result of the impacts to the Nicola basin.

Table 49. DFO threats assessment calculator results for impacts from Habitat Shifting and 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 and Alteration	DU1	Known	Low-High	High	Low - (2)	High	Historical/Current/ Anticipatory	Continuous	Extensive
	DU6	Known	Low-High	High	Low - (2)	High	Historical/Current/ Anticipatory	Continuous	Extensive
	DU13	Known	Low-High	High	Low - (2)	High	Historical/Current/ Anticipatory	Continuous	Extensive
	DU15	Known	Low-High	High	Low - (2)	High	Historical/Current/ Anticipatory	Continuous	Extensive

Table 50. 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	DU1	Known	Low-Medium	High	Low-Medium (2)	Historical/Current/ Anticipatory	Recurrent	Extensive
	DU6	Known	Low-Medium	High	Low-Medium (2)	Historical/Current/ Anticipatory	Recurrent	Extensive
	DU13	Known	High	High	High (2)	Historical/Current/ Anticipatory	Continuous	Broad
	DU15	Known	High	High	High (2)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 51. 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	DU1	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Recurrent	Extensive
	DU6	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Recurrent	Extensive
	DU13	Known	Medium-High	Medium	Medium-High (3)	Historical/Current/ Anticipatory	Recurrent	Broad
	DU15	Known	Medium-High	High	Medium-High (2)	Historical/Current/ Anticipatory	Recurrent	Extensive

Table 52. DFO threats assessment calculator results for impacts from Storms and 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 (2014) 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 and Flooding	DU1	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Recurrent	Extensive
	DU6	Known	Negligible	Medium	Low (3)	Historical/Current/ Anticipatory	Recurrent	Negligible
	DU13	Known	Low-Medium	Medium	Low-Medium (3)	Historical/Current/ Anticipatory	Recurrent	Broad
	DU15	Known	Medium	Medium	Medium (3)	Historical/Current/ Anticipatory	Recurrent	Broad

3.1.12. 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 and upper range values of the overall score for all the DUs under consideration was determined to be Extreme, resulting in 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 71% to 100% for DUs with an Extreme risk level. The summary table below (Table 53) provides the comments from the threats workshop that accompany the overall rating. The threats tables for each individual DU are provided in Appendix E.

Table 53. The overall threat rating from the COSEWIC threats calculator workshop with summary comments.

DU	Overall Threat Risk	Comments from Threats Workshop
DU1 – Boundary Bay Ocean Fall	Extreme	*71-100% population level decline expected over the next three generations* DU1 was assigned an overall impact rating of Extreme. The three populations exist in a highly urbanized area and there is relatively little known about their distributions and demographics. This overall threat rating was based on the loss of freshwater habitat due to ecosystem modifications and dams and water management from development, a high level of hatchery enhancement with a history of out-of-DU introductions, and pollution from multiple sources. Boundary Bay Chinook are also particularly vulnerable to predation within and near DU habitat. Threats workshop participants thought a 100% reduction in population size might be reasonable, but that the possibility of losing greater than 70% was certainly reasonable given the observed trends in abundance and the cumulative effects of the threats described in Element 8. *Highest Ranked Threats: Marine and Freshwater Aquaculture (M-H), Fishing and Harvesting Aquatic Resources (M-H), Dams and Water Management Use (H), Other Ecosystem Modifications (H), Introduced Genetic Material (M-H), Household Sewage & Urban Wastewater (M-H).*
DU6 - Lower Fraser Ocean Summer - Maria	Extreme	*71-100% population level decline predicted over the next three generations* DU6 was assigned an overall impact rating of Extreme. This DU has one small population that uses a single spawning site where invasive species are significantly modifying habitat. Fishing is thought to be extensive due to overlapping spawning migrations with South Thompson Chinook. Threats workshop participants thought a 100% reduction in population size might be reasonable, but that the possibility of losing greater than 70% was certainly reasonable given the observed trends in abundance and the cumulative effects of the threats described in Element 8. *Highest Ranked Threats: Marine and Freshwater Aquaculture (M-H), Fishing and Harvesting Aquatic Resources (H), Other Ecosystem Modifications (M-H).*
DU13 – South Thompson Stream Summer	Extreme	*71-100% population level decline expected over the next three generations* DU13 was assigned an overall impact rating of Extreme. This DU has four populations that occur in varied habitats. The majority of Chinook Salmon occur in the Salmon and Eagle Rivers, the former of which is particularly susceptible to the consequences of climate change that are exacerbated by significant water withdrawals. Threats workshop participants thought a 100% reduction in population size might be reasonable, but that the possibility of losing greater than 70% was certainly reasonable given the observed trends in abundance and the cumulative effects of the threats described in Element 8. *Highest Ranked Threats: Dams and Water Management Use (M-H), Other Ecosystem Modifications (M-H), Droughts (High), and Temperature Extremes (M-H).*
DU15 – Lower Thompson Stream Spring	Extreme	*71-100% population level decline expected over the next three generations* DU15 was assigned an overall impact rating of Extreme. This DU has six populations that are all particularly susceptible to the effects of climate change, the effects of which are worsened from extensive wildfires and water extraction. All but one population has been enhanced, with all fish in some systems with some degree of hatchery ancestry. Threats workshop participants thought a 100% reduction in population size might be unreasonable, but that the possibility of losing greater than 70% was certainly reasonable given the observed trends in abundance and the cumulative effects of the threats described in Element 8. *Highest Ranked Threats: Dams and Water Management Use (H), Other Ecosystem Modifications (H), Introduced Genetic Material (M-H), Agricultural and Forestry Effluents (H), Droughts (H), and Extreme Temperatures (M-H).*

Table 54. Overall threat ranking for SBCC 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	DU1	DU6	DU13	DU15
Residential and commercial development	Unknown	Low	Low	Low
Agriculture and aquaculture (Hatchery competition)	Medium-High	Medium-High	Low-Medium	Low-Medium
Energy production and mining	NA	Low-Medium	Low-Medium	Low-Medium
Transportation and service corridors	Negligible	Low-Medium	Low-Medium	Low-Medium
Biological resource use (Fishing)	Medium-High	High	Low	Low-Medium
Human intrusions and disturbance	Negligible	Negligible	Negligible	Low
Natural systems modifications (Water management, ecosystems modifications)	High	Medium-High	Medium-High	High
Invasive and other problematic species and genes	High	Low-Medium	Low-Medium	Medium-High
Pollution (From all sources and threats)	Medium-High	Medium	Medium	High
Geological events (Landslides)	Unknown	Unknown	Low	Unknown
Climate change and severe weather (Shifting habitats)	Low-High	Low-High	High	High
OVERALL THREAT RANKING	Extreme	Extreme	Extreme	Extreme

3.2. 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 3.1.12 Summary.

3.3. 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 2014b). 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.

3.3.1. 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 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). Additionally, salmon populations can differ in their migratory thermal optima and limits (Eliason et al. 2011). As such, the thermal tolerances of salmonids can be considered a limiting factor for SBCC at all life stages.

Salmonids typically cannot extract sufficient oxygen to maintain resting physiological functions when temperatures exceed 25°C (Clark et al. 2008). Clark et al. (2008) suggest that the critical thermal maximum for resting adult Chinook Salmon is mass dependent and lies around 25°C for large fish (>4kg) and around 27°C for smaller adult individuals. Upstream migration rates are affected if water temperatures exceed 18°C at which point Chinook Salmon slow their rate of upstream movement. A thermal barrier can completely stop Chinook migration if water temperatures exceed 20°C; 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 (Dr. Timothy Clark, pers. comm.); 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.

Chinook Salmon eggs survive and hatch between 5-15°C (Leitritz and Lewis 1976; Boles et al. 1988; McCullough 1999); 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 SBCC 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 (Richard Bailey, DFO, Kamloops, BC, 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 internal gamete quality 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. Nicola River Chinook (DU15) can experience extreme diurnal fluctuations at spawning with overnight low water temps <10°C and daytime up to 23°C due to low flows and diurnal air temp fluctuations. Salmon River (DU13) and Maria (DU6) Chinook can also experience spawning ground temperatures in the low to middle range of 20 degrees.

3.3.2. Predation

Predation is a source of mortality for Chinook Salmon at all life stages, the specific rates of predation at different life stages and the direct impacts on SBCC mortality remain uncertain. The threat of predation begins as an egg and continues throughout 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 SBCC 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 are 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 and their predation impacts on FRC are therefore currently unquantifiable.

River Otters (*Lontra canadensis*) may predate on adult salmon in their spawning streams. Otters were identified as a threat to the 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 (Richard Bailey, DFO, Kamloops, BC, pers. comm. 2019). Otters are likely to be more efficient capturing salmon in smaller rivers at reduced flows and in areas of low 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 mammals, however, is definitively considered to be a threat as anthropogenic activities are/have been exacerbating the negative effects of predation on SBCC. Pinniped specifically has been specifically suggested to play a significant role in declining Chinook Salmon abundance and is discussed in detail in section 3.1.8.2 Problematic Native Species.

Three distinct ecotypes of Killer Whales (*Orcinus orca*) exist in coastal waters of the northeast Pacific. One ecotype, comprised of Northern and Southern Resident Killer Whales (RKWs), has 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 3.1.8.2 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 selectively forage 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 through genetic analysis that 80–90% of Chinook Salmon prey in summer SRKWs were spawned in the Fraser watershed, while only 6–14% were inferred to have originated in the Puget Sound area rivers. Riddell et al. (2013) discuss workshop findings that identified the South Thompson Chinook Salmon populations as the dominant stocks in SRKW diets. Annual estimates of the number of Chinook Salmon consumed by RKWs are fairly speculative as the proportion of the predator's diet that Chinook comprise during winter is poorly known. Although Chinook represent the majority of RKW prey during summer, this may differ during December through April when the whales forage off the outer coast. However, an estimated 500 000 fish may be consumed annually if it is assumed that one-half of their year-round energetic requirements are fulfilled by predation on Chinook (Ford et al. 2010). It has also been estimated that RKWs may consume up to 100,000 Chinook during July and August in waters around Vancouver Island (Brown et al. 2019).

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). Stream-type Chinook Salmon populations have a longer freshwater residence than ocean-type populations and are therefore more vulnerable to avian predation. For ocean-type populations in coastal BC, the largest impact from avian predators occurs during the seaward migration with maximum mortality rates reported between 8% (Wood 1987a) and 12% (Mace 1983). Stream-type populations spend at least one year rearing in freshwater, while ocean-type populations spend up to 5 months in freshwater before arriving in the Fraser River or Boundary Bay estuaries. Although a direct assessment of avian predation rates on stream-type Chinook Salmon was not found, Wood (1987b) reported high mortality rates of 24-65% of potential smolt production for Coho Salmon, which have a one year stream residence.

The population dynamics of Salmon Sharks in the north Pacific Ocean is currently unknown, yet anecdotal reports suggest they have rebounded substantially since the termination of the high seas drift gillnet fishery (1992) and Canadian flying squid fishery (1987) (Okey et al. 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 indicates Salmon Shark predation may be a substantial source of oceanic mortality of large immature and maturing Chinook Salmon during the summer and winter and throughout a wide geographic range including the Aleutian Islands and extending to the central and eastern Bering Sea (Seitz et al. 2019). 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 SBCC stocks along the Pacific coast.

Salmon are an exceptionally nutritious, predictable, and easily-acquired food source for bears (Quinn 2005). Bears can kill far more salmon than any other terrestrial predator and salmon can constitute the majority of annual diet for brown (*Ursus arctos*) and black (*U. americanus*) bears in coastal regions (Hilderbrand et al. 1999a, 1999b; Reimchan 2000; Mowat and Heard 2006). Bears congregate along salmon-bearing streams during salmon return migrations (Quinn 2005) and tend to kill the largest and newest-arrived salmon (Ruggerone et al. 2000). Bears selectively feed on fat-rich body parts of salmon, particularly the brains and eggs from females (Gende et al. 2001, 2004); they tend to leave 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 SBCC-specific, a multi-year predation study in Bristol Bay, Alaska, reported that bears killed less than 25% of the total biomass consumed from 4,218 Sockeye Salmon (Quinn 2005). It has been suggested that intense predation may exert selective pressure on large salmon from populations in small streams and 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 SBCC DUs is unknown; however, bear predation is unlikely to significantly contribute 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 SBCC DUs. Their study also identified a number of information gaps surrounding the abundance and population trends of these co-occurring species and the need to better monitor abundance and distribution to elucidate their influence on Chinook Salmon, particularly in their early freshwater life stage.

Table 55. Predators likely encountered by SBCC.

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*

3.3.3. Competition

Competition with Pacific Salmon occurs across 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 thought to be minimal, as these species occupy somewhat different spatiotemporal ecological niches (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. Current SBCC populations are unlikely to compete for spawning area because considerably larger historical abundances were once supported. However, spawning habitat is thought to be limited in Maria Slough. It should be noted, however, that hatchery-origin spawners may exacerbate competition for spawning areas (discussed in detail in section 3.1.2.3 Marine and Freshwater Aquaculture).

Jellyfish have been suggested to indirectly exploit Pacific Salmon and there is evidence that jellyfish populations in coastal ecosystems may be increasing (Brotz et al. 2012; Purcell 2012). Several characteristics render jellyfish highly influential in the restructuring of 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 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 (Weil et al. 2019). The authors highlight that these results contrast with previous research that did not report *H. medusarum* in the diets of Coho or Chinook Salmon sampled in the same region between 1973 and 1976, noting that ongoing shifts in the marine environment that can lead to changes in prey and competitor species composition.

Disease, predation, and competition are an interrelated and complex suite of factors, the two former of which can exacerbate the degree of competition experienced by SBCC. 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 greater exposure to predation and the threat of predators may incur vigilance costs that cause schooling behaviour and increase 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 SBCC, but cumulative impacts from other threats may exacerbate competition throughout the Chinook Salmon lifecycle.

3.4. 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 can be categorized as 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. Threats will typically negatively impact predators 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 visual acuity but not affect non-visual predators, thus increasing the likelihood a predator will succeed. Competitors will generally benefit from lower abundances of Chinook Salmon, unless various threats are negatively impacting shared habitat or prey requirements. Chinook Salmon and their competitors in the marine environment may be similarly impacted by threats to ocean productivity, a decline in which is also likely to directly impact marine prey species of Chinook Salmon.

Most of the threats affecting habitat features would simultaneously impact many of the co-occurring species. For example, any terrestrial predator, trees or riparian vegetation would be impacted by changes to the watershed catchment, such as decreases in forest cover or increased urbanization. In addition to habitat destruction, declining salmon populations can impact riparian vegetation through a reduction in nutrient inputs from carcasses (Hocking and Reynolds 2011). While the impact of reduced nutrients will vary 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 mostly likely incur negative impacts on all aquatic species. Some introduced and invasive species may benefit from warm freshwater temperature regimes because they have physiological tolerance to high temperatures and can outcompete native species. The BC Ministry of Environment and Climate Change Strategy currently surveys introduced aquatic species such as Yellow Perch and management action to eradicate them in several freshwater lake systems has occurred.

There are significant knowledge gaps surrounding SBCC that impair stock status assessment and the establishment of meaningful and quantifiable recovery targets. The following is a brief summary of the main sources of uncertainty identified during this RPA process:

- SBCC freshwater distribution spans a large geographical area within the Fraser Basin and Boundary Bay drainages and much of this habitat has not been thoroughly studied. Aspects of freshwater distribution, particularly in juvenile life stages, are unknown and therefore challenging to evaluate in a threat context. Furthermore, the marine distribution of SBCC 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.
- The quality and coverage of escapement data varies within and between DUs, leading to more confidence in some estimates and greater uncertainty in others. Therefore, trends in abundance, particularly in DU1, may be inaccurate and annual escapements may be underestimated if portions of a DU are not surveyed.
- Accurate time series for PNI are limited for multiple integrated populations due to limited mark recovery programs. Wild population trends can therefore be inaccurate, particularly in DU1 where significant enhancement and limited marking occur. Future effects of large-scale increases in hatchery production on SBCC are unknown, including how the genetic profiles of wild populations will change and whether competition will increase for finite and limited ecological resources between hatchery-origin and wild salmon in the Fraser River and Boundary Bay drainages. The magnitudes of genetic and competitive effects that hatchery-origin SBCC incur on wild populations are largely unknown due to unmonitored genetic diversity of populations and unknown habitat carrying capacities, respectively.
- Although we have a basic understanding of the freshwater and marine biology of SBCC, we lack specific information such as egg-to-fry survival, detailed freshwater habitat use, productivity, stock-recruit data, and freshwater and marine survival information for all DUs. However, these data exist for Nicola River Chinook but may not be representative of the DU as a whole (See Element 13 for context).
- The impacts of fisheries (both targeted and non-targeted at Chinook) is currently limited or unknown for all DUs. Nicola Chinook from DU15 are the only population with a long-standing time series of CWT data, although generalizing CWT data to other populations in DU15 is limited due to significant differences in migration timing.

- There are significant gaps in our knowledge of current invasive species distributions and their potential effects on SBCC 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 expand its range in BC.
- There are a multitude of sources for pollution in the Fraser River and Boundary Bay drainages, yet there is currently limited available information surrounding the effects of these contaminates on SBCC and how they affect SBCC survival in both marine an d freshwater environments.
- Although threat assessments were decided on the best available knowledge, significant uncertainty exists around the magnitude and impacts of climate change. SBCC are uniquely adapted to certain characteristics and the degree to which they can exhibit phenotypic plasticity to buffer environmental changes is unknown.

4. ELEMENTS 12 TO 15: RECOVERY TARGETS

4.1. ELEMENT 12: RECOVERY TARGETS

Propose candidate abundance and distribution target(s) for recovery.

For all SBCC DUs considered in this report, both a survival and recovery target were proposed and used in this RPA (Table 56). The survival target is aimed at reaching a COSEWIC status of Special Concern, whereas the recovery target represents a benchmark of recovery or a status of Not at Risk. This approach is consistent with DFO advice on setting SARA recovery targets (DFO 2011, 2021b). The survival target may represent a limit reference point that triggers rebuilding and recovery plans when spawner abundances drop below the target; whereas the recovery target may indicate an ideal management objective. In other words, the survival target represents the minimum population level required for long-term persistence, and could be viewed as a short-term goal on the way to recovery. The definition of the survival target in this report does not match the definition of survival under SARA guidance, as the survival target defined here is based on the COSEWIC approach and can include a declining trend if abundance is sufficiently high. Biological recovery benchmarks for these SBCC DUs were selected based on both the COSEWIC criteria for status designation and the WSP benchmarks. While the targets presented here attempt to be consistent with the COSEWIC and WSP assessments, the suggested targets are highly simplified targets compared to the more nuanced criteria used in the expert driven processes involved in the COSEWIC and WSP assessments, which include a broad range of criteria. Accordingly, achieving either the survival or recovery target does not necessarily mean that there will be a corresponding change in the COSEWIC or WSP status of a DU.

The recovery targets proposed here contain abundance and a population trajectory benchmarks. There are other variables that could be considered as part of the recovery, such as expansion of distribution, productivity levels or inferences of productivity (e.g. trends in fecundity, size at age or maturation rates), genetic diversity, PNI values, or threat mitigation which all could provide indications of the state of the population and its resiliency. A discussion of trends in many of these life history parameters were discussed in Element 3, but many of these variables remain unknown for these populations and hence no specific targets were set. These variables, to the extent that data existed were considered when assessing the ability of these stocks to achieve the survival and recovery targets, and further discussion is in Section 4. It should be noted that, although distribution targets are not specified, the intention is to maintain all spawning locations. Spawning distribution can be monitored through spawning escapement estimates over the spatial extent of the DU; however, data on both freshwater rearing and marine habitat are more sparse and difficult to assess. A lack of detailed distribution data has been included as a research need so that distribution targets can be set for each life stage. All of these aspects mentioned above are recommended for consideration in the definition of recovery and setting targets if these DUs are listed by SARA; however, for the purpose of the RPA, targets were focused on those attributes which can be objectively assessed.

These DUs were designated Threatened and Endangered by COSWEIC largely due to small population sizes and declines in spawner abundances. Accordingly, minimum abundance targets were included as these DUs currently have historically low estimates of relative abundance and the percent change requirements will not adequately ensure recovery. The spawner level required to achieve the number of spawners at maximum sustainable yield (S_{msy}) within one generation (S_{gen}) was selected for the survival abundance target as this metric has performed well in evaluations under scenarios with varying productivity (Holt 2009; Holt and Bradford 2011) and is consistent with the WSP abundance lower benchmark. The recovery abundance target was set to 85% of S_{msy}, to correspond with the abundance component of WSP green status for Chinook Salmon. These abundance benchmarks are evaluated as a generational average abundance. For DUs with an S_{gen} or S_{msy} less than 1000, the abundance target was set to a minimum of 1,000 to ensure that COSEWIC Criterion D is exceeded. The population trajectory component of the recovery targets is measured through the percent change over three generations. The percent change requirements associated with the two abundance targets described above, are based roughly on COSEWIC criterion A and C. When the abundance target is above 10,000 spawners, a less than 30% decline is required (Criterion A), and when the target is below 10,000, positive population growth is required (Criterion C). Both criterion A and C, have more nuanced requirements that are not described here.

DU estimates of S_{gen} and S_{msy} were generated using a habitat-based method (Parken et al. 2006; referred to as “the habitat model”). The habitat-based estimates presented in this report are updates to the benchmarks presented in the 2014 WSP Assessment, updated using the most recent version of the habitat model (Table 57). An overview of the process to calculate the benchmarks is provided below. An excerpt from a WSP Assessment Research Document[39] with the detailed description of the methods used to calculate the benchmarks is provided in Appendix G. The habitat model is a predictive regression model based on a meta-analysis of stock-recruitment reference points (i.e. S_{msy} and S_{rep}) and the accessible watershed area. The updated equation from Parken et al (2006) used for the benchmarks in this report is provided in Table 57. Watershed areas were previously calculated for the 2014 WSP Assessment with ArcGIS, using the BC Watershed Atlas, the Fisheries Information Summary System (FISS), and peer review by field program staff who conduct spawning ground surveys. This information was applied to determine the Chinook accessible watershed area for each DU. DUs with spawning in a single watershed have only one estimate of S_{msy} and S_{rep}, while other DUs with spawning across multiple watersheds, have several estimates of watershed areas with individual estimates of S_{msy} and S_{rep} that align with the stock units to align with the population dynamics. To arrive at a DU-level habitat estimate of S_{msy} and S_{rep} for DUs with multiple watershed areas, joint distributions of S_{msy} and S_{rep} from the individual estimates for all watersheds contributing to the DU were calculated, from which a DU level estimate of S_{gen} and S_{msy} could be calculated. The watershed areas used for the DUs in this report are presented in Table 58. Scotch Creek and Seymour River watersheds were omitted from the DU13 recovery targets as they are not

[39] Brown, G., Thiess, M.E., Pestal, G., Holt, C.A and Patten, B. In prep. Integrated Biological Status Assessments under the Wild Salmon Policy Using Standardized Metrics and Expert Judgement: Southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) Conservation Units. DFO Can. Sci. Advis. Sec. Res. Doc.

currently surveyed and there are no plans to survey them in the future. Therefore, recovery targets for DU13 are calculated using only the watershed areas for the Eagle and Salmon rivers. The estimates of S_{gen} and S_{msy} estimated from the habitat model output could vary from estimates derived using stock-recruit (S-R) analyses with DU specific data, based on the leave-one-out analysis conducted in Parken et al. (2006). At this time it is not possible to verify these model estimates against DU specific data. As S-R data for these DUs becomes available, it can be used to generate more representative recovery targets for the DU, and it can be included in the model to provide more accurate predictions and better represent the productive capacity of Chinook stocks.

The habitat-based benchmarks represent absolute abundance targets for all DUs. Absolute abundance benchmarks are difficult to evaluate against for these DUs as only relative abundance data is available. The escapement estimates available for these DUs will be an underestimate of the population and there will be a discrepancy when comparing to the absolute abundance benchmarks. Until absolute abundance estimates are available for these DUs, either through a significant expansion of stock assessment activities or the development of scalers to relate relative abundance to absolute abundance, it is recommended that evaluating whether the abundance target is met or not is done using the relative abundance estimates that are available. The lack of absolute abundance data is a gap that needs attention, but will take time to address and using relative abundance for now will provide a precautionary assessment of DU status.

The DUs presented in this RPA all have varying levels of hatchery enhancement which can limit the ability of the wild population to recover due to decreased fitness from the presence of hatchery genetics. Recovery targets should be aimed toward the survival and recovery of wild populations but this can prove difficult when dedicated monitoring programs are limited or do not exist. In the context of this RPA, recovery targets must include both hatchery and wild individuals spawning in the natural environment as, in most instances, they cannot be distinguished by existing escapement monitoring programs. Proportion of natural influence (PNI) is a metric used to measure the level of hatchery influence in enhanced populations and the inclusion of PNI values can be used as a way of accounting for the impacts of hatchery effects on recovery targets. Withler et al. (2018) proposed values of PNI for different levels of hatchery designation (Table 59). For populations to be considered recovered, we recommend that PNI values should align with the value of greater than or equal to 0.72 to fall under the integrated-wild designation. However, we also recognize the role that hatchery enhancement plays in recovering vulnerable populations and that PNI values may be less than this value over a period of time. Additionally, the value of the CWT data provided from hatchery fish is highly important for bilateral agreements between the United States and Canada. As such, the importance of the CWT data would override the requirement for the PNI values to meet or exceed 0.72. It is critical that PNI is directly measured in order to ensure the recovered population can be considered wild and that this recovery objective is achieved.

As noted above, there are many variables and factors that could change the selection and estimation of survival and recovery targets. Many of these variables (e.g. distribution of all life stages, fecundity, size at age, productivity) are data gaps for most of the DUs assessed here. As mandated by SARA, models and targets should be reviewed as more data become available.

Table 56. Survival and recovery targets for each DU assessed. The survival target aims to achieve COSEWIC Special Concern status. The recovery target is set to achieve Recovered or Not at Risk status. To meet the target each population must achieve both the abundance and % change requirement. Abundance is based on Sgen or 85% Smsy for the survival or recovery targets respectively, unless otherwise indicated, and is measured against a generational average.

-		Survival Targets		Recovery Targets		
DU	**DU Short Name**	**Abund.**	**% Change Requirement**	**Abund.**	**% Change Requirement**	**Average PNI**
DU1	Boundary Bay-Fall	1,000	Positive population growth	1,780	Positive population growth	≥ 0.72
DU6	LFR-Summer (Maria)	1,000	Positive population growth	1,000	Positive population growth	≥ 0.72
DU13	STh-Stream-Summer	1,000	Positive population growth	3,351	Positive population growth	≥ 0.72
DU15	LTh-Stream-Spring	4,038	Positive population growth	16,627	< 30% decline	≥ 0.72

Table 57. The equation and parameter values to estimate S-R benchmarks based on watershed area developed in Parken et al 2006. These parameters estimates are updated values compared to the initial report and represent the most up-to-date values for the habitat model. Parameters are provided for both ocean and stream type populations (b).

a)

Equation
$\ln(\hat{y}) = \ln(\hat{a}) + \left(\hat{b} * \ln(x)\right) + (\widehat{\sigma^2}/2)$

b)

	Stream-type S_{msy}	**Stream-type S_{rep}**	**Ocean-type S_{msy}**	**Ocean-type S_{rep}**
$\hat{y}$	S_{msy}	S_{rep}	S_{msy}	S_{rep}
$\ln(\hat{a})$	3.06	3.99	2.36	3.67
$\hat{b}$	0.686	0.691	0.887	0.852
x	Accessible watershed area			
$\widehat{\sigma^2}$	0.260	0.208	0.136	0.124

Table 58. Accessible watershed areas, listed as major tributary names, used in the Habitat Model to estimate the S-R benchmarks for each DU.

DU	Watershed(s)	Area (km^2)
DU1	Little Campbell, Nicomekl, Serpentine rivers	339
DU6	Maria Slough	33
DU13	Eagle and Salmon rivers	1,456
DU15	Bonaparte, Deadman, Nicola, and Coldwater rivers, Louis and Spius creeks	10,457

Table 59. Potential guidelines for the inclusion of integrated hatchery populations in Wild Salmon Policy assessments based on their biological designation from Withler et al. (2018).

Designation	PNI	Inclusion in WSP Assessment	Rationale
Wild	n/a	Yes	No integrated hatchery; minimized risks from strays
Wild-Stray Influenced	n/a	Provisional	Most fish are wild, but long term effects of one-way gene flow are expected to be risk factors
Integrated-Wild	≥0.72	Yes	Most fish are natural origin and >50% are wild; gene flow favours natural environment
Integrated-Transition	≥0.5, <0.72	Provisional	Gene flow favours natural environment but <50% of fish are wild. Hatchery program may be a risk factor to the wild population
Integrated-Hatchery	<0.5	No	Hatchery selection dominates as most fish are hatchery origin; <25% of spawners are wild.

4.2. ELEMENT 13: POPULATION TRAJECTORIES AT RECENT PRODUCTIVITY AND MORTALITY

Project expected population trajectories over a scientifically reasonable time frame, and assess the ability of the trajectories over time to reach the potential recovery target(s), given current population dynamics parameters.

For Element 13, the general RPA terms of reference involves projecting the trajectories over a scientifically reasonable time frame (minimum of 10 years or three generations) and trajectories over time to the potential recovery target(s), given current population dynamics parameters for these four DUs of Chinook Salmon. Several types of information are necessary to describe the current population dynamics for a DU; however, none of the four DUs have all the required information. Instead, a similar approach was followed for the four enhanced DUs as was applied for the non-enhanced Fraser Chinook RPA (DFO 2021b), as specified in the Terms of

Reference for this Recovery Potential Assessment for Enhanced Chinook DUs. This section within Element 13 describes the rationale for providing qualitative assessments of population trajectories for each DU. A detailed explanation of the variability in data quality and stock assessment methodologies that exist between the biological populations in each DU and why that information is insufficient to generate scientifically robust population trajectories forward through time is also provided.

Estimation of the population dynamics for a Chinook Salmon DU requires considerable information to reconstruct the density-dependent and density-independent productivity components for each cohort of the DU (Pacific Salmon Commission [PSC] 1999). The past productivity must be constructed for each cohort in order to generate a population dynamics relationship that represents the DU and current conditions in order to make the forward projections. The productivity of each cohort is estimated from (1) spawner data, measured by cohort, age and origin (HOS and NOS) for each DU site, and (2) the corresponding exploitation data, also measured by cohort, age and origin (HOS and NOS) for each DU site. These data are used to estimate the pre-fishery abundance of Chinook, by origin and cohort, that are adjusted into units of adult equivalents. This adjustment is necessary since Chinook Salmon experience fisheries-related mortality at both immature and mature life stages and in the absence of fisheries there is natural mortality that reduces the number of fish that survive to the reproductive stage (i.e. same biological life stage for recruitment and spawners). The population dynamics functions are estimated separately for the Natural Origin and Hatchery Origin fish, along with representation of their interaction, if any, for each biological population in the DU. The biological populations have sufficient reproductive isolation that lead to variation in demographics and adaptive biological traits among them (e.g. migration timing, maturity patterns, etc.).

There is a long history of differences in the scale of units used for the conservation of fish biodiversity and fisheries management (Hyatt and Riddell 2000), which has led to iterative developments in the units used by COSEWIC for Chinook Salmon. Canada's Chinook Salmon DUs are established from their geographic distribution, life history variation and genetic data for the purpose of COSEWIC assessments to support Canada's *Species at Risk Act*, whereas other assessments, such as the Conservation Units described in DFO's Wild Salmon Policy (WSP), have been designed for different conservation purposes; the CU scale is smaller than a DU or the same size, but not larger for Chinook Salmon. The WSP (DFO 2005) provided an overview of the population structure for wild salmon, with the population level having sufficient reproductive isolation for persistent adaptations to the local habitat to develop over time. In comparison, DFO's Stock Management Units (SMU) are at a scale that corresponds with the DU scale or larger, e.g. an SMU consists of 1 or more DUs.

One of the most significant contributions to the knowledge of the diversity of Chinook Salmon biology was gained by the advent of Coded Wire Tags (CWT) and sampling programs in the late 1960s and early 1970s (Jefferts et al. 1963; Johnson 2004; Nandor et al. 2009). The technique provided evidence that populations can make very long distance ocean migrations and mature at different ages compared to other ones (Healey 1991), and a very large number of populations have been identified over a wide geographic area (Nehlsen et al. 1991; Slaney et al. 1996). With this knowledge, agencies in Canada and the United States initiated CWT programs at the biological population scale, but only a few populations from California to Alaska had these programs begin in the 1970s and 1980s due to high program costs.

Canada initiated a Key Stream program for Chinook in 1984, with CWT programs in several locations to implement the Pacific Salmon Treaty and to support fisheries management. Populations were identified by early CWT studies which described the homing behavior and extent of straying, as well as other adaptive characteristics (e.g. run timing, ocean distribution among fisheries, see Fraser 1983). The Key Stream programs became an important component of the Salmon Stock Assessment Frameworks, which aimed to have intensive, extensive and random population monitoring programs for each stock group. Subsequently, more intensive CWT programs were developed to represent the varied production characteristics of the Chinook resource. However, in Canada, these populations were opportunistically selected for practicality, based on a representation of biological characteristics (e.g. life history) and operational attributes, such as the ability to accurately estimate escapement by age, sex and CWT cohorts, and opportunities to use hatchery fish for stock assessment objectives, since wild Chinook Salmon tagging programs had survivals that were too low to be cost effective. These CWT populations are called Exploitation Rate Indicator Stocks (ERIS; PSC 2021), although concerns about their representation of the biological characteristic of the untagged populations (e.g. same maturation and exploitation rates and other behavioral patterns PSC 2008; PSC 2015) have led experts to recommend increasing their number and examining their representation of Chinook production for stock assessment and fishery management (Riddell 2004, PSC 2008; PSC 2015).In the 1990s, fisheries managers began to reduce harvest rates to ameliorate declining survival and promote spawner escapement. This led to a reduction in the recovery of CWTs which subsequently led to increased uncertainty of CWT-based estimates of fishery impacts and the inferences used in the ERIS program (Riddell 2004; PSC 2015). However, increased CWT recoveries on the spawning grounds has allowed for the maintenance of appropriate CWT sampling rates on ERIS stocks (PSC 2008).

The ERIS monitoring programs are carefully designed and standardized to facilitate inference-making. Many programs release tagged smolts at the same time and size each year to facilitate inferences about changes in age- and cohort-specific exploitation, survival, and maturation patterns. These programs include sampling to monitor several other biological characteristics to estimate escapement by cohort, age, origin, and other biological patterns, such as physical condition and growth rates (Xu et al. 2020).The stock assessment frameworks used for Canadian Chinook Salmon were designed for a set of objectives that have supported the management and evaluation of fisheries and assessment of stock group status in Canada and the United States for decades. The objective of conducting stock assessment at the scale of the SARA DUs is a recent one, and the DUs continue to be re-evaluated with new information. The current stock assessment framework has not been modified for all the DUs to meet new objectives, such as the ability to perform population dynamics evaluations and projections at the DU level instead of the spawning population. Accordingly, the circumstances for the enhanced DUs in this report have resulted in insufficient information to project the DU abundances, and more detailed explanations follow.

4.2.1. Estimation of Cohort Escapements by Age, Origin and Site

There are several fundamental differences for the escapement estimation and sampling methods between the monitoring programs at ERIS (intensive) and non-ERIS populations (extensive and random) that can limit the ability to estimate cohort escapements by age and origin for each population in the DU. At an ERIS, escapements are estimated using methods that produce unbiased estimates of spawners, whereas less accurate and more uncertain methods are typically used at the non-ERIS populations. The ERIS must produce total escapement estimates that are unbiased to achieve the primary objective of accurate exploitation rates (i.e. the catch and escapement data must have the same accuracy). In comparison, the primary objective for the extensive non-ERIS is to produce relative escapement abundance estimates for among-year relative comparisons. The relative abundance estimates are used by the PSC and fisheries management entities to plan fisheries from Alaska to Oregon (PSC 2021). Unbiased escapement estimates can be based on census counts passed a fixed location (e.g. a fishway, weir, SONAR) and mark-recapture methods (see PSC 2008 and PSC

2018 method descriptions). In comparison, the escapement methods for the non-ERIS can have variable bias, as reported by Parken et al. (2003) for the peak count expansion method (-14% to +24% relative to the mark-recapture method), and can have systematic bias when only part of the population is surveyed for the spawning escapement. Several programs have been used to improve the accuracy of the escapements for the non-ERIS (see PSC 2018).

Typically, the escapement estimation at the ERIS involves a high degree of stratified sampling compared to non-ERIS. The ERIS spawner population is stratified due to variations in sampling rates related to sex, size and adipose fin presence and the collection of data for the mark-recapture study design. Carcasses are randomly sampled for scales, CWTs, adipose fin presence/absence, and other structures (e.g. otoliths) within each stratum which produce accurate estimates cohort escapements by age and origin for the total population using the stratified sampling design. Scales are sampled for multiple objectives, including examination of the mark-recapture samples for any biases, estimation of the escapement by age for natural origin fish, and when collected with CWTs, to evaluate the error in the scale aging process. The DFO sclerochonology lab in Nanaimo, BC, has limited scale aging capacity, and depending on limits and competing priorities, scale samples can be further subsampled, adding more complexity to the stratified sampling design. At many non-ERIS populations, the escapement by age and origin cannot be estimated accurately because age and origin samples are not collected (e.g. due to insufficient capacity to process scales at the DFO lab), collected opportunistically, or collected when sampling rates cannot be measured by the sex and size strata. Furthermore, unmarked hatchery fish have often been released at the enhanced DU populations, or nearby populations which can stray to the DU, and prevent reasonably accurate estimation of escapements by origin.

4.2.2. Spawner Origin

Accurate estimates of the cohort escapement by spawner origin are necessary because of the growing body of evidence that hatchery origin fish that spawn in the natural environment have a lower relative reproductive success (fitness) than natural origin fish (Williamson et al. 2010; Christie 2014b; Withler et al. 2018). Accordingly, Pacific Salmon population dynamics models examine and then represent these productivity differences as needed (Tompkins et al. 2005; Buhle et al. 2009).

To represent the population dynamics of these four enhanced DUs, spawners must be estimated by eight strata to identify the origin (i.e. natural, same population-hatchery, same DU-hatchery stray, different DU-hatchery stray) and presence of fin clips (present/absent). CWTs and adipose fin clips (CWT-AFC) are often used at ERIS to identify hatchery origin fish, however non-ERIS have used other types of fin clips (e.g. adipose, ventral, pelvic fins), tags (e.g. CWT, PIT), marks (e.g. otolith thermal marks, calcein) and genetics (e.g. Parental-Based genetic Tags; PBT) to identify hatchery-origin fish, or the hatchery fish may be released unmarked, and in which case they cannot be distinguished from natural origin fish. Few, if any, of the ERIS and non-ERIS have had sampling for all of these types of hatchery marks in all years, which creates un-estimated uncertainty in the cohort escapements by age and origin, and causes overestimation of the escapement for natural cohorts by age, and hence overestimation of productivity for spawners in the natural environment.

4.2.3. Exploitation by Cohort, Age, Origin and Site

To calculate recruitments, the CWT ERIS data are used since they represent the combination of kept catch and incidental (non-landed) mortality for each age by cohort in units of adult equivalents. Another management tool is the Fraser Run Reconstruction model (English et al. 2007), but this tool is not suitable for the objective of using the exploitation estimates to calculate recruitments, since the tool represents only kept catch, only the catch of adult sized (age x.2 and older fish), and only represents fisheries in the Fraser River. Another tool, used to review the management of stream-type Chinook in the Fraser River (Dobson et al. 2020a) relies on the Fraser River run reconstruction model outputs and estimates of genetic stock group catches in Southern BC fisheries that have been sampled for genetics in recent years. There are some limitations and caveats (e.g. outputs are not in adult equivalents by age for all fisheries in Canada and the US) for these estimates which limit their suitability to the objectives outlined by Dobson et al. (2020b), and they do not represent the impacts of all fisheries, by age in units of adult equivalents. Another complication with the catch estimates identified by genetics happens when there are cross-DU strays and introductions, which can lead to genetic stock identification errors due to introgression.

The adult equivalent exploitation rates must be available for each DU by cohort, age, origin and site for several reasons. For age, exploitation rates vary due to the relationship between fish size and age, and fishing gear can be size-selective (e.g. selectivity varies among gillnet mesh size; Howard and Evenson 2010). Also, fishing regulations can vary by the size of fish, such as with the minimum size limits in sport and troll fisheries, and some sport fisheries use slot size limits with different bag limits depending on the size of the fish. Adipose fin clip status is also an important consideration because fisheries can be mark selective for full retention or mixed bag retention regulations. Site is another consideration when there are differences in the migration timing between an ERIS and non-ERIS in the DU, and when there are different types and impacts among the last terminal fisheries for the populations.

Another example of a challenging regulation, from the perspective of recruitment and productivity estimation, happens when the last terminal fishery has regulations that restrict harvests to males only. In reality, a mixture of sexes comprises the harvest due to errors in sex identification in these fisheries. The differential exploitation by sex causes more females to be concentrated in the spawner abundance, but when the spawner abundance is not estimated by sex then this type of population will have a higher productivity estimate for the spawner cohorts that experienced the sex-selective regulation than the spawner cohorts that experienced the unselective regulation. The situation can lead to time series patterns in the productivity among spawning years for a population, and productivity differences among populations in the DU.

4.2.4. Temporal Variation in Non-Fishing-Related Survival Rates Among Populations

The temporal variation in non-fishing-related survival rates can vary among populations in a DU during the same year because of circumstances that may happen at one population, but not others. These variations in survival influence the population dynamics and productivity patterns, which can lead to inaccuracies if one population is used to make these types of inferences for others. These situations can produce different density-independent recruitment variations among the populations, which can be measured and represented when there are intensive monitoring programs at all the populations, but they cannot be measured by the extensive monitoring programs with limited or opportunistic sampling. Temporal variations in survival among populations can arise from numerous factors, including adult salmon migration blockages, water extraction and extreme impacts of low river discharge, the effects of forest fires, and localized aquatic pollution events and riparian habitat alterations.

Adult salmon mortality and dispersal can happen when rivers become obstructed and blocked by landslides or failed fishways, which can cause different density-independent productivity patterns among populations in the same DU. When a blockage happens, adult salmon spend resources attempting to pass the obstruction or barrier, and after many attempts some salmon will disperse to nearby areas for spawning, including the same river downstream of the obstruction, and others will die from injuries incurred while attempting pass the obstruction or via other pathways ending in mortality due to fish stress caused by the obstruction. These situations may not be detected immediately and the effects on salmon mortality and dispersal may not be measured. This situation will affect population productivity, with substantial reductions possible for the population with the obstruction/barrier, but also increased abundances for the populations that receive the dispersing salmon. These situations can cause variations in the density-independent component of productivity among the DU populations.

River flow and temperature can influence the survival of adult and juvenile salmon that are in the river at the same time, and a single year event can affect the density-independent component of productivity for five cohorts simultaneously in a population. Low river flows reduce the wetted area of streams and the productive capacity for Chinook juveniles, and low river flows can concentrate adult Chinook in holding pools which can facilitate the transfer of pathogens among individuals, resulting in localized prespawn mortality events. Low river flows can also facilitate more rapid warming of rivers to temperatures that adult Chinook stop their upstream migration, or the high temperatures can lead to stress and mortality among adult and juvenile Chinook (Bowerman et al. 2021). River flow and temperatures can vary among the populations in a DU from natural and anthropogenic factors, and some river systems are more sensitive than others due to local fluvial geomorphology and anthropogenic activities. For example, some rivers vary in the extent of water extraction from the river and hyporheic zone typically because the amount and type of agricultural development can vary substantially among rivers, along with their hydrology.

Forest fires can have local, negative impacts to population productivity from the modification of riparian vegetation and landslides, but also from the use of chemical fire retardants dropped into the river, which can lead to variations among populations in the same DU when the fires do not affect all the populations equally in the same year. Riparian vegetation benefits Chinook Salmon survival by providing shade to the stream and cool river temperatures, stabilizing the shoreline and reducing erosion and sedimentation, contributing woody debris to the stream channel and resultant complex salmon habitats, and by providing habitat for several types of terrestrial and aquatic insects which are prey for juvenile Chinook. Forest fires can contribute to landslides and debris flows which add sediment to streams that can reduce egg to fry survival and cause the river channel to change course and increase bank erosion, which reduces the capacity of the river to produce juvenile Chinook Salmon. Accidental discharge of forest fire retardant chemicals into the river can cause acute mortality of stream-type Chinook and reduced survival when the fish transition from fresh to saltwater (Dietrich et al. 2013).

Populations can vary in their survival when there are local pollution events, changes in river volume or habitat alterations that result in acute fish kills. These events often lead to high levels of media attention, but the amount of mortality is often roughly measured since these situations are irregular and not part of the salmon stock assessment framework[40]. When it has been measured scientifically, the mortality rate can be alarming[41] (90% mortality). These events will typically affect one population in a DU, but not the others in the DU during the same year, which leads to variations in the density-independent components of productivity and errors when information is extrapolated from one population to another.

[40] CBC. 2019. Hundreds of spawning salmon killed in Squamish river; BC Hydro admits responsibility | CBC News [Accessed March 14, 2022]

[41] Globe and Mail. 2019. B.C. closes Cheakamus to fishing - The Globe and Mail [Accessed March 14, 2022]

4.2.5. Summary

Sufficient data to develop population dynamics relationships and subsequent forward population trajectories for Chinook Salmon exist for only one population in one DU of the four DUs that are evaluated within the body of this paper (Nicola River). While some may argue that we can use the parameters from stock-recruit models using the Nicola data to at least provide forward projections for DU15 (Lower Thompson Stream Spring), we assert that given the lack of data regarding estimation of escapement over relevant strata, spawner origin, exploitation rates over relevant strata, and particularly the variability in temporal variation in non-fishing related survival rates between populations within this DU (e.g. Bonaparte fishway failure, forest fire impacts in different years in different areas of the DU) that it would not be representative of the DU as a whole. Therefore, it would lack scientific rigor to perform this analysis. A summary of available data types within each DU are summarized in Table 60.

4.2.6. Qualitative Assessments

Due to the data constraints described in Element 13, the remaining DUs are assessed qualitatively.

The recent trends in escapement and the number of threats documented in Element 8 provide no indication that the trends and abundances observed (see Element 2) in these DUs (Table 56) are likely to improve in the short term. Historically low abundances have continued in recent years despite efforts to reduce harvest rates. It remains uncertain whether harvest reduction measures have effectively reduced harvest pressure on populations. A recent review determined that the measures put in place in 2012 aimed at reducing harvest rates on the Spring and Summer 5_2 MUs were likely successful; however, several uncertainties were noted that prevented a definitive conclusion (DFO 2019; Dobson et al. 2020a). Assuming harvest rates have in fact declined, the concurrent decrease in abundance indicates that these DUs are likely experiencing declining productivity. The data necessary to assess trends in productivity in the stream-type DUs is lacking, but the qualitative evidence supports the hypothesis of a decline. This aligns with evidence of decreased size at age in Fraser River Chinook (Xu et al., 2020) and is supported by other studies which have documented widespread declines in Chinook Salmon productivity (Dorner et al. 2018) and survival (Welch et al. 2020).

The impacts of the threats facing these DUs were discussed extensively in Element 8, and provided significant evidence that these threats will likely continue to impact the survival and recovery of SBCC DUs covered in this report. For two of the main threats to the Interior BC DUs (13 and 15; STh-1.3 and LTh-1.2), removal of forest cover and climate change, there is limited control over the impacts and no short-term mitigation options available. Massive losses of forest cover largely due to extremely large and intense forest fires in Interior BC have led to unstable freshwater habitat and hydrological conditions as was especially evident in the flooding events in the Coldwater and Nicola rivers in November 2021. The frequency and intensity of major forest fires is expected to increase under climate change scenarios. Years of extensive forestry in both of these DUs has also led to decrease forest cover. Mitigation measures (e.g. reforestation) to improve forest cover are unlikely to improve these conditions for several generations (Perry and Jones 2017; Tschaplinski and Pike 2017). The loss of forest cover in the Fraser River basin will become increasingly evident in the future, as climate change effects are anticipated to exacerbate shifting hydrological conditions (earlier onset of freshet, changes in snowpack, drought, flooding; Brown 2002; Shrestha et al. 2012; Kang et al. 2014, 2016; Islam et al. 2019). This can profoundly affect the quantity and quality of freshwater rearing habitats, particularly for stream-type Chinook Salmon which use these freshwater rearing habitats for longer (Brown et al. 2019). These changes in hydrological conditions may also result in timing mismatches regarding the windows of habitat and prey availability in the lower Fraser and estuary (Richard Bailey, DFO, Kamloops, BC, pers. comm.). While in the North Pacific Ocean, climate driven changes (increasing temperatures/heat waves, ocean acidification, shifts in prey distribution) are expected to continue to lower ocean productivity, and ocean conditions are not expected to improve in the near future (Walsh et al. 2018; Young and Galbraith 2018; Galbraith and Young 2019). Lower ocean productivity is likely to negatively impact the productivity of these DUs.

The ability to achieve survival and recovery targets for these DUs is difficult to assess due to the lack of absolute escapement data, uncertainty around the effects of hatcheries, and the uncertainty around the impact of varying threats. Long term and recent trends in abundance as well as ongoing threats are considered in the context of each DU and their ability to achieve respective survival and recovery targets in the paragraphs below.

DU1 (BB) is located in a highly urbanized environment and currently lacks robust escapement programs in two of the three rivers in the DU to properly assess trends in abundance. Current trends suggest that this population is increasing (See Element 2) but abundances remain low. This DU is also highly enhanced with large releases of unmarked hatchery juveniles each year and a large number of adult hatchery strays from other populations return to the Little Campbell River. The inability to distinguish between wild and hatchery fish for this DU is problematic and needs to be addressed to determine the true trend in abundance for wild Chinook in Boundary Bay. Habitat availability is likely limited due to the highly developed environment of DU1 which reduces the resilience of the population to threats, such as chemical spills, urban development, and pollution, which are common in urban centers. Improvements in escapement monitoring and generating more accurate estimates of wild spawner abundance is critical for the achievement of both the recovery and survival targets for this DU.

DU6 (Maria) spawns in a single location in the Lower Fraser watershed making it highly susceptible to decline due to almost any threat. This DU already faces access to spawning ground issues especially in low water situations which are likely to become more prevalent as climate change progresses. Additionally, the presence of invasive species known to be detrimental to salmon populations has been confirmed. The trend in abundance over the length of the time series shows a slightly positive trajectory but the recent trend in abundance for this population is highly negative suggesting that drastic mitigations are likely required to ensure the persistence of this DU. Achieving the survival and recovery targets for this DU will be difficult given the limited spawning area, depressed population status, and numerous threats to Chinook in Maria Slough. DUs 13 and 15 are geographically wide spread and escapement programs do not exist for all populations within these DUs but robust programs exist for at least one of the populations within each DU. Both of these DUs exhibit patterns of decreasing trends in abundance over the long term with a stabilizing, more moderate decline in the more recent time period of the last three generations. The biomes in these regions of BC are highly susceptible to the impacts of wildfires and drought which are both expected to increase in frequency and severity over time due to the impacts of climate change. Based on the data available for writing this report, DU15 would be likely to achieve the survival target set out in this report over the next three generations. However, the severe flooding that occurred in the Coldwater and Nicola rivers in November of 2021 are likely to negatively impact the survival and recovery of this DU and the stabilizing trend is unlikely to persist. It is likely that the abundance portion of the survival recovery target for both of these DUs can be reached in the next three generations but the overall population trends are still negative (See Element 2).

Due to the enhanced nature of the DUs assessed in this report, PNI values needed to be considered with regards to the survival and recovery targets. Average PNI values for available populations generally align with the recommended values for integrated hatchery-wild populations set out in DFO 2018 with some inter-annual variation (Table 11), with the exception of DU1 where PNI values are on average lower than this benchmark. However, the difficulty in differentiating hatchery from wild on the spawning grounds for many populations generates a great deal of uncertainty around these estimates.

Given suspected declines in productivity, and the number and severity of threats impacting these SBCC DUs, it is anticipated that these DUs will either continue to decline or level off at the recently observed low population abundances. It is unlikely they will recover without drastic measures taken to mitigate threats.

Table 60. Summary of data availability within four SBCC DUs

Site Description	DU1 (BB)	DU6 (Maria)	DU13 (STh-1.3)	DU15 (LTh-1.2)
# of population sites	3	1	4	6
Sites with absolute escapement by age	3	0	0	1
Sites with exploitation rate by age	0*	0*	0	1
Sites with direct and recent enhancement	3	1	1	4
Sites with recent escapement by age and origin	0	1	1	1
Sites with data to represent temporal variation in productivity	0	0	0	1

*Proxy

4.3. ELEMENT 14: SUITABLE HABITAT SUPPLY

Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12.

RPAs aim to provide advice on the status of habitat *supply* and *demand* and to inform discussion about whether habitat availability is limiting population growth at present and or preventing a population from reaching the proposed recovery target(s) (DFO 2014a). *Supply* in this context refers to the amount of different habitat types known to exist and how much each habitat type can be expected to support should the population of the species saturate the habitat. *Demand* refers to habitat usage by the species and is estimated from the population size and densities that can be reached in different types of habitat.

Freshwater habitat has been generally described for SBCC (Element 4), yet it is difficult to assess this habitat in the context of requirements and supply and demand. This is particularly true for stream-type FRC that rear in freshwater for one or more years (DUs 13 and 15) and cover relatively large geographic areas within the watershed (DU13 (STh-1.3; 424km^2), and DU15 (LTh-1.2; 1330km^2); COSEWIC 2020). Stream-type FRC have been observed to exhibit three main strategies during the freshwater rearing stage:

- Juveniles rear in their natal stream from emergence until smolting.
- 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 before smolting the following spring.

- Juveniles immediately leave their natal stream after emergence and disperse (actively and passively) downstream to overwinter in the mainstem, side channels, and small tributaries of the lower Fraser River and the estuary.

Collectively, this rearing habitat in the Fraser watershed makes up thousands of kilometers of streams of variable width and depth, and suitability within this habitat may change annually or seasonally due to environmental conditions (i.e. flow conditions, temperatures, turbidity, etc.). Further to rearing habitat, quantifying the supply and demand of spawning habitat for stream-type DUs also poses challenges as many DUs have multiple spawning sites, and not all are surveyed or surveyed consistently through time due to a variety of constraints (remote access, water turbidity, financial constraints, etc.). The availability and quality of spawning habitat and substrates can also change annually or seasonally due to environmental conditions or extreme weather events (high or low flows and temperatures, sediment inputs, anchor/frazil ice formation, etc.), posing further challenges in estimating habitat supply.

It is unlikely that insufficient freshwater habitat supply is limiting in DUs 1, 13, and certain parts of DU15 under current environmental conditions. Habitat supply in the Nicola basin could potentially be limiting after the November 2021 floods and will require evaluation. DU6 (Maria) is the only population covered in this RPA that uses a single and well-defined spawning site and the amount of spawning habitat is thought to be limiting, both at current population levels and at proposed recovery targets. Maria Chinook spawn in an extremely limited area within the slough caused by intense habitat impacts throughout the twentieth century that severely degraded and reduced spawning habitat. It is unclear whether significantly larger historical abundances existed in Maria Slough because escapement records do not antedate 1986. Escapement surveys from 1986 to present estimate total (hatchery and wild) Chinook abundance below 1000 individuals, aside from four years between 1000-1500 individuals. An existing spawning channel was elongated in 2001 from 60m to 210m to provide additional habitat for Chinook; however, the number of suitable redd sites in this stretch of channel is unknown. Maria Slough requires consistent human intervention to ensure that habitat remains accessible and suitable for Chinook Salmon. Salmonid spawning habitat has been reported to be low in the Serpentine River (DU1) and spawning gravel was added to certain stretches from 2013-2016 (Yuan 2018); however, Chinook spawning distribution and escapement in this system are largely unknown.

Limited habitat in the Fraser River estuary may be contributing to declines in Chinook productivity (Chalifour et al. 2020), perhaps due to significantly less habitat than was historically available (Finn et al. 2021). Levy and Northcote (1982) reported Chinook Salmon had the highest density in brackish marsh channels in the Fraser estuary (maximum of 0.18 fish·m^2), which is approaching densities in which substantially shorter residency times and decreased growth rates were observed in juvenile Chinook in the Nisqually River Delta (0.20-0.25 fish·m^2; (Davis et al. 2018)). However, it is highly likely that the estuarine carrying capacity has been diminished through a variety of historical activities and continued increases in hatchery production potentially exacerbate this loss by increasing density-dependent effects in the remaining habitat (David et al. 2016; Chalifour et al. 2020). Estuarine habitat supply may therefore be limiting in some contexts, yet limited understanding of habitat use in the estuary, paired with limited surveying and monitoring of estuarine habitat suitability, restricts our ability to provide advice on habitat supply and demand in the context of the RPA.

Marine habitat supply and demand is not well understood for SBCC due to inherent challenges in surveying and monitoring vast unconstrained areas. Ocean carrying capacity is a highly dynamic ecosystem principle that fluctuates often, is strongly influenced by a plethora of ecological variables, and is generally poorly understood (Heard 1998). It has been suggested that the carrying capacity of the ocean may have been reached in recent decades, supported by relatively stable biomass estimates of both adult and immature wild and hatchery salmon in the north Pacific Ocean (Ruggerone and Irvine 2018). The size-structure and age-structure of Chinook Salmon has also changed considerably across the Northeast Pacific Ocean since the late 1970s, with lower proportions of older age classes throughout most regions and simultaneous declines in length-at-age of older fish and increased length-at-age of younger fish (Ohlberger et al. 2018). It remains unclear whether these demographic changes are a result of high levels of competition from hatchery production, changing environmental conditions impacting habitat and resource availability, changes in predator and prey interactions, or a multitude of other concurrent marine ecosystem processes. Despite this uncertainty, this may indicate that habitat supply and demand in the marine environment is an important factor limiting the recovery of SBCC DUs considered in this RPA.

This Element represents a notable gap in knowledge in the context of SBCC and has been highlighted as a major research need (Element 11). For this element to be properly addressed, research on fry dispersal, behaviour, densities, and survival at the DU level is required alongside an assessment of the state of knowledge on habitat throughout their respective watersheds, estuaries and the North Pacific Ocean. Future assessment of the supply of suitable habitat would benefit from collaboration between DFO Science, DFO Fish and Fish Habitat Protection Program (FFHPP), the Ministry of Forests, Lands, Natural Resources Operations and Rural Development (FLNRORD) and the Ministry of Environment and Climate Change (MOE), as well as many other organizations that have compiled information in various mapping databases. Future assessments may also benefit from attempting to assess changes that have likely impacted the carrying capacity in the marine environment.

4.4. ELEMENT 15: ABILITY TO ACHIEVE RECOVERY TARGETS UNDER CHANGING CONDITIONS

Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.

As mentioned in previous sections, data limitations prevented meaningful modelling for the DUs covered in this RPA. The qualitative assessment conducted for these DUs in Element 13, indicated that these populations will continue to decline under current conditions. Any increase in the number or severity of the threats discussed in Element 8, mitigation time delays, or even the continued unabated impacts of current threats are likely to result in the continued or even an increased rate of decline for these DUs. Efforts to improve the productivity and survival of these populations, through mitigating of both current and past threats and preventing or mitigating future impacts, will increase the chances of recovery for these populations. While current harvest rate levels on some of these DUs is unknown, reducing the impacts of fishing will likely increase the chance of recovery for these DUs as found with Interior Fraser Coho and DU2 (Harrison) in the previous Chinook RPA (DFO 2021b).

5. ELEMENTS 16 TO 20: EVALUATION OF POTENTIAL MITIGATION OPTIONS

5.1. ELEMENT 16: INVENTORY OF MITIGATION MEASURES AND ALTERNATIVE ACTIVITIES

Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10).

When species are threatened and decline due to human influences, mitigations are often implemented to reverse or limit impacts. Threats to species and their habitat often have ecological impacts that can be cumulative and interconnected which can lead to a lack of understanding of the results of mitigation measures or uncertainty in determining the level of efficacy of actions. While measures to mitigate in the marine environment are often broad and too large a scale for meaningful results, protecting the freshwater environment for salmonids has the potential to be impactful. A literature review by McClelland (2021) determined that there was a great deal of variation of actual impacts for habitat restoration measures. They determined that salmon will utilize restored habitat but that this did not necessarily result in an increase in survival or abundance. The author linked this to the fact that often only the restored reach was monitored and asserted that the goal of restoration should be to restore ecological processes which would include a combination of actions. To that end, McClelland provides two key recommendations when considering salmon habitat restoration initiatives.

- The first is to implement long term, effective monitoring. This would also require selecting meaningful controls and choosing reference reaches to account for changes in the natural environment.
- The second is to coordinate efforts and that multiple, coordinated projects at the watershed level would be most beneficial to salmon populations.

While it is quite difficult to determine the efficacy of restoration measures, Sawyer (2021) performed a literature review and concluded there were four types of habitat measures that would benefit salmonid populations:

- The first measure is to protect habitats in the headwaters of DU streams. Sawyer (2021) determined that this would be the simplest, least expensive and most effective means of sustaining ecologically functioning habitats for at-risk Pacific Salmon.
- The second was the reconnection of freshwater habitats through the removal of barriers to increase carrying capacity and reduce density dependent pressures in freshwater spawning and rearing habitat.
- The third measure is the restoration of flow and sediment transport. Although the DUs in this report are not subject to any large dams, many of them are heavily impacted by agricultural and municipal water withdrawals. Specific programs that encourage water conservation or improve tracking and regulation of ground and surface waters for agricultural and municipal use would be highly beneficial. Additionally, storm water control measures to mitigate run-off from impervious surfaces in urban environments and road resurfacing, sideslope stabilization and road removal in regions heavily impacted by forestry practices.
- The final measure that Sawyer determined to be effective was the rehabilitation of riparian function including riparian buffer planting, livestock exclusion and rest/rotation grazing strategies. While these measures are not specific to SBCC directly, the principles can be applied when considering mitigation measures to recover these DUs.

SBCC use an extensive and diverse range of habitats throughout their life cycle, with considerable variability in habitat use and migration timing between populations (e.g. ocean-type vs. stream-type; see Element 1 for detailed descriptions of SBCC life-history). This variability places some DUs at greater risk than others, particularly for stream-type variants that rear in freshwater for one or more years (DUs 13 and 15). There is also considerable inter-annual variability within the freshwater and marine environments that affect the severity of the suite of threats and limiting factors on spawning success (see Table 54 for summary of threats to SBCC). Further to this, many of the threats identified in Element 8 of the RPA are extremely difficult to mitigate due to the many interrelated physical, biological, and chemical processes involved in large ecosystems. The combination of these factors poses many challenges for mitigation planning and creates a large amount of uncertainty associated with quantifying the effectiveness of mitigation measures once they are employed. There is also currently insufficient data to quantify DU-level benefits from individual mitigation activities for all DUs, which greatly limits our ability to prioritize mitigation activities by both their importance to SBCC recovery and by their feasibility to maximize use of resources. For these reasons, this section does not attempt to prioritize mitigation options, rather provides an overview of both broad and specific mitigation actions to address threats identified in Element 8 of the RPA. However, at the end of this section results from a mitigation survey conducted by the experts who attended the threats workshop is summarized and discussed. This was added to the RPA as a means of identifying the potentially most impactful mitigation measures as determined by the expert opinion available at the threats workshop.

5.1.1. Mitigation Strategies

5.1.1.1 Development

Mitigation of threats associated with new developments can be addressed through project-specific measures to reduce, eliminate, or buffer the harmful effects associated with them. Coker et al. (2010) developed a broad guidance document to accompany Central and Arctic Region RPAs but it is relevant to all fish-bearing systems. Coker et al. (2010) comprehensively detailed linkages between works and activities and their “pathways of effects”, as well as mitigation strategies to break those pathways. These are specific mitigation measures that can be undertaken by those working in and around water. When development activities do not directly occur in fish habitat, the potential larger-scale implications on fish productivity are often not considered. Planning for development within all sectors needs to consider the cumulative hydrological effects within watersheds and the existing state of a watershed’s hydrological health, as which is inextricably linked to salmon survival and productivity (Hartman and Brown 1988; Tschaplinski and Pike 2017).

Legislation including but not exclusive to: the Provincial *Riparian Areas Protection Act*, the *Forest and Range Practices Act*, the *Mines Act*, the *Water Sustainability Act,* the modernized *Federal Fisheries Act* and the *Fisheries Protection Policy Statement,* provide the framework for protection of fish habitat. These Acts and associated regulations recognize the link between activities and habitat threats but are only effective when implemented consistently. This requires multijurisdictional cooperation, precautionary policy interpretation, better and more holistic land use planning, and adequate monitoring and enforcement. All of which require ongoing and consistent support and funding.

The Acts listed above, policies, and guidance documents are only as useful as they are enforceable. In many cases mitigation is associated with extra costs. Significant challenges to compliance with regulations have been identified in situations where habitat protections depend on professional reliance or potential development impacts must be proponent declared (Carter 2014; Haddock 2018). These planning and monitoring methods create a conflict of interest between profit and fish protection, which has detrimental effects on mitigation enforcement (Haddock 2018). Adequate agency resourcing to assist with third party planning, monitoring and enforcement of regulations is required. In addition to enforcement and third party planning, mandatory financial safety-nets for unforeseen problems (e.g. spills or breaches) would be beneficial. A legal and policy framework that is consistently applied at the municipal, regional district, provincial, federal, and First Nations levels would help to ensure the protection of salmon.

5.1.1.2 Agriculture and Aquaculture

Several threats to SBCC associated with agriculture (loss/degradation of habitat, livestock entering streams) and aquaculture (various competitive interactions with hatchery fish) were identified in Element 8 of the RPA. Other threats related to agriculture and aquaculture such as water extraction and pollution were also identified, but are discussed in separate sections within this document (sections 5.1.1.7 Dams and Water Management and 5.1.1.8 Pollution, respectively).

Agricultural activities occur throughout the majority of SBCC habitat. The threat is likely highest in regions most susceptible to drought, such as in DUs 13 and 15, and are more likely to be negatively impacted by agricultural water withdrawals. As within other sectors, mitigating the impacts of new agricultural development needs to consider both the direct physical impacts from those activities such as loss or degradation of habitat, and the larger scale implications such as impacts on stream hydrologic function, runoff dynamics, and pollution, among others. In addition to the acts listed above in section 5.1.1.1 Development, there are additional pieces of legislation that aim to reduce the impacts from agriculture, and include: the *Environmental Management Act, Public Health Act*, and *Integrated Pest Management Act*. Further to this, better planning of on-site agricultural activities would likely contribute to SBCC recovery. Programs such as the Environmental Farm Plan[42] aim to support agricultural operations in order to minimize environmental risks, and provide on-site assessments and guidance for factors such as riparian integrity, irrigation and drainage, water quality, air quality and emissions control, and on-farm materials storage. Programs such as these should be utilized when possible to ensure the protection of SBCC habitat.

Fish aquaculture is pervasive on the Southern coast of British Columbia and in nearshore rearing habitats, and it is probable that all SBCC 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 on SBCC resulting from the footprint of open net pens, yet there are concerns surrounding transmission of disease, introduction of genetic material, and fish escaping into the wild, among other and closed containment or land-based aquaculture would likely eliminate these interactions. DFO has committed to developing an open-net transition plan by 2025.

There are also concerns surrounding competitive interaction between SBCC and hatchery-origin fish, which compete for resources at all life stages and in all associated habitats and can negatively affect wild populations when resources are limited (Tatara and Berejikian 2012; see elements 2 and 8 of the RPA for discussion of competitive interactions between wild and hatchery Chinook). Interactions between hatchery and wild SBCC are discussed further in section 5.1.1.6 Hatchery Enhancement.

5.1.1.3 Fishing Impacts

The nature of fisheries impacting SBCC has changed significantly over the past 40 years. Reduced marine survival in the 1980s and subsequent management actions throughout the 1990s to conserve at-risk populations resulted in coast-wide reductions in fishing effort and landed catches observed over time (Brown et al. 2019). In 1997 and 1998, Canadian ocean fisheries were dramatically reduced to lessen impacts on Interior Fraser River Coho Salmon, further altering marine catch distributions and lowering ocean catches of SBCC (Brown et al. 2019).

There are, however, a number of factors confounding the true effects of the reduction in fisheries. The harvest of co-migrating stronger and weaker salmon populations, whether wild or enhanced, is an inherent challenge in estimating the impacts of fisheries (Brown et al. 2019). In mixed-stock fisheries, there are risks of overfishing reproductively weaker or less abundant salmon populations that are mixed with stronger or more abundant wild or enhanced populations (DFO Salmonid Enhancement Program 2013). There is currently an inadequate

[42] Province of British Columbia. Environmental Farm Plan Program. [Accessed October 15, 2022]

understanding of the full impact of non-retention fisheries due to the potential for under-reporting of bycatch and uncertainties in the mortality rates of released fish. However, handling methods and release conditions have been shown to affect post-release mortality (Gale 2011; Robinson 2013).

There are also unaccounted impacts from illegal fishing activity that further confound the response of populations to changes in fisheries. The impacts of non-retention fisheries and illegal fishing activity have been identified as future research needs.

Impacts from net fisheries during co-migration of SBCC can be further mitigated by stipulating shorter opening durations, shorter gill-net set times, shorter nets, larger gill-net mesh size or tangle tooth gear and active fishing of set nets as opposed to passive fishing methods. Making use of brailing methods on seine boats facilitates recovery of released fish, as do recovery tanks when they are properly used. Recreational fisheries mitigation may include but is not limited to: use of gear which decreases impacts to released fish such as barbless hooks, mandatory fish handling and fish identification courses/exams (similar to a Conservation and Outdoor Recreation Education exam for hunting), and diminished fishing opportunities when compliance with regulations fail to reach target levels. Research and stock assessment activities must use the least invasive methods when possible.

Reduced harvest represents one of the few immediate mitigation measures available to reduce impacts on SBCC, but even in the absence of fishing many DUs may not recover in the short-term. Reduced fishing pressure can be accomplished by both reduced effort in mixed stock fisheries or more focused fisheries effort in terminal areas where stronger populations are no longer mixed with weaker ones.

5.1.1.4 Forestry and Wildfire Management

Numerous activities related to forestry and wildfire management, both historical and current, were identified as threats to SBCC in Element 8 of this RPA (see sections 3.1.4.3 Shipping Lanes, 3.1.5 Biological Resource Use, and 3.1.7 Natural Systems Modifications). In summary, historical clear-cut logging and riparian vegetation removal have resulted in significant negative impacts on stream channel stability and habitat complexity, sediment and nutrient budgets, stream temperatures, runoff dynamics, seasonal hydrographs, and overall forest health throughout areas of the Fraser Basin and Boundary Bay drainages. Current forestry practices are under review by the BC government. The review and changes to regulations aim to reduce these impacts by encouraging better planning for sustainable and selective cutting rates, and considering information such as forest health/diversity, wildfire and fuel management, fish and wildlife status, climate change, and cumulative effects into timber management goals (BC Ministry of Forests, Lands and Natural Resource Operations [FLNRO] 2017); however, wildfires, pest infestations and disease are becoming a more recurrent threat within BC, and subsequent salvage logging operations following these events were identified in Element 8 of the RPA as a likely threat to SBCC in the future. Salvage logging typically covers larger areas than conventional cutblocks and can occur within riparian habitat due to exemptions for salvaging timber damaged by fire, insects, or disease, suggesting that unless forest regulations and practices change, impacts from future salvage logging on SBCC is probable.

Future planning for salvage logging and timber harvesting needs to consider and align with the recovery goals of SBCC, including both the physical impacts from these activities and more importantly, the larger implications on hydrological function through modified catchment surfaces. There are several pieces of provincial legislation in place to guide sustainable forestry practices both on public and private land, including the *Forest Act, Forest and Range Practices Act,* and *Private Managed Forest Land Act*, yet as with other sectors, these acts need to be updated regularly and require support for monitoring and enforcement. Changing legislation to eliminate or reduce aggressive salvage logging operations following forest disturbances, as was seen following the outbreak of Mountain Pine Beetle in BC, is also critical for the long-term recovery of SBCC. Further, logging practices should be conducted in a manner that ensures hydrological function and slope stability are not compromised in fish-bearing watersheds to avoid increased sedimentation and landslides into fish habitat.

Log storage in the lower Fraser was also identified in Element 8 of the RPA as a threat to SBCC transiting and rearing in the lower Fraser River (section 3.1.4.3 Shipping Lanes) (Healey 1980). The lower Fraser is a highly active channel for log boom shipping and contains a high concentration of log booms and barges, which can lead to a variety of adverse physical, chemical, and biological effects to the surrounding environment (Power and Northcote 1991; 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 Harbour Seals, which use log booms as haul-out sites and for pupping (Baird 2001; Brown et al. 2019). This area is also known to support millions of outmigrating salmon which occupy marine foreshore areas after smoltification, and prior to migrating out to sea (Nelitz et al. 2012). Removals or reductions of current log storage impacts in the lower Fraser River and estuary will likely improve the quantity and availability of nearshore habitat for SBCC (and other Pacific Salmon species) rearing in or travelling through the lower Fraser River, and should be considered as a mitigation activity to improve SBCC habitat.

5.1.1.5 Invasive and Problematic Species

The introduction of aquatic invasive species (AIS) is extremely difficult to mitigate as it takes only a few individuals, sometimes introduced unintentionally, to irrevocably alter a watershed. There has been a long history of failures to manage aquatic invasive species before irreversible damage has been done to ecosystems, both on the federal and provincial/state level in the Pacific Northwest (i.e. Columbia River and tributaries); therefore, early action is paramount in managing AIS. Once AIS become established, they can be extremely difficult to manage without impacting native biological communities using conventional suppression techniques such as physical removal (netting, electrofishing) and chemical intervention (i.e. Rotenone). Where AIS are detected, all efforts to eradicate those species should be undertaken as quickly as possible and monitoring programs should be implemented and sustained to ensure eradication is complete. This is particularly true for species that have short maturation times, high fecundity, and great dispersal mechanisms such as Dressenid mussels and European Green Crab (see Element 8 for detailed descriptions of threats to SBCC from AIS, which have been identified as potential major threats to ecosystem function in the Fraser River and Boundary Bay drainages. Detection of biological invasions in their early stages is, however, challenging when population densities are at a minimum, and conventional surveying techniques require considerable resources to conduct and have the potential to negatively impact non-target species, in addition to having questionable effectiveness when target species abundance is low (Olsen et al. 2015). The use of environmental DNA (eDNA) sampling has gained considerable interest since its inception (Ficetola et al. 2008) as a non-invasive technique to detect and monitor invasive or rare freshwater species, requiring minimal effort in the field and eliminating potential negative impacts on non-target species. The implementation of routine eDNA monitoring programs in likely areas of introduction may be an option to track the colonization and/or spread of AIS.

Mitigation of AIS should involve a multipronged approach of public education, monitoring of areas likely to be points of introduction, and enforcement through strong disincentives. Preventing or slowing the secondary spread of already established invasive populations is also an important consideration in long-term management of AIS (Vander Zanden and Olden 2008).

Predation by pinnipeds (Harbour Seals, Stellar Sea Lions, California Sea Lions) was identified as a potentially major source of mortality for SBCC in element of the RPA, particularly for DUs with significantly depressed abundances (see section 3.1.8.2 Problematic Native Species). While there has been considerable work investigating the effects of predatory interactions between SBCC and pinnipeds, there are vast numbers of other ecological processes at play within the Salish Sea confounding our understanding of these interactions and their impacts on SBCC.

There are few direct mitigation strategies available to reduce impacts of predation, with the exception of lethal removal (culling) or non-lethal removal (capture or relocation). A recent technical workshop hosted by the Institute for the Oceans and Fisheries (University of British Columbia), which included a broad group of scientists and managers from both Canada and the US with technical expertise on pinnipeds and salmonids, convened to evaluate the current state of knowledge and uncertainties surrounding the diets and population dynamics of pinnipeds, as well as the impacts that pinnipeds may be having on Pacific Salmon in the Salish Sea (Trites and Rosen 2019). The proceedings from this workshop go into considerable detail surrounding pinnipeds and their interactions with Pacific Salmon (see Trites and Rosen (2019)); however, the general consensus from this workshop was that data are insufficient at this time to justify mitigation in the form of culling pinnipeds in the Salish Sea, due to high levels of uncertainty of both our current state of information and the indirect effects of conducting a cull. Non-lethal alternatives such as capturing or harassing pinnipeds during critical times were also discussed, yet considerable thought would have to be given to implement such actions as to avoid habituation over time. As mentioned in section 5.1.1.4 Forestry and Wildfire Management, log booms were identified to attract SBCC and other salmon seeking refuge, but also attract other predators and serve as haul-out sites for Harbour Seals. Removal of log booms in key areas, particularly in estuaries, may be beneficial in reducing the number of pinnipeds that predate on SBCC seeking refuge.

Further research is needed to better understand the indirect effects of culling predators and other factors that influence ecosystem function such as food web relationships, shifting prey/predator distributions, and hatchery practices. Further to this, with our limited understanding of both Pacific Salmon and pinniped population dynamics, we have little capability in determining whether removals are producing the intended effect. Further investigation of pinniped predation has been identified as a future research need for SBCC mitigation planning.

5.1.1.6 Hatchery Enhancement

Hatchery enhancement has been used both as a conservation tool and for maintaining Pacific Salmon fisheries in Canada following recognition of rapidly declining catches in the 1970s. Hatcheries have been used successfully to meet certain conservation goals, yet they have also raised a number of ecological concerns and have become a controversial issue in conservation biology (National Research Council 1996; Myers et al. 2004; Lackey 2013). In Element 8 of the RPA, potential issues stemming from high levels of hatchery production are discussed in detail. In summary, enhancement and hatchery programs can reduce genetic diversity, increase intraspecific competition in highly degraded habitat, and can lead to higher fishing mortality rates for wild salmon. In the U.S. Pacific Northwest, Chinook Salmon conservation activities have been occurring for many decades, dating back to the period when dams were being constructed on the mainstem of the Columbia River, which can provide helpful information for programs aimed at rebuilding depleted SBCC populations. The negative effect of hatcheries on wild Chinook survival has been reported in the Columbia River, and numerous studies have reported hatchery-wild interactions that have negative effects to no negative effects 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.

Mitigating interactions between hatchery and wild fish across their entire shared environment, and over their entire life cycle, is particularly challenging due to the migratory behaviour of salmon where multiple stocks often mix. Genetic effects from interbreeding with hatchery fish may also remain for several generations after hatchery reductions are made. However, even moderate decreases in the level of hatchery production will decrease hatchery-wild fish interactions and allow wild fish to locally adapt to their environment (Kostow 2009). Therefore, genetic impacts may only be mitigated by reductions of interbreeding in a natal river but other ecological processes may be mitigated by managing regional hatchery production. Hatchery-origin fish may also transmit pathogens to wild conspecifics. Hatchery practices should therefore aim to reduce pathogen loads, which may be accomplished by limiting river water withdrawals during periods with high water temperatures when certain pathogens replicate at a faster rate (Karvonen et al. 2010) or using prophylactic treatments.

The message is not to shut down hatcheries, but to more actively collect information about the ecological interactions of hatchery and wild Chinook, and to use enhancement to provide information about smolt-age-2 survival processes that will help future management of stocks. This additional information can then be used to inform decisions about hatchery production levels and release strategies that may hinder the recovery of depleted wild populations.

The extremely low abundance of SBCC in DU6 and uncertain abundance of wild fish in DU1 poses a serious risk of extirpation of these DUs without some form of hatchery intervention. Conservation hatchery programs should be carefully implemented and be dynamic in their processes to alter their activities when benchmarks to recovery are achieved to reduce the threat of the introduced hatchery genetics to the population.

5.1.1.7 Dams and Water Management

The threat to SBCC through water management and utilization (for a variety of sectors) in the Fraser River basin and Boundary Bay drainages 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.

There are no large hydroelectric dams in SBCC habitat, but there is the potential for smaller water impoundment structures to exist in these regions. Water management with regard to extraction of overland flows and aquifers may be in direct conflict with the water needs of SBCC and other stream-dwelling animals. These structures are mostly in place for irrigation and flood mitigation purposes, most of which are not currently managed in a manner that addresses passage or flow requirements for fish. Floodgates exist in Boundary Bay and have the potential to be built in other DUs. They impede Chinook passage at multiple life stages and can impact habitat characteristics. Flood mitigation structures impede the dispersal of juvenile Chinook Salmon into favoured off channel areas during spring freshets. Recognition and protection of off-channel habitat for SBCC rearing is critical to maintaining productivity into the future.

Mitigation of smaller water impoundment structures is difficult because mitigation often involves maintaining or restoring the flood function of streams, which is frequently in direct conflict with human settlement (see Estuary Restoration section above). The current water extraction network is difficult to govern, monitoring of surface extraction is inadequate, and monitoring of groundwater removal is almost non-existent. As well, in times of drought, the enforcement response is frequently slow and until conditions are extreme, mitigation is strictly voluntary. Though modern water licenses may be granted with metering requirements many still exist that are unmetered. Water extraction in some river systems is now recognized to be over-allocated, but there are few options to retract licenses (Brown et al. 2019). There is growing recognition in BC's regulatory framework of the importance of aquifer sources to environmental needs. Section 55(4) of *The Water Sustainability Act* now clarifies that government has the discretion to consider environmental flow needs when adjudicating both new and pre-existing groundwater use. Though *The Water Sustainability Act*'s move to license ground water is a step forward, there is still work required to incorporate current ground water wells into the regulatory framework, meter all extraction activities, and create water allocation regimes that include planning for fish-habitat requirements in order to sustain salmon habitat.

Water extraction also poses the threat of juvenile salmon entrainment and improper screening or sizing of intakes can lead to impingement. Though screening of water intakes is required, screens are often removed or not replaced once lost as they can serve to increase maintenance work and cost. Monitoring of screen intakes is required to enforce compliance.

5.1.1.8 Pollution

Numerous sources of pollution, both historical and present, were identified in Element 8 of the RPA as posing a significant threat to SBCC, and include: Household Sewage and Urban Waste Water; Industrial and Military Effluents; Agriculture and Forestry Effluents; Garbage and Solid Waste; and Airborne Pollutants. Many of these contaminants are persistent in the environment, may travel long distances, and have a tendency to accumulate in sediments and food chains from multiple sources. Further to this, contaminants generated from multiple sources accumulate as mixtures in the environment; therefore, the effects from individual pollutants are extremely difficult to ascertain from one another, and thus prioritize mitigation activities to reduce their harm.

The principal pieces of legislation in place for environmental pollution issues in British Columbia include the provincial *Environmental Management Act* and *Waste Discharge Regulation*, and the federal *Canadian Environmental Protection Act*, *Fisheries Act,* and *Canada Water Act*. Legislation and operational changes over the last several decades have been effective in reducing pollution from a variety of sectors, and while current legislation/regulation aims to reduce environmental contamination, the effects of historical activities still pose a noteworthy threat to SBCC at all life stages. This is particularly true within the Southern mainland, and lower Fraser River and estuary, which has historically been the epicenter of anthropogenic activities within the province that generates pollution, in addition to serving as a bottleneck for pollutants accumulated throughout the Fraser Basin (refer to section 3.1.9 Pollution and Contaminants in Element 8 for discussion of pollution in the Fraser Basin). All SBCC must transit through the Lower mainland via the lower Fraser or the rivers within DU1 (BB) during outmigration to the ocean and during their return spawning migration, and are thus exposed to environmental pollutants twice within these areas.

One of the few current options we have available for mitigating future pollution is the adoption and enforcement of more strict regulations on activities that generate and release contaminants into the environment. There are, however, inherent challenges in monitoring the release of pollution due to the vast number of sources within the Fraser Basin and surrounding coastal areas. This is particularly true when self-reliance of reporting and potential loss in revenue is involved (see section 5.1.1.1 Development). Monitoring programs like PollutionTracker[43] are currently working to document the levels and trends of a variety of contaminants within coastal BC. Biomonitoring of macroinvertebrates can show changes in water quality and capture

[43] Pollution Tracker. Pollution Tracker – How polluted is your ocean? [Accessed March 15, 2022]

cumulative effects and community composition. Expansion of monitoring programs such as these, particularly within the interior Fraser Basin, would be beneficial for identifying and reducing the release of pollution that may impact SBCC.

Remediation of polluted sites that are either within salmon habitat, or that influence salmon habitat through the release of contaminates (effluents, runoff, groundwater inputs, etc.), is another important component for the recovery of SBCC. Remediation of contaminated sediments commonly employs activities such as dredging (mechanical or hydraulic removal of contaminated sediment), dry excavation (de-watering and physical removal of contaminated sediment), capping (covering contaminated sediments with clean material or geotextiles), the use of sorptive agents (mixing of sediments with reactive sorbants to isolate contaminates), and in-situ amendments (addition of chemicals/compounds to promote destruction or immobilization of contaminates) (Perelo 2010; Bullard et al. 2015). An alternative non-invasive mitigation strategy for contaminated sediments is monitored natural recovery (MNR), which relies on the metabolic potential of microorganisms, paired with naturally occurring physical and chemical processes to degrade contaminates over time (Perelo 2010; Bullard et al. 2015). Each of these mitigation strategies have number of associated considerations in terms of their usefulness, feasibility, and sustainability, and should be thoroughly investigated on a project-specific basis.

Considerable work is needed in order to inventory and prioritize remediation of environmental pollution for SBCC, particularly at the DU level, and has been identified as a major knowledge gap that needs to be addressed for future recovery planning.

5.1.1.9 Climate Change

Climate change encompasses a large suite of complex and inter-related issues that threaten SBCC, and is likely to exacerbate many of the threats discussed in Element 8. These cumulative impacts add a layer of complexity to many of the previously recommended mitigation measures and climate change must be explicitly addressed during all mitigation planning moving forward. For example, more extreme precipitation events caused by climate change will compound the effects of certain activities such as further increasing run-off rates already impacted by logging and forest fires. Improperly planned or older mitigation structures and practices may be overwhelmed and there may be increased failures of tailings ponds and water treatment facilities, as well as higher rates of scouring and the increased likelihood of bank failure and avulsion events. In addition, failures of infrastructure due to extreme events may lead to a greater number of in-stream work that may in turn contribute to threats as discussed under the Development threats section in Element 8.

The current regulatory framework and best practices with regard to emergency works, water and tailings dam planning and management, forestry cut rates and block planning, bridge engineering, storm-water management and occupation of flood plains through urban encroachment may all need to be reconsidered to mitigate for the more regular arrival of higher flood flows, and altered snowpack melt regimes. The current practices of unregulated groundwater extraction, unmonitored surface water extraction activity, slow reaction times to drought conditions, and lack of watershed-level hydrological function planning will all need to improve and be more responsive to climate change.

Combatting climate change is a global issue, and there are no simple measures available to curtail increases in global average temperatures. The negative effects from climate change are not anticipated to diminish or reverse in the foreseeable future. Therefore, considerable preparation and planning is needed to restore and conserve the remaining habitat available to

SBCC and other imperiled salmonids. The recent Paris Agreement[44] and the United Nations Intergovernmental Panel on Climate Change[45] provide guidelines to aid in the global effort of combatting and adapting to climate change, and SBCC populations and their habitats should be managed according to these guidelines so that they are resilient and can adapt to future environmental changes.

5.1.1.10 Estuarine, Intertidal, and Riparian Habitat Restoration

There has been significant degradation of historical rearing habitat in DU1 (BB) and the lower Fraser River and estuary from various developments and flood control structures (e.g. dikes, flood boxes, tide gates, etc.). These developments have led to major losses of the Fraser River estuary (70-90 %; Levings 2004), and restricted access to floodplain and off-channel habitat that provide critical foraging and growth opportunities for juvenile SBCC. There can be substantial early natural mortality in the marine environment resulting mostly from predation when 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). Fostering the restoration of freshwater, brackish, and saline marshes is one possibility for increasing the functional capacity of the estuarine habitat, and represents a crucial mitigation option to prevent habitat loss from rising sea levels (Temmerman et al. 2013). Habitat restoration in estuaries is, however, often confounded by the complexity of the salmon life cycle and variation in habitat needs at multiple spatiotemporal scales (Simenstad et al. 2000). Additionally, there frequently appears to be no effect, or even detrimental effects related to biological interventions undertaken to promote the recovery of biodiversity and functionality in estuaries (Moreno-Mateos et al. 2015), and there are demonstrated risks to over-engineering an ecosystem or encouraging homogeneity among habitats (Elliot et al. 2016). Careful consideration must therefore be put into restoration planning to overcome these challenges.

While not SBCC specific, recent habitat restoration efforts in the Nisqually River Delta, Washington, provide evidence that re-establishing tidal influences to a heavily modified estuarine ecosystem can increase prey resources and forage opportunities for juvenile salmon. Post-restoration monitoring data indicates substantial increases in invertebrate biomass following re-establishment of tidal inundation, greatly enhancing foraging capacity of salmon (Woo et al. 2018). Similar restorations of habitat within the Fraser River estuary and Boundary Bay may be a viable mitigation measure to provide valuable prey resources for juvenile salmon and other fishes, and to increase the recovery and survival of SBCC. This could be accomplished through the removal of engineered barriers to tidal exchange (i.e. tide gates, flood boxes) encouraging the formation of tidal channel networks, increasing overhanging riparian vegetation, and improving environmental conditions for invertebrate productivity loss (Davis et al. 2019). The development of complex tidal channel networks with overhanging vegetation can lead to shaded waterways with more stable water temperatures (Beck et al. 2001; Bertness and Ewanchuk 2002; Whitcraft and Levin 2007), while also providing habitat and structure for terrestrial prey (Kneib 1984; Allan et al. 2003; Woo et al. 2018). There may be more beneficial implications for wild Chinook Salmon populations, which appear to have longer delta residence times and are more likely to use estuarine tidal wetlands during their out-migration to the sea when compared to hatchery origin fish (Chittenden et al. 2018; Davis et al. 2018). The broader trophic niche and longer delta residence times of wild juvenile Chinook Salmon may allow them

[44] Paris Agreement. [Accessed March 15, 2022]

[45] Intergovernmental Panel on Climate Change. [Accessed March 15, 2022]

to exploit resources better than hatchery Chinook and thus to have higher bioenergetic growth potentials (Davis et al. 2018).

There are currently efforts underway through a variety of organizations to restore marsh and tidal channel habitat in the lower Fraser River, to enhance connectivity within the Fraser River delta, and improve habitat within the interior Fraser. Examples include: the Fraser River Estuary Connectivity Project (Raincoast Conservation Foundation); Connected Waters (Watershed Watch Salmon Society); Resilient Waters (MakeWay Foundation); and the Tsawwassen Eelgrass Project (Vancouver Fraser Port Authority Habitat Enhancement Program). There would be a major benefit from improved coordination and planning of restoration activities within the Fraser River estuary, as mitigating historical damages to this highly degraded habitat will require both considerable planning and the use of large-scale operations to make meaningful improvements to ecosystem function.

5.1.1.11 Conclusion

The above sections have identified a broad range of mitigation activities/strategies and their relation to threats identified in Element 8 of the RPA, yet alleviating many of these threats will be extremely challenging, especially since many are interrelated and exacerbated by climate change. Within many sectors a rapid change in practices, consideration of cumulative effects and planning in the context of climate change is needed to reduce further impacts on SBCC and the other imperiled Pacific Salmon species in the Fraser (Interior Fraser Coho, Interior Fraser Steelhead, Fraser Sockeye). Further to alleviating future threats, there is also a great need to restore historical damages from development and resource extraction activities that continue to impact hydrologic function within the Fraser Basin and Boundary Bay drainages. Re-stabilization of more natural hydrological regimes and restoration of highly degraded habitat, particularly in the lower Fraser River and estuary, would facilitate work to address many of the aforementioned issues negatively impacting freshwater and estuarine productivity. These are, however, multi-generation endeavors, and are only possible if future management/planning from all sectors is in line with the recovery goals of SBCC.

A common theme within the mitigation categories discussed above is that a more coordinated and informed approach to managing anthropogenic activities is needed. Undertaking a more coordinated approach across jurisdictions would promote more efficient use of limited human resources, and facilitate access to the broad range of specialists required to develop such a strategy and manage its implementation over time. Mitigation activities can be monitored for their efficacy and employ the latest science, which considers the current research on land-use changes, intra- and interspecific competition, changing ocean and estuarine habitat conditions, and climate change (Maas-Hebner et al. 2016).

Appendix F provides a summary of research needs for SBCC recovery planning, and considerable work is needed in these areas before prioritizing mitigation actions for the DUs assessed in this RPA; however, by promoting the recovery actions as beneficial across multiple species, there may be greater acceptance of measures and financial cost required to achieve recovery.

Table 61. General mitigation strategies to address threats to SBCC.

COSEWIC Major Threat Category	Threat Category Description	Possible Pathway(s)	Possible Mitigation Options	Notes
Residential and commercial development	• Footprints of residential, commercial, and recreational development	• Loss or degradation of habitat	• Manage ongoing and future development in the context of salmon habitat requirements, mandate and monitor compensatory works for loss of habitat • Proper catchments for the filtration of runoff • Adequate riparian and flood plain set backs • Installation of non-impervious surfaces • Water smart planning • Properly sizing culverts or choosing to install bridge structures • Land use planning exercises	-
Agriculture and aquaculture	• Footprints of agriculture, horticulture, and aquaculture • Competitive interactions with hatchery fish	• Loss or degradation of habitat • Competition	• Manage ongoing and future activities/development in the context of salmon habitat requirements, mandate and monitor compensatory works for loss of habitat • Transition to closed containment aquaculture • Reduce hatchery production, employ adaptive and alternative hatchery production strategies (e.g. time and size of release) • Livestock watering stations installed in areas away from watercourses • Maintenance of riparian buffers • Water smart planning • Proper crop choices for climate • Adoption of Environmental Farm Plans	Refer to Environmental Farm Plan and other related policies. Note that there is a large amount of surplus hatchery production outside of the Fraser River; the Chilliwack River Hatchery is a notable exception
Energy production and mining	• Footprints and extraction activities from mining (e.g. gravel extraction, placer mining, etc.)	• Loss or degradation of habitat	• Manage ongoing and future activities/development in the context of salmon habitat requirements, mandate and monitor compensatory works for loss of habitat	-
Transportation and service corridors	• Footprints from roads, railroads, utility and service lines, and shipping lanes	• Loss or degradation of habitat	• Manage ongoing and future activities/development in the context of salmon habitat requirements, mandate and monitor compensatory works for loss of habitat • Use salmon friendly stream crossings (e.g. free span bridges, baffles, etc.), upgrade old passages (e.g. hanging culverts)	-
Biological resource use	• Logging and wood harvest in riparian areas, transport of logs via rivers • Fishing	• Loss or degradation of habitat • Direct and indirect mortality	• Update/improve forestry policy in the context of protecting and restoring salmon habitat and riparian areas, managing the time and abundance of log booms in river, monitor and enforce water quality requirements for salmon health • Development and adherence to ECA thresholds at an appropriate spatial scale • Riparian setbacks written into regulations that are adequate for the protection of fish and fish habitat • Greater involvement of regulators during forest harvest planning	Fishing effects are transboundary and are associated with mixed stocks and mixed species

COSEWIC Major Threat Category	Threat Category Description	Possible Pathway(s)	Possible Mitigation Options	Notes
			• Better guidance from governments and professional associations for forestry professionals including but not exclusive to: hydrologists, geomorphologists, engineers, biologists and foresters • Consideration of cumulative effects in forestry • Strategic decommissioning and rehabilitation of forestry roads. • Strategic replanting, species selection and thinning of new forests (to provide for climate change resilience and mitigate for increased water usage by young trees) • Integrated and transparent planning for forestry operations in watersheds that are worked both by single forestry entities and where multiple forestry companies are operative • Adoption of First Nations forest and watershed principles into forestry planning • Review of the laws and regulations governing forestry activity in BC by a joint BC and DFO panel to determine the current frameworks ability to protect fish and fish habitat under the *Fisheries Act* • Manage the time and abundance of log booms in river, monitor and enforce water quality and effluent targets around booms • Adaptive fisheries management, increased monitoring and enforcement, minimize fisheries related mortality (direct and incidental), education on identification of salmonids and conservation concerns	
Human intrusions and disturbance	• Recreational activities (e.g. ATVs in streams, jet boats, etc.)	• Loss or degradation of habitat • Direct and indirect mortality • Alteration of behaviour	• Manage access (e.g. infrastructure) to water and allowable activities (e.g. regulations) over time and space, increased monitoring and enforcement • Increased education on interacting with streams and salmon	-
Natural systems modifications	• Fire and fire suppression • Dams and water management • Modifications to catchment surfaces, forestry, and linear development	• Loss or degradation of habitat • Direct and indirect mortality • Alteration of behaviour	• Update/improve forestry policy in the context of conserving watershed functions that support salmon; mandate, monitor, and manage reforestation and restoration activities (including managing for mature forest characteristics) • Use strategic treatments such as thinning, forest floor clearing/ burning to prevent large fires • Manage ongoing and future development of water resources, increase monitoring and enforcement of surface and ground water, specifically with salmon biological requirements as targets • Decommission or remove dams, increase, monitor, and maintain fish passage infrastructure for adults and juveniles (fishways, fish ladders, etc.) • Adaptively manage water in the face of climate change and increased variability • Manage ongoing and future linear developments by imitating more natural waterways, reconnecting off-channel habitat, removing or restoring old developments, and set and monitor water quality and sediment targets	-

COSEWIC Major Threat Category	Threat Category Description	Possible Pathway(s)	Possible Mitigation Options	Notes
			• Consider the impacts of cumulative effects in decision making • Initiate habitat complexing projects, such as groins and LWD, to improve habitat quality	
Invasive and other problematic species and genes	• Aquatic invasive species (AIS), introduced pathogens and viruses, problematic native species (e.g. pinnipeds, parasites, and disease), interbreeding with hatchery-origin fish	• Loss or degradation of habitat • Alteration of behaviour • Predation and competition • Increased prevalence of infection • Reduced genetic diversity and natural selection forces	• Removals of AIS, prevention of introduction through increased monitoring for new and of existing AIS populations, increased enforcement and education surrounding introductions of AIS • Monitoring and treatment of pathogens in aquaculture, transition to land-based aquaculture and increased treatment of aquaculture effluent, implement and monitor predator control measures • Reductions in log booms in lower Fraser and estuary that serve as haul-out sites for pinnipeds • Monitor hatchery and wild genetics and implement adaptive production planning, mass mark hatchery fish to identify and remove from natural breeding population, minimize hatchery production	Pinniped populations have increased due to protection of marine mammals; research is required on the efficacy and direct applicability of predator controls
Pollution	• Introduction of exotic and/or excess materials or energy from point and nonpoint sources, including nutrients, toxic chemicals, and/or sediments from urban, commercial, agricultural, and forestry activities	• Altered behaviour and physical condition due to hormone and developmental que mimics, gene regulation, and other toxicities, potentially reducing survival and resilience	• Manage ongoing and future activities/developments that contribute to pollution, improve waste water management and monitoring, increase enforcement of best practices for water quality • Removal or remediation of contaminated sediments	-
Geological events	• Avalanches and landslides	• Stop or reduce passage • Increased mortality associated with passage	• Increase, monitor, and maintain fish passage infrastructure for adults and juveniles (e.g. fishways, fish ladders, etc.) • Proactively identify areas that are at risk of landslides that could result in passage impediments, and implement regular monitoring to decrease mitigation response times to initiate mitigation activities	-
Climate change and severe weather	• Freshwater and marine habitats shifting, and increasing frequency of severe weather events (e.g. droughts, floods, temperature extremes, etc.)	• Loss or degradation of habitat • Direct and indirect mortality • Exacerbate impacts from other threats	• Follow guidelines from the recent Paris Accord and International Panel on Climate Change reports • Proactively manage habitats and populations so that they are resilient and may adapt to future changes	Adaptive management is required for all mitigation activities in the context of climate change and the increased frequency of severe weather events

5.1.2. Mitigation Survey Results

The threats workshop (held virtually in October 2021) participants proposed an inventory of DU-specific mitigation strategies in response to threat classifications determined at the workshop. The inventory was subsequently assembled into a Likert-scale based survey where workshop participants were asked to rank how important they thought each mitigation strategy may be in facilitating the recovery of a DU by selecting either 'not important at all (1),' 'slightly important (2),' 'somewhat important (3),' 'moderately important (4),' 'extremely important (5),' or 'unsure or do not know.' The weighted average ratings for all proposed mitigation measure were calculated from the responses of 13 participants (93% response rate), all of whom participated in the Threats' Workshop, and are summarized in Figure 23 to 27. Responses in the 'unsure or do not know' category were excluded from the calculation of weighted averages. The top three rated mitigation measures for each DU are discussed below. The scope of some mitigation measures overlap; however, they are intended to identify a breadth of potential mitigation avenues, some of which could be more feasibly implemented than others.

For DU1, the highest rated mitigation measure involves working with municipalities to improve tidal flood gates (sea dams) to improve fish passage on the Nicomekl and Serpentine rivers. Closure of the gates restricts adult and juvenile migration, which in turn causes individuals to accumulate and increases their exposure to predators. The degree of temporal overlap between Chinook migrations and sea dam closures is unknown; however, Chinook accumulations and significant predation have been observed during periods of closure. Sea dam operations could be modified to include effective salmon passage gates for Chinook (and other fish) or ensure that gates are not closed for extended periods during the juvenile and adult salmon migrations. The second mitigation measure proposed that hatchery program targets and monitoring should align with DFO genetic objectives for integrated-wild Chinook populations. It is recommended that DFO invests time and effort to work with the three community-based hatcheries in DU1 to standardize methods to adhere to the genetically-based targets for enhanced contributions to Canadian Pacific Chinook Salmon (DFO 2018a), improve or initiate escapement estimates, and improve overall data quality. Additionally, it is recommended that CWT mark recovery programs are developed to measure PNI, out-of-basin stray rates, marine distribution, and fishery exploitation, and smolt survival for this DU. These modifications are expected to improve the genetic integrity of the wild population and address significant knowledge gaps in the assessment of this DU for the future. The third proposed mitigation measure addresses the discharge of storm water concentrated by roads and impervious surfaces to reduce the amount of pollution that enters DU1 habitats. DU1 habitats are highly developed for urban, industrial and agricultural uses. Pollutants and contaminants enter DU1 waterways via surface runoff and storm drains, which cause harm to Chinook, their ecosystem and their habitat. Swales or grader berm gaps could be used to reduce the amount of direct runoff into DU1 tributaries and rivers.

For DU6, measures to assess and reduce the fishing exploitation rate to enable the population to increase are ranked as the top mitigation measure. Sufficient quantitative data do not exist to estimate the total or fishery-specific exploitation rates for DU6 ; however, Chinook Salmon from DU6 co-migrate with South Thompson Summer 0.3 Chinook, for which significant fishing mortality occurs. It is therefore inferred that fishing could have a substantial impact on DU6, which may be further exacerbated when Chinook stage in the Fraser River near the mouth of Maria Slough during periods of low flow, further exposing them to local fishing pressure. Increasing the sampling of catches for CWTs would facilitate exploitation rate measurement, while a reduction in fishing pressure during the DU6 adult migration and staging periods could positively impact this population. Participants ranked the control of invasive plants (e.g. Reed Canary Grass) as the second most important mitigation measure for DU6. Reed Canary Grass is currently overwhelming some locations along the Chinook spawning channel in Maria Slough and it has the imminent potential to physically impede migration and adversely affect riparian and aquatic ecosystem function. Reed Canary Grass is difficult to control due to its persistent rhizome system and ability to reproduce by both rhizomes and seeds; however, the entire root mass and rhizome system can be manually removed to help control its spread and reduce its abundance and extent. The introduction of additional flow in Maria Slough could potentially aid in Reed Canary Grass growth as well. The third mitigation measure aims to restore riparian habitat via multiple strategies, the need for which is partially attributed to Reed Canary Grass limiting native riparian plants. Water temperatures in Maria Slough can exceed 20°C during summer months, which could be offset by multiple degrees in pockets of cooler water with sufficient riparian cover (Justice et al. 2017).A suggested mitigation for this DU includes the potential of reconnecting Maria Slough to the Fraser River. While this action is likely to improve water quality for spawning and rearing Chinook Salmon, there are negative implications for the surrounding communities who live in the region with regards to flood control.

Effective implementation of water management actions, including timely *Water Sustainability Act* (Section 88) orders supported by critical environmental flow thresholds, is ranked as the top mitigation measure for DU13. Similarly, the second most important mitigation measure involves purchasing water licenses and leases to ensure sufficient stream flows for Chinook and stream ecological processes. There is significant water demand in the Salmon River, which has many individual agricultural water licenses, and in the Eagle River, which has many industrial and agricultural water licenses; water demand appears minimal from Scotch Creek and the Seymour River which each have fewer than five water licenses, although it is possible that a single water license could have a significant effect on water levels. Low flows are most serious in the Salmon River where they have prevented Chinook from ascending during their spawning migration and dry sections have been reported in the mainstem. Additionally, temperature extremes are pronounced during low flows, leading to thermal barriers, stress or mortality from disease and predators. Summer water temperatures in the Salmon River may reach mid to high 20s, are exacerbated by low water levels and have been known to cause fish kills. Critical flow thresholds for Chinook adults are unknown in the Salmon River and should therefore be identified and evaluated using improvements to the existing adult Chinook Salmon monitoring program and implementation of a CWT program to measure survival and productivity. The restoration of riparian habitat via multiple strategies is identified as the third most important mitigation measure, which is most relevant for the Salmon River watershed. Riparian restoration could be less impactful in other systems within DU13 because the glacial-fed Perry River, existing riparian habitat, and groundwater sources cool the Eagle River drainage, whereas Scotch Creek and Seymour River have relatively more effective riparian habitat, mossy areas, and many cedars to provide shade and buffer against warm temperatures.

The top three proposed mitigation strategies for DU15 relate to improvements to abiotic habitat conditions. Similar to DU13, effective implementation of water management actions is identified as the most important mitigation strategy for DU15. Spius Creek, Coldwater River, Nicola River, Deadman River, Bonaparte River, and Louis Creek are all drought-sensitive systems. Low flows are known to restrict passage and exacerbate warm water temperatures, which lead to thermal barriers, stress, disease and pre-spawn and juvenile mortality. There are many individual agricultural water licenses within DU15, with the highest proportion in the Nicola basin. In the Nicola River, effective water management is most pertinent in August when low flows have been demonstrated to impair adult and juvenile Chinook productivity (Warkentin 2020). There is additional evidence that decreasing river levels from activated irrigation pumps can cause fish stranding, sometimes with withdrawals from only one water license producing a significant effect (Richard Bailey, DFO, Kamloops, BC, pers. comm. 2021). However, the efficacy of restricting water withdrawals may differ between tributaries. Total shutoffs in the Coldwater River have been shown to only lead to minor gains in certain conditions and the benefits in the Nicola River are insufficient to achieve optimum flow conditions (Paul Mozin, Scw'exmx Tribal Council, Merritt, BC, pers. comm. 2022). Stabilizing channels and upland areas may also facilitate water management actions for fish passage and thermal barriers. Critical flow thresholds and temperature limits for Nicola Chinook are identified in Element 4; however, similar studies have not been conducted in other drought-sensitive systems within this DU due to limited data collected by the Chinook monitoring programs. Identifying and protecting cold water refugia sources on and near the spawning grounds is ranked as the second most important mitigation measure, as all streams in DU15 are temperature-sensitive. A thermal imaging study was conducted on 23km of the Nicola River between from the confluence of the Coldwater River to the confluence of Spius Creek, as well as a 1km segment immediately downstream of the Nicola dam (Willms and Whitworth 2016). Subsequent years of funding for this project have been secured to expand the thermal mapping dataset and include *in situ* monitoring of stream temperature and groundwater upwelling at identified thermal refugia. However, it is important to note that the magnitude of impact of the November 2021 floods may have altered flow thresholds and known thermal refugia. Stabilizing upland areas after fires and excessive clear-cutting is identified as the third most important mitigation measure. Wildfires and logging have significantly affected upland portions of the catchments within many areas of DU15, leading to compromised slope stability and increased sedimentation. For example, major flooding events caused 250 000 ± 90 000m^3 of sediment to enter Guichon Creek between 2016 and 2018 (Reid 2020). Finer-grained (small gravel, sand, and silt) sediment loads are problematic for Chinook because they adversely affect egg-to-fry survival and fill interstitial spaces between larger gravel and cobbles that juveniles use for thermal and predator refugia, thus reducing the amount of available habitat (Chapman 1988). Stabilizing channels using vegetation, especially around major point sources of sediments created by the November 2021 flood, may be particularly effective.

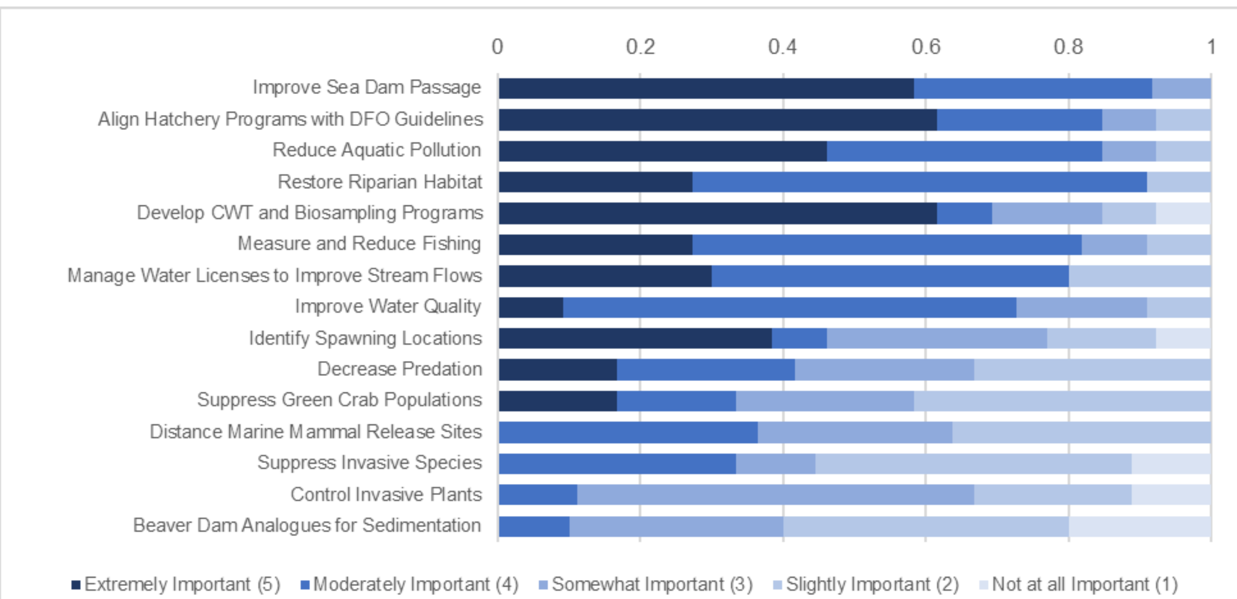

Figure 23. Proportion of mitigation survey responses for each measure, ordered by weighted averages (top=highest) for DU1.

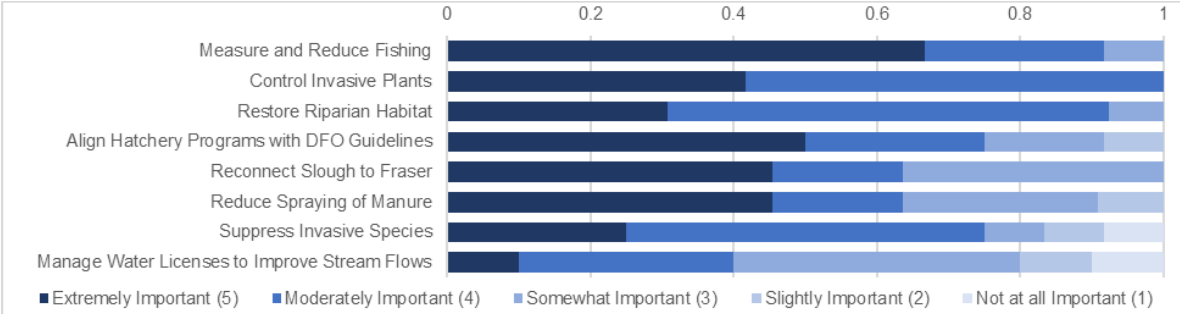

Figure 24. Proportion of mitigation survey responses for each measure, ordered by weighted averages (top=highest) for DU6.

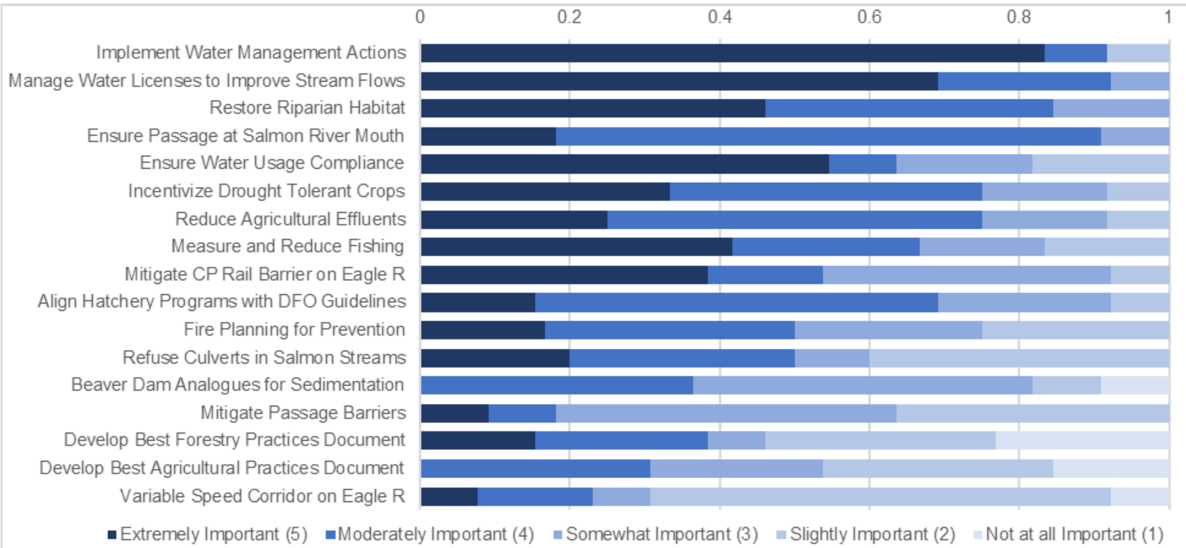

Figure 25. Proportion of mitigation survey responses for each measure, ordered by weighted averages (top=highest) for DU13.

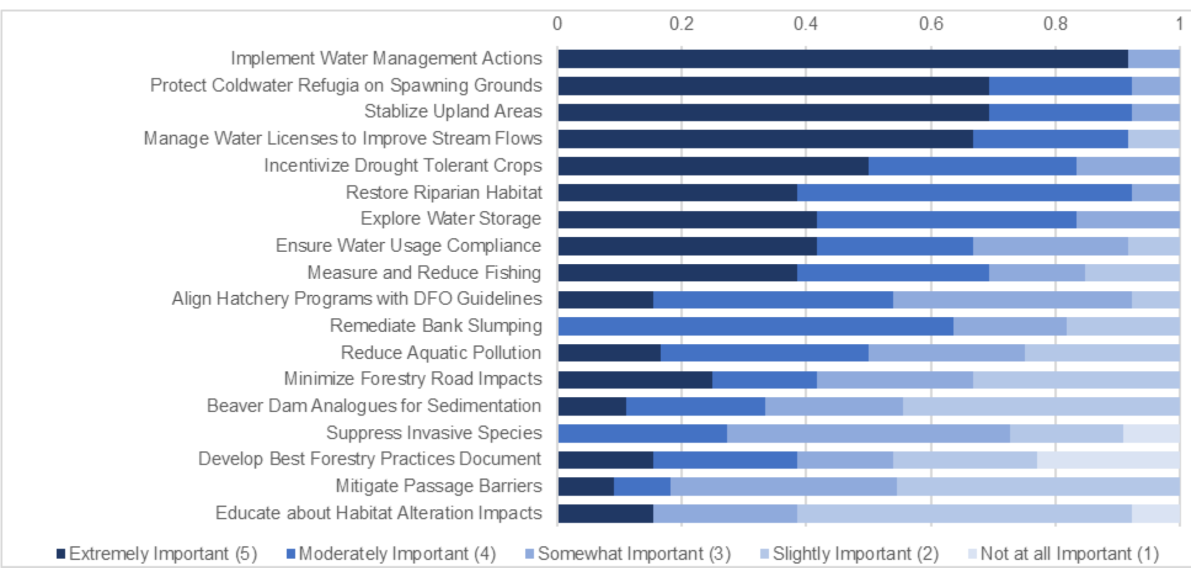

Figure 26. Proportion of mitigation survey responses for each measure, ordered by weighted averages (top=highest) for DU15.

5.2. ELEMENT 17: INVENTORY OF ACTIVITIES THAT COULD INCREASE PRODUCTIVITY OR SURVIVAL

Develop an inventory of activities that could increase the productivity or survivorship parameters.

In Element 16, an inventory of activities was provided that could mitigate the identified threats and limiting factors, most of which could potentially increase productivity or survival of SBCC. To avoid redundancy, they are not listed again here (see possible mitigation actions and Table 61 for a specific list of mitigation strategies). However, as noted in the previous sections, there is limited information on distribution and habitat use, the exact impact of threats and limiting factors, and increasing inter-annual variation in environmental conditions throughout the Chinook lifecycle, which hinders our ability to measure the impact mitigation activities may have on productivity or survival.

5.3. ELEMENT 18: ADVICE ON THE FEASIBILITY OF RESTORING LIMITING HABITAT

If current habitat supply is insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets.

As discussed in Element 8, there is currently insufficient data to state whether the supply of suitable SBCC habitat is currently limiting these 4 DUs from reaching their recovery targets. However, many of the mitigation activities outlined in Element 16 (see Table 61) may help restore habitat properties to greater qualities. Coker et al. (2010) identified a suite of activities to mitigate threats in aquatic environments that could increase habitat quality. The number of confounding ecological processes that may change habitat supply and demand through time greatly limits our ability to provide advice on the feasibility or the effectiveness of habitat restoration. Research is needed to begin prioritizing habitat restoration activities for SBCC. This has been identified as a major research need as noted in Appendix F; Research Needs.

5.4. ELEMENT 19: REDUCTIONS IN MORTALITY RATE EXPECTED BY MITIGATION MEASURES AND INCREASE IN PRODUCTIVITY OR SURVIVAL ASSOCIATED WITH MEASURES IN ELEMENT 17

Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in Element 16 and the increase in productivity or survivorship associated with each measure in Element 17.

Given the current state of information surrounding SBCC, we are unable to quantify reductions in mortality from the mitigation options discussed in Element 16, nor their increase in productivity or survival. The interaction between changes in habitat quality and quantity to changes in life-history parameters is a major knowledge gap for SBCC, and has been identified as a future research need (Appendix F). These interactions are likely system-specific and will require substantial resources and time to asses. Additionally, the success of mitigation activities would likely vary substantially for different types of projects and between individual projects of a similar nature. It may be possible in the future to estimate reductions in mortality and ranges of productivity changes for certain projects as more research is conducted on the efficacy of mitigation measures.

5.5. ELEMENT 20: PROJECTED EXPECTED POPULATION TRAJECTORY GIVEN MORTALITY RATES AND PRODUCTIVITIES ASSOCIATED WITH THE SPECIFIC MEASURES IDENTIFIED FOR EXPLORATION IN ELEMENT 19

Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.

Neither mortality rates nor productivities were identified in Element 19, as it is not currently possible to identity mitigation specific productivity or mortality parameters.

5.6. ELEMENT 21: RECOMMENDED PARAMETER VALUES FOR FUTURE ASSESSMENTS

Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process.

Current data are insufficient for population modelling and the development of recommended parameter values.

5.7. ELEMENT 22: ALLOWABLE HARM ASSESSMENT

Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery.

Allowable harm is: “Harm to the wildlife species that will not jeopardize its recovery or survival” (DFO 2014a). It is important to note that **survival** represents a stable or increasing state where a species is not facing imminent extirpation, and **recovery** is a return to a state in which the population and distribution are within the normal range of variability (DFO 2014a). Therefore, recovery is higher on the spectrum of population persistence than survival, and is more likely represented by the recovery target.

Quantitative forward projections are not reliable nor robust for the four DUs due to the uncertainty that stems from the quality of the relative escapement data and lack of reliable exploitation estimates. Therefore, the allowable harm assessment is based on the threats assessment from Element 8, recent trends in relative abundance (Element 2), and the possible future trajectory of these populations based on qualitative assessments. The results of the threats workshop indicated that all 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. Alleviating many of these threats may be difficult given the widespread nature of these threats, especially as many are exacerbated by climate change, posing a risk of extinction for these DUs within the next three generations.

There is considerable uncertainty about the future trajectory of these populations, but based on the threats assessment and the qualitative description in 4.2.6 Qualitative Assessments, these populations are at great risk. Based on this information, a precautionary approach is indicated unless sufficient increases in generational average abundances and trends in abundances are confirmed due to mitigation measures or changes in natural conditions. **Further harm may continue to jeopardize recovery. Therefore, to promote the survival and recovery of these DUs, it is recommended that all future and ongoing human-induced harm should be**

prevented so as not to jeopardize recovery. It is important to note that some activities in support of survival or recovery could result in harm but may have a net positive effect on the population and should be considered.

For DU 6, there is additional concern due to the limited area of the spawning habitat and a single, small population.

For DU 15, there is additional concern due to the increased threat risk from landscape level changes throughout the watershed due to the number, size and intensity of recent forest fires and floods.

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APPENDIX A. EARLY MARINE DISTRIBUTIONS OF SBCC

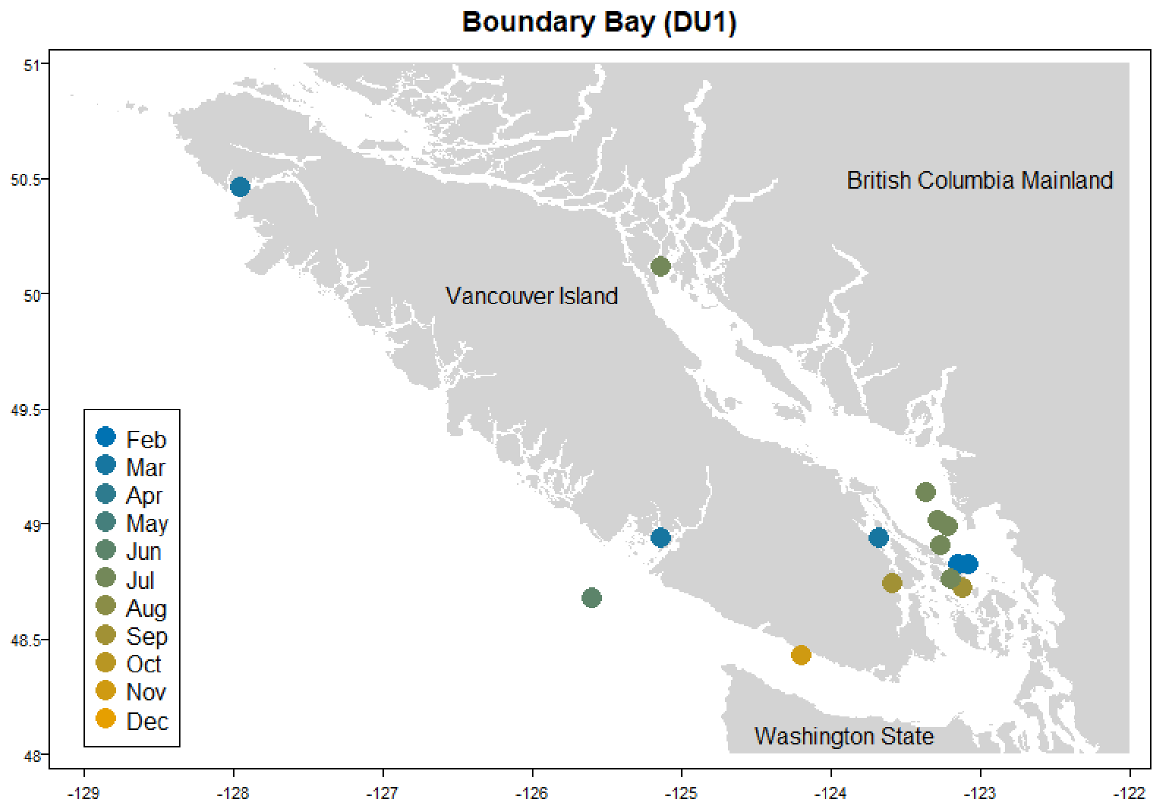

Figure 27. Map of British Columbia depicting detections of hatchery and wild post-smolt Chinook Salmon from DU1 by month during their first year at sea for years 2008-2018. Each circle indicates one encounter and colours indicate the month of the year. Credit to Bass, Arthur.

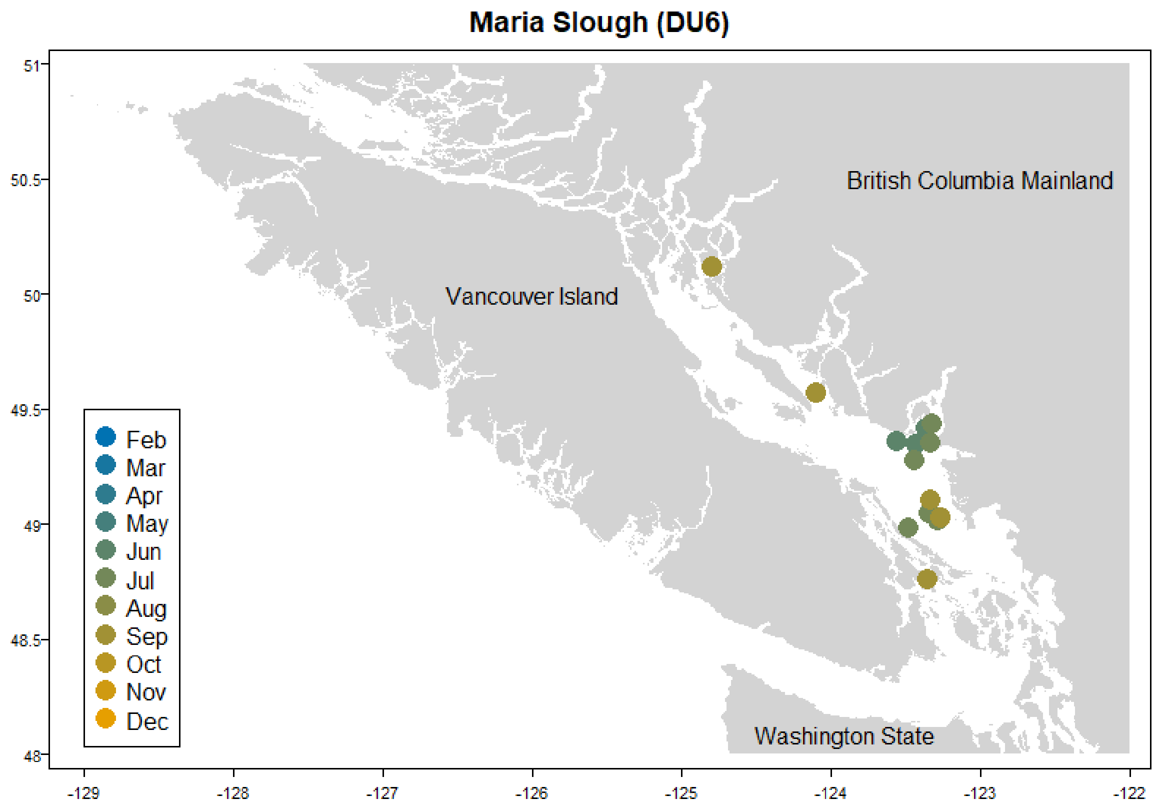

Figure 28. Map of British Columbia depicting detections of hatchery and wild post-smolt Chinook Salmon from DU6 by month during their first year at sea for years 2008-2018. Each circle indicates one encounter and colours indicate the month of the year. Credit to Bass, Arthur.

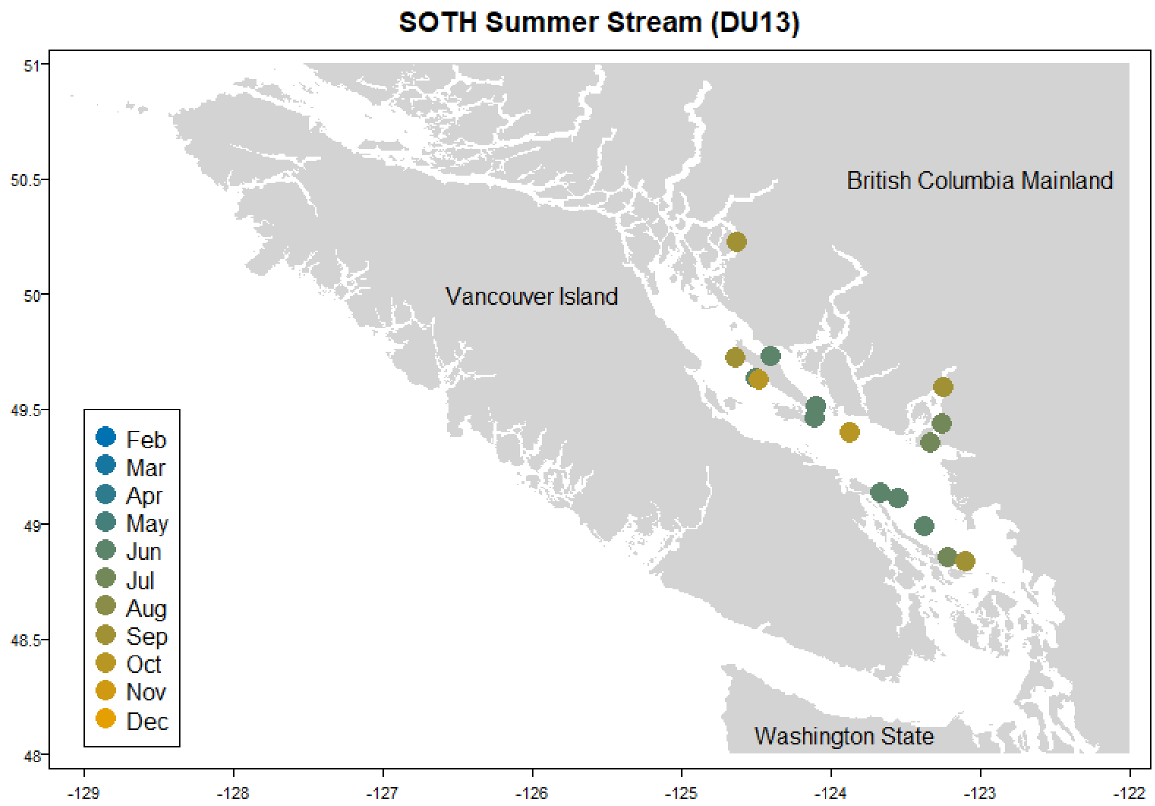

Figure 29. Map of British Columbia depicting detections of hatchery and wild post-smolt Chinook Salmon from DU13 by month during their first year at sea for years 2008-2018. Each circle indicates one encounter and colours indicate the month of the year. Credit to Bass, Arthur.

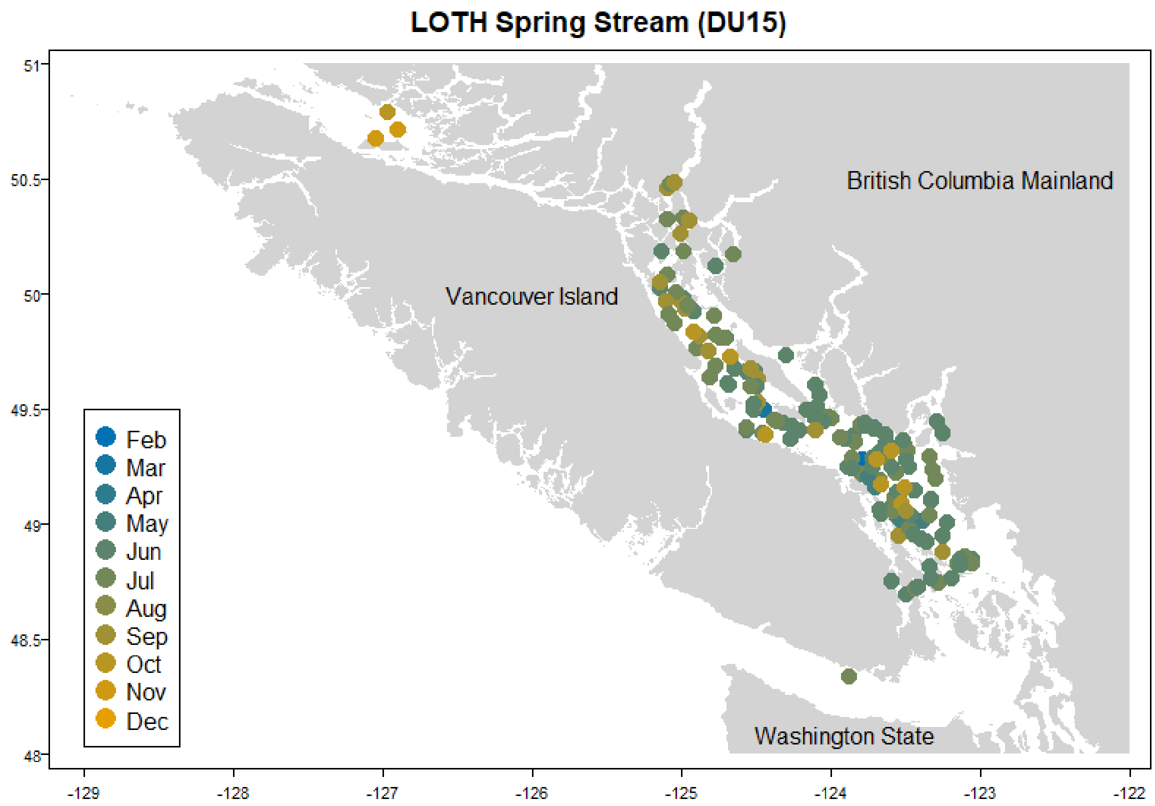

Figure 30. Map of British Columbia depicting detections of hatchery and wild post-smolt Chinook Salmon from DU15 by month during their first year at sea for years 2008-2018. Each circle indicates one encounter and colours indicate the month of the year. Credit to Bass, Arthur.

APPENDIX B. INFECTIVE AGENTS DETECTED IN CHINOOK JUVENILES

Table 62. Infective agents detected in >1% of juvenile Chinook Salmon within at least one season. Hotspot indicates agents detected at higher prevalence than by chance within the region where these enhanced DUs were caught during each of spring-summer and fall-winter. Remaining indices indicate evidence that a given agent carries pathogenic potential in Chinook Salmon, gleaned from laboratory challenge studies (established), pathological investigations within the Strategic Salmon Health Initiative (SSHI), CWT-driven smolt to adult survivorship models, and mass deviations (condition). Agents identified from models are ranked by intensity of color (dark red to light salmon), with numbers representing their rank order of association.

Agent Type	Agent Name	Spring Summer Hotspot	Fall/ Winter Hotspot	Established Pathogen	SSHI Pathology	Spring/ Summer Survival	Fall/ Winter Survival	Spring/ Summer Condition	Fall/ Winter Condition
Bacterium	Candidatus Branchiomonas cysticola	-	-	-	Y	-	-	-	3
	Candidatus Syngnamydia salmonis	Y	-	-	-	1	-	-	-
	Canditatus Piscichlamydia salmonis	-	Y	-	-	-	-	-	-
	Flavobacterium psychrophilum	Y	-	Y	-	-	5	-	-
	Piscirickettsia salmonis	-	Y	Y	-	-	-	-	-
	Renibacterium salmoninarum	-	-	-	-	-	-	6	-
	Rickettsia-like organism	-	Y	-	-	2	-	-	-
	Tenacibaculum maritimum	Y	Y	-	-	4	-	2	5
	Vibrio salmonicida	-	-	-	-	-	-	-	-
Parasite	Ceratomyxa shasta	-	Y	Y	Y	-	-	1	-
	Cryptobia salmositica	-	-	-	-	-	-	-	-
	Dermocystidium salmonis	-	-	-	-	-	-	-	-
	Facilispora margolisi	-	-	-	-	-	-	-	-
	Ichthyosphonus hoferi	Y	Y	-	Y	-	-	-	4
	Ichthyophthirius multifiliis	Y	Y	Y	-	3	4	-	6
	Kudoa thyrsites	-	-	-	-	-	-	-	-
	Loma salmonae	Y	-	Y	Y	-	-	-	1
	Myxobolus arcticus	Y	-	-	-	-	1	3	-
	Myxobolus insidiosus	-	-	-	-	-	-	-	-
	Nanophyetus salmincola	-	-	-	-	-	-	-	-
	Neoparamoeba perurans	-	-	-	-	-	-	-	-
	Paranucleospora theridion	Y	Y	-	Y	-	-	-	-

Agent Type	Agent Name	Spring Summer Hotspot	Fall/ Winter Hotspot	Established Pathogen	SSHI Pathology	Spring/ Summer Survival	Fall/ Winter Survival	Spring/ Summer Condition	Fall/ Winter Condition
	Parvicapsula kabatai	-	Y	-	-	-	-	-	-
	Parvicapsula minibicornis	-	Y	-	Y	-	-	-	-
	Parvicapsula pseudobranchicola	Y	-	-	-	-	2	-	-
	Sphaerothecum destruens	-	-	-	-	-	-	-	-
	Tetracapsuloides bryosalmonae	Y	Y	Y	-	-	-	-	-
Virus	Atlantic salmon calicivirus	-	-	-	-	-	-	-	-
	Cutthroat trout virus-2	-	-	-	-	-	-	-	-
	Erythrocytic necrosis virus	Y	-	-	-	-	-	4	-
	Infectious hematopoietic necrosis virus	-	-	-	-	-	-	-	-
	Pacific salmon nidovirus	-	-	-	-	5	-	-	-
	Pacific salmon parvovirus	-	-	-	-	-	-	-	-
	Piscine orthoreovirus-1	-	Y	-	Y	-	3	5	2
	Putative RNA virus-1	Y	Y	-	-	-	-	-	-
	Salmon pescarenavirus-1	Y	-	-	Y	6	-	-	-
	Salmon pescarenavirus-2	-	-	-	-	-	-	-	-
	Viral encephalopathy and retinopathy virus	-	-	-	-	-	-	-	-
	Viral hemorrhagic septicemia virus	Y	-	Y	-	-	-	-	-

.

APPENDIX C. SUMMARIES OF AVAILABLE DATA FOR EACH DU

C.1. SUMMARY OF DU1 (BOUNDARY BAY)

C.1.1. Estimation of Cohort Escapements by Age, Origin, and Site

There are insufficient data to estimate the cohort escapements by age and origin at the three populations in DU1 (BB).

The escapement has been estimated at the Little Campbell River since 1980, but it has not been estimated at the Serpentine or Nicomekl rivers based on the data in the Salmon Enhancement Program (SEP) Enhancement Planning and Assessment Dataset (EPAD) and NuSEDS (Table 63). At the Little Campbell River, escapements are counted near the river mouth at a fence that operates over the entire duration of the adult migration. The program produces an unbiased, total estimate of the escapement, since the fence is operated over the entire migration and it is not breached during high river discharge. At the Serpentine and Nicomekl rivers, there are temporary fences in the spawning areas used to collect brood stock for the hatchery programs, but there are no records in the EPAD database of fish counted through the fences, estimates of spawner abundance upstream or downstream of the fence, or the duration of fence operations. These numbers of brood stock collected at the fences are not reliable indicators of the escapement abundance.

No scale age samples have been collected from these populations.

C.1.2. Spawner Origin

There have been considerable numbers of hatchery fish released in the DU, but they have not been adequately marked to enable hatchery origin to be estimated. Hatchery origin fish originating from DU1 (BB) have been released either without a fin clip or with left or right ventral fin clips since brood year 1983, when hatchery productions began for this DU (Table 64). DU1 had unclipped (and unmarked) hatchery production from the Chilliwack and Harrison stocks transplanted and released for Brood Years 1990 to 2003 (Table 65). Chinook have been examined for the presence of adipose and ventral fin clips at the Little Campbell River, but none have been examined at the Serpentine or Nicomekl rivers based on the EPAD data (Table 66); thus, there is insufficient data to measure the spawner origin.

In addition to measuring the abundance of hatchery origin fish from DU1 (BB), there is also evidence that other DUs stray to DU1; however, insufficient fish have been sampled for CWTs and other types of marks to estimate their contributions to the escapement. Since 2012, adipose clipped hatchery adult Chinook have been regularly observed at the Little Campbell River fence (Table 63); however, AFC fish have only been released once in the DU (1,000 untagged fish released into the Nicomekl in 2004; Table 64). Accordingly, these recent fish are strays from another DU, however the adipose clipping rates vary substantially among hatchery programs in the Salish Sea, and the adipose clipped fish would need to be sampled for CWTs to measure hatchery origin, since many hatchery programs only tag and clip a fraction of the total production released. Since hatchery and escapement programs began in this DU, only one fish has been sampled for a CWT (in 1997) and it was identified as a Cowichan River fall Chinook. The stewardship program speculates that many of the strays originate from the nearby rivers in northern Puget Sound and those as far south as Seattle, but the stray fish could also be from multiple Salish Sea sources including production from the nearby Cowichan, Capilano, Chilliwack and Harrison hatcheries. A biological sampling program that collects the same types of data as the ERIS programs would greatly improve the knowledge for DU1 (BB) and the utility of the community stewardship program for stock assessment and hatchery management objectives that are consistent with those outlined by DFO (2018a).

C.1.3. Otolith Samples

The hatcheries in DU1 (BB) do not have the capacity to apply thermal otolith marks and no samples have been collected from the escapement or brood stock (Table 67).

C.1.4. Exploitation by Cohort, Age, Origin and Site

There is not an ERIS in DU1 (BB) and no fish have been released from this DU with CWTs in nearly four decades of hatchery activities to compare to other nearby DUs which have an ERIS. COSEWIC (2020) assumed that the Samish-Nooksack Fall CWT ERIS suitably represented the BB DU; however, Brown et al. (2015) did not make that assumption and simply indicated that there were not adequate data to estimate the exploitation for the stock. In the nearby Puget Sound, there have been many ERIS representation studies which identified differences among stocks for the larger basin and migration timing groups, and a comparative tagging study among fish tagged at BB and other nearby ERIS would be helpful to evaluate if there are suitable ERIS proxies for DU1.

Using information from the Samish ERIS involves some data treatments as there are differences in the terminal and freshwater fisheries for the stocks. The Samish is a large production hatchery with very intense fisheries in the terminal area and freshwater, whereas the terminal and freshwater FN and recreational fisheries in DU1 (BB) are believed to be very low intensity fisheries, but kept and released catches are not estimated. Accordingly, only the ocean fishery ER for the Samish was illustrated as those fish will likely experience the same fisheries as DU1 (BB), but there may be some differences in ocean distribution. All fish that were harvested in the freshwater fisheries and taken into the Samish hatchery were included as escapement to represent DU1 (BB), and no further adjustments were made for DU1 hatchery brood stock removals.

C.1.5. Temporal Variation in Non-Fishing-Related Survival Rates Amongst Populations

The three rivers in DU1 (BB) drain a mixture of urban and agricultural lands, and they are prone to acute aquatic pollution events that cause fish kills. These events often cause the mortality of thousands of juvenile salmon, and mortality of adult salmon has been identified in the urban streams in Puget Sound during storm water run-off events (Feist et al. 2011). These events lead to temporal variation in non-fishing related survival rates among the populations; however, there are not any monitoring programs that measure changes in survival and population productivity for these rivers. These events can be widespread and they are often reported in the media, as noted in 3.1.9.2 Industrial and Military Effluents.

C.2. SUMMARY OF DU6 (MARIA OCEAN SUMMER)

C.2.1. Estimation of Cohort Escapements by Age, Origin and Site

There are insufficient data to estimate the cohort escapements by age and origin at DU6 (Maria). The escapement has been estimated annually since 1975 with the exceptions of 1991-1995 and 2004 (Table 68). Escapements have been estimated using foot surveys and the area-under-the-curve method or fence counts in some years. The fence counts are considered unbiased total estimates of the escapement, but there is little documentation of the programs to know if there were any operational issues or uncertainties. The area under the curve (AUC) estimates are developed from regular stream walks conducted weekly over a period of 8-10 weeks, and survey life is an assumed value and there are no adjustments for observer efficiency. The AUC estimates are more uncertain than estimates from the mark-recapture (MR) method, and PIT tag MR methods was initiated with Brood Year 2020 to yield more accurate and precise estimates of the spawner abundance and to calibrate the historic AUC estimates for any estimation biases.

Scale samples have not been collected with sufficient regularity to estimate the escapement by age for each cohort (Table 69). Since 2002, scale samples have been collected in most years, with the number of samples per year ranging from 0 to 314.

C.2.2. Spawner Origin

Spawner origin cannot be estimated because 4 of the 11 cohorts that had hatchery enhancement were unmarked and their contributions could not be measured in the escapement (Table 70). All enhancement has used brood stock collected from Maria Slough and there have been no transplants of fish from other DUs into Maria Slough. Hatchery fish have been released intermittently since brood year 1989 (brood years 1989, 1996-2003, 2006 and 2019) and at relatively small numbers annually (~500-50,000), with about 20,000 fish marked with CWTs and AFC from Brood Year 1998 to 2002. Since 1998, 21 of the 23 years had fish examined for adipose fin clips, however 4 years had relatively few fish examined (i.e. <15; Table 71). A total of 304 adipose fin clipped fish have been sampled for CWTs and all the tags originated from Maria Slough, with no evidence found for strays from other DUs.

C.2.3. Otolith and PBT Marking

The hatcheries in the Maria Slough DU have the capacity to apply thermal otolith marks and collect PBT samples. No PBT samples have been identified yet because the PBT sampling was initiated with Brood Year 2019.

C.2.4. Exploitation by Cohort, Age, Origin and Site

The ERIS for the Maria Slough DU is the Lower Shuswap River, located about 500km upstream near Enderby, B.C., and those data must be adjusted to represent the differences in the freshwater fisheries that each population experiences. For example, the Lower Shuswap experiences fisheries that are upstream of Maria Slough in the Fraser, Thompson, and Lower Shuswap rivers, which are not expected to harvest any Maria Slough Chinook. Another difference in exploitation may be from the Maria Slough Chinook holding behavior and more time spent in the Fraser River near Maria Slough, since at least part of the population likely holds in the mainstem of the Fraser River until the fish migrate into the spawning area in late September and October. This behavior could lead to higher exploitation on Maria Slough Chinook in this fishery than the level measured for the Lower Shuswap ERIS. Currently, there are insufficient data to adjust the Lower Shuswap ERIS to represent the Maria Slough. Beginning with Brood Year 2019, a small-scale CWT project began at Maria Slough to enable the CWT data to be compared to the Lower Shuswap and to develop adjustment methods to represent Maria Slough, if needed. The CWT component of the multiyear study was delayed by one year because of the COVID19 pandemic.

C.2.5. Temporal Variation in Non-Fishing-Related Survival Rates Among Populations

DU6 (Maria) only has one population; thus, there are no issues with temporal variation in non-fishing related survival rates among populations.

C.3. SUMMARY OF DU13 (SOUTH THOMPSON STREAM SUMMER)

C.3.1. Estimation of Cohort Escapements by Age, Origin and Site

There are insufficient data to estimate the cohort escapements by age and origin at the four populations in DU13 (STh-1.3).

The escapement has been estimated annually at the Salmon and Eagle rivers since 1975, and it has been estimated intermittently at Scotch Creek (16 of 46 years) and Seymour (23 of 46 years) based on the data in the EPAD and NuSEDS (Table 72). At the Salmon River, escapements are counted near the river mouth at a fence that operates over the entire duration of the adult migration. The program produces a nearly unbiased, total estimate of the escapement, since the fence is operated over the entire migration and it is not breached during high river discharge. However, a few Chinook have been observed spawning downstream of the fence in some years.

Although escapements have been estimated regularly at the Eagle, the methods have varied among years and the quality, in terms of accuracy and precision, of the escapement estimates varies among years. These data have not been standardized to estimates using a single methodology. A fence was used to count and pass fish upstream during 1986-1990 and again in 1994; however, the fence was found to impede migrating Chinook and affect the distribution of spawners. Estimates were made for the amount of the escapement downstream of the fence using visual fish counts, but the Perry River tributary can have turbid water, from melting glaciers, and the accuracy of the Chinook counts in that area vary among years in an unmeasurable way. When the fence was found to have a negative influence on the distribution of Chinook spawners, the escapement program changed afterward to visual survey methods. The methodology relied on 1 to 4 surveys per year, which contributes to interannual variation in the quality of the escapement estimates, since the number of surveys affect the precision of the AUC escapement estimates (Hill 1997) and the accuracy of the peak count estimates, especially in years when only one survey was done.

Scale samples have not been collected with sufficient regularity to estimate the escapement by age for each cohort at Salmon (n=1), Scotch (n=2), Seymour (n=49) and Eagle (samples collected in 13 years; Table 73).

C.3.2. Spawner Origin

Spawner origin cannot be estimated because several of the cohorts that had hatchery enhancement were unmarked and that their contributions could not be measured in the escapement (Table 74). All enhancement has used brood stock collected from and released back into the same river (e.g. collected from the Eagle and then released into the Eagle) and there have been no transplants of fish from other DUs. At the Eagle River, hatchery production ranged from 100,000-660,000 fish from Brood Year 1983-1993 and all the brood years had CWT application to estimate the cohort escapements by origin. At the Salmon, hatchery production from 7,000-480,000 fish for Brood Years 1984-2019, but only 22 of 37 cohorts had CWT application to identify the hatchery origin fish in the escapement. At the Eagle River, Chinook were examined for adipose fin clips from 1986 to 1996 and each year since 2015, whereas at the Salmon River Chinook have been examined for adipose fin clips from since 1986 with a few exceptions (2007-08, 2015-16, and 2018-2020; Table 75). Among all of the fish sampled for CWTs at Eagle (1,105) and Salmon (388) rivers, only two fish were identified from outside the DU (1 fish from the Deadman, DU15, and 1 fish from the Middle Shuswap, South Thompson Summer Age 0.3 DU).

C.3.3. Otolith and PBT Samples

The Spius Creek hatchery which conducts the Salmon River program has the capacity to apply otolith marks and collect PBT data from the brood stock. The Eagle hatchery programed ended before the development of both otolith and PBT marking techniques.

C.3.4. Exploitation by Cohort, Age, Origin and Site

There is not an ERIS in DU13 (STh-1.3) currently and one is in development at the Chilko River, about 650km away in the Middle Fraser River. These populations experience different freshwater fisheries, and adjustments to the Chilko ERIS data would be needed to estimate the exploitation by cohort, age, origin and population site. Tagging and escapement CWT sampling have been conducted for the Salmon River for 22 cohorts; however, tag numbers were generally low, averaging about 50,000 annually, and the escapement sampling often collected too few CWT samples each year to adequately represent the cohorts (1 year with greater than 50 CWT samples collected). Future tagging studies may enable the Salmon CWT data to be compared to the Chilko ERIS data and to develop adjustment methods to represent DU13 (STh-1.3); however, larger tagging and escapement sampling programs are needed to collect sufficient data to represent all cohorts and ages in the escapement and fisheries.

C.3.5. Temporal Variation in Non-Fishing-Related Survival Rates Among Populations

There are several sources of variation in the survival among the populations in DU13 (STh-1.3). The Salmon River regularly experiences freshwater habitat conditions that are known to cause poor survival and smolt production, related to high water temperature and low river flow, which are not experienced at the Eagle, Scotch and Seymour populations. The variation in these habitat conditions among years can lead to temporal variation in non-fishing related survival rates among the populations and differences in stock productivity.

Based on the escapement data for the Salmon and Eagle rivers, these systems have fluctuated in their abundance with different patterns through time, as evidenced by their very low association ($r^2 = 0.22$). One large source contributing to the different patterns results from the enhancement programs and the differences between the populations. The Eagle program had a very high level of enhancement for about a decade, whereas the Salmon program has much smaller but also much more regular supplementation over two decades. As aforementioned, the absence of marking the hatchery production and sampling the escapements prevents reasonable estimation of the hatchery contributions to escapement at these sites. The limitations with the monitoring programs will need to be addressed in the future if there is an objective to monitor the productivity of the populations in the DU and to have the information that is needed to conduct the types of forward projections desired for Element 13.

C.4. SUMMARY OF DU15 (LOWER THOMPSON SPRING 1.2)

C.4.1. Estimation of Cohort Escapements by Age, Origin and Site

There are insufficient standardized data to estimate the cohort escapements by age and origin at the six populations in DU15 (LTh-1.2).

The escapements have been estimated annually at all the populations since 1975, with a few exceptions (i.e. Bonaparte in 1993 and Deadman in 2016 and 2017) based on the data in the EPAD and NuSEDS; however, only one has had the escapement estimates standardized to a common method for consistent data quality, in terms of accuracy and precision, among years (Table 76). Most of the years at the Bonaparte and Deadman rivers are based on counts at the

Bonaparte fishway or the Deadman resistivity counter (19 years) or fence counts (15 years), whereas most years at the Nicola were estimated using the MR method (post 1995) or Peak Count Escapement (PCE) estimates (1975-1994; Parken et al. 2003) that were calibrated to the MR estimates in years with paired methods. Nearly all of the estimates for the Spius and Coldwater populations were based on the PCE method, but a fence was operated on Spius Creek near the hatchery in some years. The Louis Creek escapements have been estimated using the MR method (tag application at a fence and then carcass sampling for tag recovery), stream walks and the PCE method.

Scale sample have been collected with sufficient regularity to estimate the escapement by age for each cohort at the Nicola since 1982, but not at any of the other populations as samples have only been collected occasionally (Table 78).

C.4.2. Spawner Origin

Spawner origin cannot be estimated because several of the cohorts that had hatchery enhancement were unmarked and that their contributions could not be measured in the escapement (Table 79). All enhancement has used brood stock collected from and released back into the same river (e.g. collected from the Nicola and then released into the Nicola) and there have been no transplants from other DUs. At the Bonaparte River, hatchery production ranged from 6,500-180,000 fish from Brood Year 1980-1992 and 2018, but only Brood Years 1987 and 1988, the years with the most hatchery fish produced, did not have any of the hatchery fish marked to identify their origin in escapements. At the Coldwater River, hatchery production ranged from 40,000-200,000 fish, and Brood Years 1987, 1996-97 and all years since Brood Year 2000 have not been marked with CWTs or fin clips. At the Deadman River, hatchery production ranged from 3,000-115,000 fish, and Brood Years 1988-1989, 1995-1996, and 1998-1999 were not marked with CWTs or fin clips. At the Nicola River, hatchery production ranged from 10,000-210,000 fish, and only Brood Year was not marked with CWTs or fin clips. At the Spius Creek, hatchery production has occurred each year since Brood Year 1986, ranging from 15,000-210,000 fish, and only Brood Years 1989 and 1992-1995 have been marked with CWTs or fin clips. There has been no hatchery production at Louis Creek.

The sampling of Chinook for fin clips and CWTs has not been conducted with sufficient regularity to measure the hatchery origin escapements for the populations in DU15 (LTh-1.2) (Table 80 – Numbers of Chinook examined for adipose fin clips and sampled for CWTs at populations in DU15 (LTh-1.2)). Escapements have been sampled for fin clips and CWTs at the Bonaparte (1983-1996), Coldwater (1982-2004, 2010-2015 and 2017), Nicola (1981-2021), and Spius (1987-2004, 2010-2015 and 2017). Among 10,489 fish that had CWT samples collected, 6 Chinook have been identified as strays from other DUs (i.e. Middle Fraser Spring 1.3, North Thompson Summer 1.3, Shuswap River Summer 0.3, South Thompson Summer 1.3, and one from the Capilano River (ECVI Fall DU) and another from the Upper Bulkley DU).

C.4.3. Otolith and PBT Samples

The Spius Creek hatchery recently has the capacity to apply otolith marks and collect PBT data from the brood stock. Samples have been collected from the brood stock collected at Spius Creek and Coldwater River.

C.4.4. Exploitation by Cohort, Age, Origin and Site

The ERIS for DU15 (LTh-1.2) is the Nicola River, and those data must be adjusted to represent any differences in the freshwater fisheries that each population experiences. For example, the Bonaparte River has had Chinook harvested directly from the fishway and there are regularly fisheries at the confluence with the Thompson River. There are also fisheries in the Deadman River and near its confluence with the Thompson River.

In addition to the variation in the terminal freshwater fishery impacts, harvesting practices can differ among the terminal freshwater fisheries that contribute to variation in the productivity among populations. In this DU, the fisheries at the Bonaparte fishway have differentially harvested males relative to females in some years, and this will cause the productivity, in terms of recruits per spawner, to be higher than if males and females had equivalent harvest rates. This situation adds variability to the productivity time series, and the years with higher proportions of females in the escapement will be more productive relative to others at the same spawner abundance. This fishery management tactic may cause the Bonaparte to appear to be relatively more productive than the other populations.

C.4.5. Temporal Variation in Non-Fishing-Related Survival Rates Among Populations

There are several sources of variation in the survival among the populations in DU15 (LTh-1.2). Some of the populations regularly experience freshwater habitat conditions that are known to cause poor survival and smolt production related to high water temperature and low river flow, which are not experienced at Louis Creek to the same extent as the other populations to our knowledge. The variation in these habitat conditions among years can lead to temporal variation in non-fishing related survival rates among the populations and differences in stock productivity. Forest fires have happened in some of the watersheds to different extents, and those in the Bonaparte during 2017 and 2018 led to large landslides and high sediment input to the rivers which likely has reduced egg survival since then. In 2021, forest fires occurred in the Deadman and Nicola watersheds and some landslide since. In 2018, the floods in two of the tributaries of the Nicola River, Clapperton and Guichon creeks contributed to considerable sediment and changes in the river channel that may have had an adverse effect on egg and juvenile survival relative to the other populations that did not have the same experience with altered habitats.

An example of temporal variation in non-fishing related survival rates among populations happened when the Bonaparte fishway degraded from 2015 to 2018, and very few (5) Chinook passed through the fishway in 2018. Escapements are often in the thousands at the Bonaparte River, with the largest escapement (12,659) in 2014 which, if one just looks at the escapement data, produced an escapement of just 5 Chinook assuming all the fish matured 4 years later in 2018. When one considers the escapement to escapement rates for 2014 to 2018 among the other populations in the DU, their survival rates appears to be about 200 to 400 times greater than the Bonaparte when the mortality related to the fishway failure is unaccounted for.

Another example of temporal variation in non-fishing related survival rates among populations arises from specific water management actions specific to the Nicola River. The Nicola River discharge is partially regulated by the Nicola Lake and Mamit Lake dams, originally constructed for irrigation. Recently, the Nicola Dam operations reduce the river level during the Chinook spawning period in order to concentrate the spawners and redds in the main channel of the river. This action is intended to increase the survival of the eggs during the winter, but its effectiveness has not been evaluated. The Mamit Lake Dam releases additional water during August to facilitate the migration of Chinook and to increase the survival of adults and juveniles during that time when water levels can be low and temperatures high. If these actions are successful then survival will be increased for Nicola, but it will be less influenced by natural environmental variation than the other populations (i.e. due the regulated and manipulated river discharge).

Table 63. DU1 (BB) escapement by river. ND identifies No Data collected and recorded in an accessible database.

Run Year	Little Campbell River						Nicomekl River						Serpentine River					
	Unclipped		Ventral Fin Clipped		Adipose Fin Clipped		Unclipped		Ventral Fin Clipped		Adipose Fin Clipped		Unclipped		Ventral Fin Clipped		Adipose Fin Clipped	
	Adults	*Jacks*	*Adults*	*Jacks*	*Adults*	*Jacks*	*Adults*	*Jacks*	*Adults*	*Jacks*	*Adults*	*Jacks*	*Adults*	*Jacks*	*Adults*	*Jacks*	*Adults*	*Jacks*
1980	18	9	0	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1981	83	30	0	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1982	75	6	0	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1983	57	36	0	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1984	155	33	0	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1985	150	44	0	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1986	36	3	2	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1987	4	1	2	2	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1988	37	17	6	72	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1989	0	0	0	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1990	58	28	53	90	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1991	88	14	204	20	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1992	19	50	35	54	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1993	34	9	35	5	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1994	34	20	18	51	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1995	103	12	94	22	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1996	123	30	78	38	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1997	195	19	58	30	1	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1998	173	12	36	9	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1999	73	12	46	17	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2000	186	40	131	28	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2001	150	13	52	18	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2002	76	27	44	108	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2003	115	24	149	68	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2004	60	14	121	22	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2005	45	41	60	59	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2006	46	49	106	15	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2007	112	34	150	56	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2008	31	3	70	5	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2009	65	86	47	71	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2010	317	156	281	73	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2011	266	122	68	36	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2012	231	41	54	8	15	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2013	202	70	47	6	97	152	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2014	106	47	6	8	152	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2015	113	10	24	3	35	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2016	157	93	15	16	17	6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2017	101	41	15	1	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2018	76	71	0	0	9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2019	413	195	0	0	43	30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2020	432	97	0	0	95	32	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 64. Numbers of hatchery fish released into DU1 (BB) by fin mark, release location name, and brood year (data from Regional Mark Information System(RMIS) database). AFC indicates Adipose Fin Clipped.

Brood Year	L Campbell					L Camp + Nic	Nicomekl			Murray (Nicomekl)	Anderson (Nicomekl)	Serpentine	Total
	Unclipped	Left Ventral	Right Ventral	Right Ventral and Right Maxillary	AFC	Unclipped	Unclipped	Left Ventral	Right Ventral	Unclipped	Unclipped	Unclipped	
1983	0	10441	0	0	0	0	0	0	0	0	0	0	10441
1984	0	0	0	0	0	0	0	10000	0	0	0	0	10000
1985	0	0	4647	0	0	0	0	0	4470	0	0	0	9117
1986	0	0	14675	470	0	0	0	3712	0	0	0	0	18857
1988	0	34677	0	0	0	0	0	0	0	0	0	5000	39677
1989	30077	0	0	0	0	0	0	0	0	0	4500	27552	62129
1990	2431	0	37880	0	0	0	0	0	0	0	10000	28368	78679
1991	0	8128	0	0	0	0	7000	0	0	0	0	21475	36603
1992	0	0	45000	0	0	0	8500	0	0	0	0	39000	92500
1993	0	15541	0	0	0	0	8000	0	0	0	0	14601	38142
1994	0	0	26898	0	0	0	50000	0	0	0	0	45000	121898
1995	0	34098	0	0	0	0	33000	0	0	0	0	45000	112098
1996	0	0	39497	0	0	0	38000	0	0	0	0	23000	100497
1997	0	42815	0	0	0	0	51000	0	0	7000	7000	70000	177815
1998	0	0	39089	0	0	0	56000	0	0	0	0	75000	170089
1999	0	22393	0	0	0	0	62000	0	0	0	0	80000	164393
2000	0	0	56000	0	0	0	21000	0	0	0	0	90000	167000
2001	0	50000	0	0	0	0	60000	0	0	0	0	80000	190000
2002	0	0	45000	0	0	0	47000	0	0	0	0	100000	192000
2003	0	34000	0	0	0	0	50000	0	0	0	0	70000	154000
2004	20000	0	0	0	1016	0	52000	0	0	0	0	100000	173016
2005	0	0	33800	0	0	0	42000	0	0	0	0	50000	125800
2006	50000	0	0	0	0	0	40000	0	0	0	0	0	90000
2007	33000	0	0	0	0	0	25000	0	0	0	0	95000	153000
2008	0	53884	0	0	0	0	51006	0	0	0	0	80000	184890
2009	0	0	48776	0	0	0	36500	0	0	13700	0	100000	198976
2010	0	55538	0	0	0	0	22503	0	0	0	0	109409	187450
2011	0	0	26975	0	0	0	38717	0	0	0	0	181110	246802
2012	0	26975	0	0	0	0	43330	0	0	0	0	86274	156579
2013	0	0	2755	0	0	0	16842	0	0	0	0	86700	106297
2014	0	32518	0	0	0	0	49435	0	0	0	0	54715	136668
2015	15014	0	0	0	0	0	43956	0	0	0	0	110950	169920
2016	0	0	0	0	0	20761	53362	0	0	0	0	102113	176236
2017	46287	0	0	0	0	0	63934	0	0	0	0	116000	226221
2018	19544	0	0	0	0	0	37579	0	0	0	0	96242	153365
2019	48411	0	0	0	0	0	42093	0	0	0	0	97869	188373
Total	264764	421008	420992	470	1016	20761	1149757	13712	4470	20700	21500	2280378	4619528

Table 65. Numbers of fish released by stock origin and life stage to a release location in the DU1 (BB) by Brood Year (data from RMIS).

Stock Origin	Brood Year	L Campbell			L Cam+ Nic	Nicomekl R		Murray	Anderson	Serpentine	Total
		Fry	Subyearling Smolt	Yearling Smolt	Subyearling Smolt	Fry	Subyearling Smolt	Subyearling Smolt	Subyearling Smolt	Subyearling Smolt	
Chilliwack +Harrison	2000	0	0	0	0	21000	0	0	0	0	21000
Chilliwack R	1990	0	0	0	0	0	0	0	10000	0	10000
	1991	0	0	0	0	0	7000	0	0	0	7000
	1992	0	0	0	0	0	8500	0	0	0	8500
	1993	0	0	0	0	0	8000	0	0	0	8000
	1994	0	0	0	0	0	50000	0	0	0	50000
	1995	0	0	0	0	0	33000	0	0	0	33000
	1996	0	0	0	0	0	38000	0	0	0	38000
	1997	0	0	0	0	0	51000	7000	7000	0	65000
	1998	0	0	0	0	0	56000	0	0	0	56000
	1999	0	0	0	0	54000	8000	0	0	0	62000
	2001	0	0	0	0	0	60000	0	0	0	60000
	2002	0	0	0	0	0	47000	0	0	0	47000
	2003	0	0	0	0	0	50000	0	0	0	50000
L Camp +Serp	1990	0	0	0	0	0	0	0	0	28368	28368
	1991	0	0	0	0	0	0	0	0	21475	21475
	1993	0	0	0	0	0	0	0	0	14601	14601
	1994	0	0	0	0	0	0	0	0	45000	45000
L Campbell R	1983	0	10441	0	0	0	0	0	0	0	10441
	1984	0	0	0	0	10000	0	0	0	0	10000
	1985	0	4647	0	0	0	4470	0	0	0	9117
	1986	0	14675	470	0	0	3712	0	0	0	18857
	1988	0	34677	0	0	0	0	0	0	5000	39677
	1989	0	30077	0	0	0	0	0	4500	27552	62129
	1990	2431	37880	0	0	0	0	0	0	0	40311
	1991	0	8128	0	0	0	0	0	0	0	8128
	1992	0	45000	0	0	0	0	0	0	0	45000
	1993	0	15541	0	0	0	0	0	0	0	15541
	1994	0	26898	0	0	0	0	0	0	0	26898
	1995	0	34098	0	0	0	0	0	0	0	34098
	1996	0	39497	0	0	0	0	0	0	0	39497
	1997	0	42815	0	0	0	0	0	0	0	42815
	1998	0	39089	0	0	0	0	0	0	0	39089
	1999	0	22393	0	0	0	0	0	0	0	22393
	2000	0	56000	0	0	0	0	0	0	0	56000
	2001	0	50000	0	0	0	0	0	0	0	50000
	2002	0	45000	0	0	0	0	0	0	0	45000
	2003	0	34000	0	0	0	0	0	0	0	34000
	2004	0	21016	0	0	0	0	0	0	0	21016
	2005	0	33800	0	0	0	0	0	0	0	33800
	2006	0	50000	0	0	0	0	0	0	0	50000
	2007	0	33000	0	0	0	0	0	0	0	33000
	2008	0	53884	0	0	0	0	0	0	0	53884
	2009	0	48776	0	0	0	0	0	0	0	48776
	2010	0	55538	0	0	0	0	0	0	0	55538
	2011	0	26975	0	0	0	0	0	0	0	26975
	2012	0	26975	0	0	0	0	0	0	0	26975

Stock Origin	Brood Year	L Campbell			L Cam+ Nic	Nicomekl R		Murray	Anderson	Serpentine	Total
		Fry	Subyearling Smolt	Yearling Smolt	Subyearling Smolt	Fry	Subyearling Smolt	Subyearling Smolt	Subyearling Smolt	Subyearling Smolt	
	2013	0	2755	0	0	0	0	0	0	0	2755
	2014	0	32518	0	0	0	0	0	0	0	32518
	2015	0	15014	0	0	0	0	0	0	0	15014
	2016	0	0	0	20761	0	0	0	0	0	20761
	2017	0	46287	0	0	0	0	0	0	0	46287
	2018	0	19544	0	0	0	0	0	0	0	19544
	2019	0	48411	0	0	0	0	0	0	0	48411
Nicomekl R	2009	0	0	0	0	0	10000	0	0	0	10000
	2010	0	0	0	0	0	22503	0	0	0	22503
	2011	0	0	0	0	0	38717	0	0	0	38717
	2012	0	0	0	0	0	43330	0	0	0	43330
	2016	0	0	0	0	0	5100	0	0	0	5100
	2017	0	0	0	0	0	12799	0	0	0	12799
	2018	0	0	0	0	0	13935	0	0	0	13935
	2019	0	0	0	0	0	42093	0	0	0	42093
Serpentine R	1992	0	0	0	0	0	0	0	0	39000	39000
	1995	0	0	0	0	0	0	0	0	45000	45000
	1996	0	0	0	0	0	0	0	0	23000	23000
	1997	0	0	0	0	0	0	0	0	70000	70000
	1998	0	0	0	0	0	0	0	0	75000	75000
	1999	0	0	0	0	0	0	0	0	80000	80000
	2000	0	0	0	0	0	0	0	0	90000	90000
	2001	0	0	0	0	0	0	0	0	80000	80000
	2002	0	0	0	0	0	0	0	0	100000	100000
	2003	0	0	0	0	0	0	0	0	70000	70000
	2004	0	0	0	0	0	52000	0	0	100000	152000
	2005	0	0	0	0	0	42000	0	0	50000	92000
	2006	0	0	0	0	0	40000	0	0	0	40000
	2007	0	0	0	0	0	25000	0	0	95000	120000
	2008	0	0	0	0	0	51006	0	0	80000	131006
	2009	0	0	0	0	0	26500	13700	0	100000	140200
	2010	0	0	0	0	0	0	0	0	109409	109409
	2011	0	0	0	0	0	0	0	0	181110	181110
	2012	0	0	0	0	0	0	0	0	86274	86274
	2013	0	0	0	0	0	16842	0	0	86700	103542
	2014	0	0	0	0	0	49435	0	0	54715	104150
	2015	0	0	0	0	0	43956	0	0	110950	154906
	2016	0	0	0	0	0	48262	0	0	102113	150375
	2017	0	0	0	0	0	51135	0	0	116000	167135
	2018	0	0	0	0	0	23644	0	0	96242	119886
	2019	0	0	0	0	0	0	0	0	97869	97869
Total		2431	1105349	470	20761	85000	1082939	20700	21500	2280378	4619528

Table 66. Numbers of Chinook examined for adipose fin clips and sampled for CWTs.

Run Year	L Campbell R		Nicomekl R		Serpentine R	
	Examined	Sampled	Examined	Sampled	Examined	Sampled
1980	27	0	0	0	0	0
1981	113	0	0	0	0	0
1982	81	0	0	0	0	0
1983	93	0	0	0	0	0
1984	188	0	0	0	0	0
1985	194	0	0	0	0	0
1986	43	0	0	0	0	0
1987	9	0	0	0	0	0
1988	132	0	0	0	0	0
1989	0	0	0	0	0	0
1990	229	0	0	0	0	0
1991	326	0	0	0	0	0
1992	158	0	0	0	0	0
1993	83	0	0	0	0	0
1994	123	0	0	0	0	0
1995	231	0	0	0	0	0
1996	295	0	0	0	0	0
1997	304	1	0	0	0	0
1998	230	0	0	0	0	0
1999	148	0	0	0	0	0
2000	385	0	0	0	0	0
2001	233	0	0	0	0	0
2002	255	0	0	0	0	0
2003	356	0	0	0	0	0
2004	217	0	0	0	0	0
2005	205	0	0	0	0	0
2006	216	0	0	0	0	0
2007	352	0	0	0	0	0
2008	109	0	0	0	0	0
2009	269	0	0	0	0	0
2010	827	0	0	0	0	0
2011	492	0	0	0	0	0
2012	349	0	0	0	0	0
2013	574	0	0	0	0	0
2014	324	0	0	0	0	0
2015	189	0	0	0	0	0
2016	304	0	0	0	0	0
2017	168	0	0	0	0	0
2018	157	0	0	0	0	0
2019	TBD	0	0	0	0	0
2020	TBD	0	0	0	0	0
Total	8988	1	0	0	0	0

TBD=To Be Determined as data have not been entered yet.

Table 67. Numbers of Chinook used for Brood Stock by return site in the DU1 (BB).

Run Year	L Campbell R	Nicomekl R	Serpentine R
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	No Data Recorded	0	0
1984	No Data Recorded	0	0
1985	No Data Recorded	0	0
1986	No Data Recorded	0	0
1987	No Data Recorded	0	0
1988	No Data Recorded	0	0
1989	No Data Recorded	0	0
1990	No Data Recorded	0	0
1991	No Data Recorded	0	0
1992	No Data Recorded	0	No Data Recorded
1993	No Data Recorded	0	No Data Recorded
1994	No Data Recorded	0	No Data Recorded
1995	No Data Recorded	0	No Data Recorded
1996	26	0	No Data Recorded
1997	33	0	No Data Recorded
1998	No Data Recorded	0	No Data Recorded
1999	No Data Recorded	0	No Data Recorded
2000	No Data Recorded	0	No Data Recorded
2001	No Data Recorded	0	No Data Recorded
2002	No Data Recorded	0	No Data Recorded
2003	No Data Recorded	0	No Data Recorded
2004	No Data Recorded	0	No Data Recorded
2005	No Data Recorded	0	No Data Recorded
2006	No Data Recorded	0	No Data Recorded
2007	No Data Recorded	0	No Data Recorded
2008	No Data Recorded	0	No Data Recorded
2009	No Data Recorded	No Data Recorded	No Data Recorded
2010	No Data Recorded	No Data Recorded	No Data Recorded
2011	No Data Recorded	No Data Recorded	No Data Recorded
2012	19	15	85
2013	20	No Data Recorded	No Data Recorded
2014	20	No Data Recorded	33
2015	20	No Data Recorded	162
2016	56	7	130
2017	40	No Data Recorded	80
2018	18	12	88
2019	36	34	58
2020	45	36	60
Total	333	104	696

Table 68. Numbers of spawners and brood stock removals by run year for the DU6 (Maria)

Run Year	Spawner	Brood Stock Removals
1975	75	0
1976	25	0
1977	200	0
1978	150	0
1979	75	0
1980	100	0
1981	20	0
1982	50	0
1983	50	0
1984	30	0
1985	200	0
1986	110	0
1987	4	0
1988	67	0
1989	50	0
1990	25	0
1991	Not Surveyed	0
1992	Not Surveyed	0
1993	Not Surveyed	0
1994	Not Surveyed	0
1995	Not Surveyed	0
1996	100	0
1997	100	0
1998	150	26
1999	198	22
2000	266	18
2001	400	24
2002	865	64
2003	729	53
2004	Not Surveyed	46
2005	325	101
2006	269	58
2007	654	65
2008	628	60
2009	594	53
2010	617	0
2011	1509	0
2012	328	0
2013	1043	0
2014	346	0
2015	1238	0
2016	105	0
2017	71	0
2018	0	0
2019	302	48
2020	26	22

Table 69. Number of scale samples with readable ages from the DU6 (Maria).

Run Year	Maria Slough
1975	0
1976	0
1977	0
1978	0
1979	0
1980	0
1981	0
1982	0
1983	0
1984	0
1985	0
1986	0
1987	0
1988	0
1989	0
1990	0
1991	0
1992	0
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0
2001	0
2002	232
2003	317
2004	0
2005	40
2006	108
2007	29
2008	134
2009	51
2010	0
2011	314
2012	49
2013	47
2014	0
2015	108
2016	6
2017	0
2018	4
2019	0
2020	0
Total	1439

Table 70. Numbers of hatchery Chinook released by brood year and fin clip for the Maria Slough DU.

Brood Year	Unclipped	Adipose Fin Clipped
1989	492	0
1996	10342	0
1997	687	0
1998	0	22233
1999	0	31814
2000	0	27747
2001	0	40238
2002	0	20179
2003	20276	0
2016	36507	0
2019	49919	0
Total	118223	142211

Table 71. Numbers of fish examined for adipose fin clips and sampled for CWTs for DU6 (Maria).

Run Year	Maria Slough	
	Examined	Sampled
1980	0	0
1981	0	0
1982	0	0
1983	0	0
1984	0	0
1985	0	0
1986	0	0
1987	0	0
1988	0	0
1989	0	0
1990	0	0
1991	0	0
1992	0	0
1993	0	0
1994	0	0
1995	0	0
1996	0	0
1997	0	0
1998	38	0
1999	55	0
2000	193	7
2001	178	61
2002	374 [A]	138
2003	145[A]	98
2004	0	0
2005	62[B]	0
2006	58 [A]	2
2007	66 [A]	0
2008	170 [B]	1
2009	53 [B]	0
2010	134 [B]	0
2011	374 [B]	0
2012	122 [B]	0
2013	113 [B]	0
2014	54 [B]	0
2015	227 [B]	0
2016	8 [B]	0
2017	0	0
2018	4 [B]	0
2019	49 [A]	0
2020	1 [B]	0
Total	2,478	307

[A]Stock assessment data base identifies different number of Chinook examined for fin clips in 2002 (308), 2003 (328), 2006 (117), 2007 (73) and 2019 (12).

[B]Source is from stock assessment database.

Table 72. Spawner abundance and hatchery brood stock removals for populations in DU13 (STh-1.3).

Run Year	Spawner Abundance				Hatchery Brood Stock Removal			
	Eagle R	Salmon R (ST)	Scotch Cr	Seymour R	Eagle R	Salmon R (ST)	Scotch Cr	Seymour R
1975	300	200	Not surveyed	Not surveyed	0	0	0	0
1976	250	150	Not surveyed	Not surveyed	0	0	0	0
1977	756	300	Not surveyed	25	0	0	0	0
1978	400	350	Not surveyed	0	0	0	0	0
1979	300	300	Not surveyed	10	0	0	0	0
1980	250	360	Not surveyed	Not surveyed	0	0	0	0
1981	250	300	0	0	0	0	0	0
1982	400	700	0	20	0	0	0	0
1983	250	300	0	0	0	0	0	0
1984	775	850	Not surveyed	15	0	0	0	0
1985	1250	1670	Not surveyed	Not surveyed	0	0	0	0
1986	1000	779	Not surveyed	Not surveyed	304	102	0	0
1987	840	475	Not surveyed	Not surveyed	350	166	0	0
1988	1000	1055	Not surveyed	Not surveyed	284	197	0	0
1989	821	1431	Not surveyed	Not surveyed	192	182	0	0
1990	1200	821	Not surveyed	Not surveyed	277	234	0	0
1991	835	479	Not surveyed	50	72	164	0	0
1992	1271	263	Not surveyed	Not surveyed	210	37	0	0
1993	1100	1949	Not surveyed	3	92	106	0	0
1994	1200	1261	Not surveyed	Not surveyed	0	0	0	0
1995	700	541	Not surveyed	Not surveyed	0	133	0	0
1996	780	554	Not surveyed	Not surveyed	0	105	0	0
1997	915	428	Not surveyed	Not surveyed	0	108	0	0
1998	Not surveyed	221	Not surveyed	Not surveyed	0	63	0	0
1999	624	248	Not surveyed	Not surveyed	0	71	0	0
2000	1085	356	Not surveyed	Not surveyed	0	70	0	0
2001	1397	1224	Not surveyed	Not surveyed	0	60	0	0
2002	1458	900	Not surveyed	Not surveyed	0	48	0	0
2003	1583	89	Not surveyed	146	0	47	0	0
2004	867	327	Not surveyed	Not surveyed	0	56	0	0
2005	427	354	Not surveyed	Not surveyed	0	60	0	0
2006	521	554	Not surveyed	Not surveyed	0	65	0	0
2007	334	173	Not surveyed	Not surveyed	0	75	0	0
2008	655	484	6	23	0	32	0	0
2009	574	246	Not surveyed	14	0	70	0	0
2010	1711	589	23	56	0	65	0	0
2011	426	112	5	23	0	51	0	0
2012	426	283	0	17	0	43	0	0
2013	885	633	0	31	0	45	0	0
2014	828	794	2	23	0	43	0	0
2015	857	131	0	51	0	49	0	0
2016	268	78	0	9	0	6	0	0
2017	909	170	0	26	0	36	0	0
2018	688	130	0	62	0	42	0	0
2019	772	372	2	35	0	49	0	0
2020	711	346	Not surveyed	12	0	40	0	0

Table 73. Number of readable scale samples collected at sites in DU13 (STh-1.3).

Run Year	Eagle R	Salmon R (ST)	Scotch Cr	Seymour R
1975	0	0	0	0
1976	0	0	0	0
1977	0	0	0	0
1978	5	0	0	0
1979	0	0	0	0
1980	7	0	0	0
1981	0	0	0	0
1982	0	0	0	0
1983	0	0	0	0
1984	0	0	0	0
1985	0	0	0	0
1986	0	0	0	0
1987	0	0	0	0
1988	0	0	0	0
1989	0	0	0	0
1990	0	0	0	0
1991	0	0	0	0
1992	0	0	0	0
1993	0	0	0	0
1994	0	0	0	0
1995	0	0	0	0
1996	0	0	0	0
1997	0	0	0	0
1998	0	0	0	0
1999	0	0	0	0
2000	0	0	0	0
2001	0	0	2	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	0	0	0	0
2008	7	0	0	0
2009	53	0	0	0
2010	239	0	0	29
2011	28	0	0	0
2012	45	0	0	0
2013	15	0	0	0
2014	56	0	0	5
2015	21	0	0	0
2016	42	0	0	0
2017	23	0	0	0
2018	12	1	0	14
2019	1[A]	0	0	0
2020	25[A]	0	0	0
Total	579	1	2	48

[A]Samples were collected but not processed by the DFO Sclerochronology Lab at the Pacific Biological Station because of insufficient capacity (i.e. due to COVID19 and other resources).

Table 74. Number of adipose fin clipped (AFC) and unclipped hatchery Chinook Salmon released by Brood Year in DU13 (STh-1.3).

	Eagle R		Salmon R	
Brood Year	**AFC**	**Unclipped**	**AFC**	**Unclipped**
1983	60541	41557	0	0
1984	277417	73185	162290	99920
1985	251286	175456	106278	189137
1986	302487	354697	53071	132891
1987	313182	259700	53868	88358
1988	282525	252802	113653	165392
1989	268290	166736	114478	225174
1990	210534	444011	137660	342547
1991	101774	84688	111410	201601
1992	115701	271011	39054	7447
1993	40484	136960	47151	62053
1994	0	0	50503	14834
1995	0	0	50668	19469
1996	0	0	49833	99523
1997	0	0	49207	53156
1998	0	0	45657	37659
1999	0	0	39006	58819
2000	0	0	58164	9831
2001	0	0	58985	4074
2002	0	0	40870	20815
2003	0	0	41026	17841
2004	0	0	0	116143
2005	0	0	0	88314
2006	0	0	42321	91799
2007	0	0	0	84081
2008	0	0	43005	65925
2009	0	0	0	95022
2010	0	0	0	98368
2011	0	0	0	73536
2012	0	0	0	81398
2013	0	0	0	67914
2014	0	0	0	75951
2015	0	0	0	88736
2016	0	0	0	7527
2017	0	0	0	46212
2018	0	0	0	63297
2019	0	0	0	81058
Total	2224221	2260803	1508158	3075822

Table 75. Numbers of Chinook examined for adipose fin clips and sampled for CWTs at sites in the DU13 (STh-1.3).

Run Year	Eagle R		Salmon R		Scotch C		Seymour R	
	Examined	Examined	Sampled	Examined	Sampled	Examined	Sampled	Sampled
1980	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	779	9	881	5	0	0	0	0
1987	662	148	441	58	0	0	0	0
1988	702	266	1152	205	0	0	0	0
1989	382	123	1338	89	0	0	0	0
1990	668	250	857	35	0	0	0	0
1991	245	77	556	29	0	0	0	0
1992	492	160	295	32	0	0	0	0
1993	688	156	1955	119	0	0	0	0
1994	722	62	1261	79	0	0	0	0
1995	368	45	133	7	0	0	0	0
1996	240	9	479	20	0	0	0	0
1997	0	0	504	46	0	0	0	0
1998	0	0	284	13	0	0	0	0
1999	0	0	319	104	0	0	0	0
2000	0	0	426	53	0	0	0	0
2001	0	0	1365	284	0	0	0	0
2002	0	0	971	234	0	0	0	0
2003	0	0	151	20	0	0	0	0
2004	0	0	438	91	0	0	0	0
2005	0	0	395	69	0	0	0	0
2006	0	0	621	110	0	0	0	0
2007	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0
2009	0	0	382	14	0	0	0	0
2010	0	0	670	119	0	0	0	0
2011	0	0	212	20	0	0	0	0
2012	0	0	394	76	0	0	0	0
2013	0	0	748	7	0	0	0	0
2014	0	0	864	0	0	0	0	0
2015	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0
2017	2[A]	0	48	0	0	0	0	0
2018	0	0	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0

[A]Source is from stock assessment database.

Table 76. Spawner abundance for populations in DU15 (LTh-1.2).

Run Year	Bonaparte R	Deadman R	Louis Cr	Nicola R	Coldwater R	Spius Cr
1975	100	250	54	5606	1500	850
1976	30	200	200	4445	500	200
1977	0	150	60	3498	600	150
1978	50	280	75	3974	750	80
1979	0	50	20	3017	300	50
1980	75	250	45	6180	710	200
1981	25	25	110	3258	200	100
1982	150	600	150	4737	800	200
1983	26	162	20	2407	547	102
1984	809	1626	100	4679	598	256
1985	800	1501	250	7088	2061	100
1986	1186	942	150	7876	2100	350
1987	398	541	25	4445	550	475
1988	694	1111	80	3246	220	150
1989	893	591	325	4445	1040	500
1990	482	483	50	3017	350	100
1991	2196	552	10	3258	325	248
1992	1728	279	6	5061	1332	250
1993	Not Surveyed	1614	20	5028	1500	900
1994	4291	1487	510	9510	275	367
1995	4225	726	800	10624	1050	575
1996	4625	1713	420	17777	1500	592
1997	9561	1655	480	9612	400	543
1998	1961	766	158	1547	300	373
1999	1979	857	183	8130	208	52
2000	5328	715	611	8183	497	668
2001	6285	1208	349	8984	781	603
2002	8371	528	481	12885	1343	869
2003	9610	2077	198	14490	1195	1170
2004	6130	1155	105	10153	1018	1866
2005	4943	426	40	3248	97	178
2006	1955	1237	315	5087	478	529
2007	1082	295	18	1010	54	15
2008	5426	1309	95	4411	365	168
2009	1286	190	6	538	15	138
2010	2412	1121	154	5258	255	206
2011	1751	413	72	2731	182	32
2012	3076	949	189	5702	795	648
2013	2520	252	117	3445	152	335
2014	12659	2282	289	7122	1145	1117
2015	5478	431	80	4836	85	240
2016	5260	Not Surveyed	155	2180	463	268
2017	2903	Not Surveyed	25	1702	74	68
2018	5	244	45	1627	97	82
2019	960	448	89	3859	255	237
2020	3448	431	106	3955	311	212

Table 77. Hatchery brood stock removals for populations in DU15 (LTh-1.2).

Run Year	Bonaparte R	Deadman R	Louis Cr	Nicola R	Coldwater R	Spius Cr
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	194	84	0	304	134	134
1987	122	0	0	380	159	0
1988	177	104	0	455	61	32
1989	169	53	0	527	160	135
1990	103	78	0	405	61	0
1991	97	0	0	342	74	78
1992	238	83	0	690	93	73
1993	0	94	0	178	95	67
1994	0	78	0	143	90	12
1995	0	122	0	138	66	51
1996	0	235	0	206	93	92
1997	0	0	0	135	105	93
1998	0	0	0	177	98	73
1999	0	0	0	151	69	114
2000	0	0	0	126	83	98
2001	0	0	0	115	67	68
2002	0	0	0	132	69	56
2003	0	0	0	137	75	40
2004	0	0	0	101	56	60
2005	0	0	0	119	68	85
2006	0	0	0	118	76	86
2007	0	0	0	112	24	28
2008	0	0	0	107	85	96
2009	0	0	0	142	45	80
2010	0	0	0	140	74	49
2011	0	0	0	119	57	14
2012	0	0	0	129	53	60
2013	0	0	0	142	62	47
2014	0	0	0	120	65	52
2015	0	0	0	119	33	58
2016	0	0	0	111	60	46
2017	0	0	0	128	54	44
2018	0	12	0	138	50	23
2019	0	0	0	161	63	41
2020	0	0	0	147	58	16

Table 78. Number of readable scale samples collected at sites in DU15 (LTh-1.2).

Run Year	Bonaparte R[A]	Deadman R	Louis Cr	Nicola R	Coldwater R	Spius Cr
1975	0	0	0	0	0	0
1976	0	0	0	99	90	1
1977	0	54	0	0	0	0
1978	0	0	1	0	0	0
1979	0	0	0	0	0	0
1980	0	77	0	0	0	0
1981	0	0	0	1	0	0
1982	0	0	0	38	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	0	0	0	0	0	0
1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	0	0
1992	0	0	0	0	0	0
1993	0	0	0	0	0	0
1994	0	0	0	0	0	0
1995	0	0	0	0	0	0
1996	0	0	0	0	0	0
1997	0	0	0	642	0	0
1998	0	0	0	319	0	0
1999	0	0	0	898	0	0
2000	0	0	0	465	0	0
2001	0	0	56	561	0	0
2002	0	0	0	1039	0	0
2003	0	0	0	783	0	0
2004	0	0	0	185	0	0
2005	0	0	0	146	0	0
2006	0	0	0	295	0	0
2007	0	0	0	92	0	0
2008	0	0	5	282	0	0
2009	0	0	0	88	0	0
2010	0	0	7	236	0	0
2011	0	0	2	158	0	0
2012	0	0	0	169	0	0
2013	0	0	0	230	0	0
2014	0	0	0	412	0	0
2015	0	0	0	569	0	0
2016	0	0	0	455	0	0
2017	0	0	0	514	0	0
2018	0	0	0	324	0	0
2019	0	0	0	611	0	0
2020	0	0	0	396	0	0
Total	0	131	71	10007	90	1

Table 79. Number of adipose fin clipped and unclipped hatchery Chinook Salmon released by Brood Year and population in DU15 (LTh-1.2).

Brood Year	Bonaparte		Deadman		Louis C		Nicola		Coldwater		Spius	
	AFC	**Unclipped**	**AFC**	**Unclipped**	**AFC**	**Unclipped**	**AFC**	**Unclipped**	**AFC**	**Unclipped**	**AFC**	**Unclipped**
1980	38613	15600	0	0	0	0	0	0	0	0	0	0
1981	44460	8040	0	0	0	0	30330	10020	0	0	0	0
1982	28683	4800	0	0	0	0	0	18000	0	0	0	0
1983	29493	4111	26570	6050	0	0	0	0	0	0	0	0
1984	41145	6900	38688	39700	0	0	198543	30311	63300	4738	0	0
1985	76922	29400	6834	716	0	0	269765	175165	-		0	0
1986	154379	39451	107999	6793	0	0	76635	159476	50787	75220	-	144500
1987	0	151941	51194	67706	0	0	225580	353984	-	194270	-	113440
1988	0	181224	18244	94098	0	0	256197	553661	50416	37459	-	62540
1989	0	69460	0	75857	0	0	248524	360293	49993	142794	-	174760
1990	75359	15314	7888	29352	0	0	221581	257530	49735	5650	-	
1991	74949	77450	3000	0	0	0	224762	281395	71767	34523	-	69448
1992	119765	100190	0	0	0	0	197772	292807	70108	27689	47264	7134
1993	0	0	31404	7506	0	0	70693	121343	20423	55804	-	56816
1994	0	0	40311	0	0	0	98078	60393	67675	24487	-	1107
1995	0	0	0	28100	0	0	100173	133667	41059	592	47160	4999
1996	0	0	0	9770	0	0	99297	244109	-	123680	49201	29712
1997	0	0	49162	33462	0	0	88482	95228	-	84830	47921	38054
1998	0	0	0	51500	0	0	42798	26382	34487	29802	-	26063
1999	0	0	0	78664	0	0	74802	152692	42268	26540	-	84726
2000	0	0	0	0	0	0	71134	134551	48549	41613	-	91206
2001	0	0	0	0	0	0	81555	119016	-	105188	-	66761
2002	0	0	0	0	0	0	88883	140287	-	89052	-	60385
2003	0	0	0	0	0	0	84133	122153	-	125474	-	14336
2004	0	0	0	0	0	0	83267	60007	-	83710	-	80789
2005	0	0	0	0	0	0	138728	31573	-	67323	-	102289
2006	0	0	0	0	0	0	146476	61118	-	95627	-	107915
2007	0	0	0	0	0	0	143178	71157	-	42897	-	30867
2008	0	0	0	0	0	0	127215	59292	-	95033	-	115426
2009	0	0	0	0	0	0	193131	20603	-	35159	-	81400
2010	0	0	0	0	0	0	187725	60111	-	125436	-	73372
2011	0	0	0	0	0	0	212951	21879	-	66269	-	18485
2012	0	0	0	0	0	0	190829	49553	-	75128	-	85408
2013	0	0	0	0	0	0	173306	20176	-	32083	-	52568
2014	0	0	0	0	0	0	169203	33822	-	57768	-	81373
2015	0	0	0	0	0	0	156997	22931	-	46423	-	81883
2016	0	0	0	0	0	0	154314	13860	-	80498	-	82834
2017	0	0	0	0	0	0	168459	7721	-	77130	-	48614
2018	0	0	0	105	0	0	181898	17610	-	76870	-	34079
2019	0	0	0	0	0	0	TBD[A]	13295	-	48140	-	4336
Total	701034	703881	381294	529379	0	0	52773940	4407171	660567	2334899	191546	2127625

[A]To Be Determined (TBD) as the production has not been reported to RMIS yet.

Table 80. Numbers of Chinook examined for adipose fin clips and sampled for CWTs at populations in DU15 (LTh-1.2).

Run Year	Bonaparte		Deadman		Louis C		Nicola		Coldwater		Spius	
	Examined	Sampled	Examined	Sampled	Examined	Sampled	Examined	Sampled	Examined	Sampled	Examined	Sampled
1980	0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	1[A]	0	0	0	0	0
1982	0	0	0	0	0	0	83[A]	0	31[A]	0	0	0
1983	6	6	0	0	0	0	0	0	0	0	0	0
1984	23	23	0	0	0	0	0	0	0	0	0	0
1985	5	5	0	0	0	0	0	0	0	0	0	0
1986	195	83	0	0	0	0	0	0	0	0	0	0
1987	122	78	0	0	0	0	414	79	159	8	0	0
1988	375	115	1079	5	0	0	1116	139	61	1	0	0
1989	724	388	575	13	0	0	1998	458	151	5	0	0
1990	444	127	190	64	0	0	1290	94	61	7	0	0
1991	2186	25	-	-	0	0	342	136	74	5	0	0
1992	1701	60	293	52	0	0	1974	226	93	5	0	0
1993	159	15	1556	-	0	0	2654	606	95	41	0	0
1994	4412	631	1454	80	0	0	4663	1108	102	37	0	0
1995	4457	374	654	32	0	0	4139	859	108	25	0	0
1996	4547	65	1547	9	0	0	8120	170	93	8	0	0
1997	0	0	0	0	0	0	4262	87	105	6	0	0
1998	0	0	0	0	0	0	618	135	98	25	0	0
1999	0	0	0	0	0	0	3100	991	69	56	0	0
2000	0	0	0	0	0	0	4541	867	83	1	0	0
2001	0	0	0	0	0	0	4625	1019	81	-	0	0
2002	0	0	0	0	0	0	5909	942	74	30	0	0
2003	0	0	0	0	0	0	7481	942	95	33	0	0
2004	0	0	0	0	0	0	3349	124	67	4	0	0
2005	0	0	0	0	0	0	1168	114	-	-	0	0
2006	0	0	0	0	0	0	1882	128	-	-	0	0
2007	0	0	0	0	0	0	500	30	-	-	0	0
2008	0	0	0	0	0	0	1558	201	-	-	0	0
2009	0	0	0	0	0	0	375	96	-	-	0	0
2010	0	0	0	0	0	0	1215	515	74	0	0	0
2011	0	0	0	0	0	0	930	232	77	0	0	0
2012	0	0	0	0	0	0	1526	171	66	0	0	0
2013	0	0	0	0	0	0	928	360	62	0	0	0
2014	0	0	0	0	0	0	2011	153	68	0	0	0
2015	0	0	0	0	0	0	2226	621	-	-	0	0
2016	0	0	0	0	0	0	634	189	-	-	0	0
2017	0	0	0	0	0	0	746	391	58	-	0	0
2018	0	0	0	0	0	0	671	465	-	-	0	0
2019	0	0	0	0	0	0	1818	952	-	-	0	0
2020	0	0	0	0	0	0	1414	465	-	-	0	0
Total	19356	1995	7348	255	0	0	80281	14065	**2105**	**297**	0	0

[A]Source is from stock assessment database.

APPENDIX D. MITIGATION SURVEY OPTIONS AND RESULTS

Table 81. Weighted averages of proposed mitigation measures for DU1 from the Threats Workshop mitigation survey.

Strategy	Weighted Average
Working with municipalities on improvement/replacement of tidal flood gates	**4.50**
Updated hatchery program targets and monitoring to align with genetic objectives for enhanced populations	**4.38**
Aquatic pollution mitigation along roads (Dispersal of water concentrated by roads via swales, grader berm gaps etc.)	**4.23**
Restore riparian habitat via multiple strategies (e.g. government habitat restoration programs, lease/compensate/tax incentives for private land owners with land that is effective riparian habitat)	**4.09**
CWT and biological sampling program at counting fences, spawning grounds and hatchery brood stock (including application of CWTs on hatchery Chinook)	**4.08**
Measure and reduce fishing exploitation rates to allow population to rebuild	**4.00**
Water license purchases and leases to ensure sufficient stream flows for Chinook	**3.90**
Water quality improvements	**3.73**
Telemetry project to identify spawning habitat locations (to support biological sampling and habitat protection)	**3.54**
Reduce light pollution and increase riparian cover to reduce predation	**3.25**
Suppression of Green Grabs in estuaries	**3.08**
Work with marine mammal rehabilitation programs to release rehabilitated animals away from the river estuaries	**3.00**
Aquatic Invasive Species predator and competitor management - suppression programs	**2.67**
Control of invasive plants (i.e. Reed Canary Grass)	**2.67**
Beaver dam analogues/rebuild beaver populations to mitigate sedimentation issues	**2.30**

Table 82. Weighted averages of proposed mitigation measures for DU6 from the Threats Workshop mitigation survey.

Strategy	Weighted Average
Measure and reduce fishing exploitation rate to allow population to rebound	**4.58**
Control of invasive plants (i.e. reed canary grass)	**4.42**
Restore riparian habitat via multiple strategies (e.g. government habitat restoration programs, lease/compensate/tax incentives for private land owners with land that is effective riparian habitat)	**4.23**
Conservation Hatchery Program with targets and monitoring that align with genetic objectives for enhanced populations	**4.17**
Investigate feasibility and desirability of reconnecting Slough at upstream end to the Fraser	**4.09**
Speak with local dairy farms about the importance of avoiding spraying manure and potential mitigation techniques	**4.00**
Aquatic Invasive Species predator and competitor management - suppression programs	**3.75**
Water license purchases and leases to ensure sufficient stream flows for Chinook	**3.20**

Table 83. Weighted averages of proposed mitigation measures for DU13 from the Threats Workshop mitigation survey.

Strategy	Weighted Average
Effective implementation of water management actions (i.e. timely WSA Section 88 orders backed up by Critical Environmental Flow Thresholds)	**4.67**
Water license purchases and leases to ensure sufficient stream flows for Chinook and stream ecological processes	**4.62**
Restore riparian habitat via multiple strategies (e.g. government habitat restoration programs, lease/compensate/tax incentives for private land owners with land that is effective riparian habitat)	**4.31**
Address access limitations for Chinook at the Salmon River mouth	**4.09**
Ensure compliance of screening on all irrigation and water intakes (development a regular monitoring program instead of relying on honor system reporting (via RAPP phone number)	**4.00**
Explore incentives/disincentives to have farmers grow less water intensive crops and lower water demand	**4.00**
Agricultural stewardship (appropriate management of agricultural effluents)	**3.92**
Measure and reduce fishing exploitation rates to allow populations to rebuild.	**3.92**
Address Mile 16 issue with CP Railway on the Eagle (Reconnect Butterball channel and ensure money is available to do work during rail line shut downs)	**3.85**
Review/Update hatchery program targets and monitoring to align with genetic objectives for enhanced populations	**3.77**
Fire planning for prevention	**3.42**
No longer allowing culverts in salmon bearing waters	**3.30**
Beaver dam analogues/rebuild beaver populations to mitigate sedimentation issues	**3.09**
Update list of and address all stream crossing and barrier issues within the DU area	**2.91**
Development of a DFO document outlining best forestry practices to protect salmon	**2.77**
Development of a DFO document outlining best agricultural practices to protect salmon	**2.69**
Reduced/variable speed limit and traffic barriers on Trans Canada Highway to reduce vehicle crashes and aquatic pollution/fuel spills into the Eagle R.	**2.54**

Table 84. Weighted averages of proposed mitigation measures for DU15 from the Threats Workshop mitigation survey.

Strategy	Weighted Average
Effective implementation of water management actions (i.e. timely WSA Section 88 orders backed up by Critical Environmental Flow Thresholds)	**4.83**
Identify and protect coldwater refugia sources on the spawning grounds and protect them	**4.62**
Stabilize upland areas after fire and excessive clear-cutting.	**4.62**
Water license purchases and leases to ensure sufficient stream flows for Chinook and stream ecological processes	**4.50**
Explore incentives/disincentives to have farmers grow less water intensive crops and lower water demand	**4.33**
Restore riparian habitat via multiple strategies (e.g. government habitat restoration programs, lease/compensate/tax incentives for private land owners with land that is effective riparian habitat)	**4.31**
Explore water storage options (i.e. Coldwater River, cold-water siphon at Nicola L., Mamit L. etc)	**4.25**
Ensure compliance of screening on all irrigation and water intakes (development a regular monitoring program instead of relying on honor system reporting (via RAPP phone number))	**4.00**
Reduce fishing exploitation rates to allow populations to rebuild	**3.92**
Review/Update hatchery program targets and monitoring to align with genetic objectives for enhanced populations	**3.62**
Look for and remediate risks of bank slumping due to road construction.	**3.45**
Aquatic pollution mitigation along roads (Dispersal of water concentrated by roads via swales, grader berm gaps etc.)	**3.42**
Reduce/close forestry roads and remediation of crossings and approaches	**3.33**
Beaver dam analogues/rebuild beaver populations to mitigate sedimentation issues	**3.00**
Aquatic Invasive Species predator and competitor management - suppression programs	**2.91**
Development of/Update a DFO document outlining best forestry practices to protect salmon	**2.85**
Update list and address all stream crossing and barrier issues within the DU area	**2.82**
Create signage near the Coldwater music festival grounds for education about how altering habitat negatively impacts salmon and enforce use of fencing and bridges during festivals.	**2.62**

APPENDIX E. THREAT CALCULATORS

Table 85. List of Threats Calculator Workshop Participants. The workshop took place virtually on October 13-15, 2021.

Last Name	First Name	Affiliation
Bailey	Richard	DFO retired
Dionne	Kaitlyn	DFO Science
Doutaz	Dan	DFO Stock Assessment
Earle	Suzanne	DFO Species at Risk Act Program
Grant	Paul	DFO Science
Jenewein	Brittany	DFO Resource Management
Labelle	Marc	Fraser Salmon Management Board
Lagasse	Cory	DFO Species at Risk Act Program
Lepitzki	Dwayne	Committed on the Status of Endangered Wildlife in Canada
Manson	Murray	DFO Salmonid Enhancement Program
Mozin	Paul	Scw'exmx Tribal Council
Parken	Chuck	DFO Stock Assessment
Potyrala	Mark	DFO Fish and Fish Habitat Protection Program
Rachinski	Théa	DFO Stock Assessment
Scott	Dave	University of British Columbia
Trouton	Nicole	DFO Stock Assessment
Walsh	Michelle	Secwepmec Fisheries Commission
Weir	Lauren	DFO Stock Assessment
Welch	Paul	DFO Salmonid Enhancement Program

Table 86. Threat calculator for DU1.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential and commercial development	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	-
1.1	Housing and urban areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	**DU1:** Although previous development is not included in this threat, the majority of this DU is highly urbanized with extensive diking and flood control that has changed the hydrographs. There is immense pressure to increase development in this area; agricultural land is being converted for urban purposes, particularly in upland areas, with the existing urban footprint growing in intensity. Ephemeral habitat is at risk from urban development. Chinook-suitable habitat is not well documented in this DU and future housing and urban development plans are unknown.
1.2	Commercial and industrial areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Pressure to urbanize habitat within this DU makes commercial and industrial expansion less likely but unknown.
1.3	Tourism and recreation areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Many marinas and boat launches exist in Boundary Bay. Pervasive was selected because we felt that as the juveniles and adults migrate through Boundary Bay, it is likely they will encounter any new developments. Plans for future expansion are unknown, but the marina at the mouth of the Nicomekl R is likely to expand to accommodate more boat traffic.
2	Agriculture and aquaculture	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	-
2.1	Annual and perennial non-timber crops	-	-	-	-	-	A massive agricultural footprint already exists in this DU. It is unlikely that more land will be converted for agricultural purposes, however.
2.2	Wood and pulp plantations	-	-	-	-	-	None
2.3	Livestock farming and ranching	-	-	-	-	-	Whether cows trample within Chinook (CN) habitat is unknown. They can access the streambed in Jacobsen Creek, which is a tributary to Little Campbell but not known CN spawning habitat.
2.4	Marine and freshwater aquaculture	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	**Fish Farms:** There are fish farms. 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/ 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. Cowichan hatchery has also seen reduced survival with increased hatchery releases (C. Parken). Hatchery fish comprise ~40% of salmon in the ocean (Ruggerone and Irvine 2018), and hence could present significant competition. The room did not feel there was a 70% decline, we had to work within the categories and people in the room felt that it could be upwards of 30% (based on Chuck's analysis and documented reduced survival with increased hatchery releases at other locations). No one suggested that it was at 70% severity. 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 8.2. Ultimately we decided that the impact is from hatchery fish generally, 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 and mining	-	-	-	-	-	-
3.1	Oil and gas drilling	-	-	-	-	-	None
3.2	Mining and quarrying	-	-	-	-	-	This category pertains mainly to the direct impact to aquatic habitat. Gravel pits exist within this DU but are far away from aquatic habitat, suggesting they are not a threat for this DU.
3.3	Renewable energy	-	-	-	-	-	None – Solar/wind/tidal energy only: hydroelectric is scored under dams and H2O management use.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4	Transportation and service corridors	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	-
4.1	Roads and railroads	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	The density of roads and their associated upgrades might increase in this area. A new road through Bear Cr has been approved by the City of Surrey. Railways (could need upgrades) intersect the mouth of the Serpentine and Nicomekl Rivers.
4.2	Utility and service lines	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	Many utility and service lines exist in this area; they will require future upgrades.
4.3	Shipping lanes	-	-	-	-	-	Not likely a threat
4.4	Flight paths	-	-	-	-	-	Not likely a threat
5	Biological resource use	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	-
5.1	Hunting and collecting terrestrial animals	-	-	-	-	-	Not likely a threat
5.2	Gathering terrestrial plants	-	-	-	-	-	Not likely a threat
5.3	Logging and wood harvesting	-	-	-	-	-	Not likely a threat since no forest remains to be logged.
5.4	Fishing and harvesting aquatic resources	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity refers to the percent decline in the population, not how many fish are caught (so if you don't have a decline there is no impact). No CWT exists for this DU. Sammish was used as a proxy, but uncertainty exists regarding similarities in marine distribution and exposure to fisheries. The group agreed that fishing negatively affects this DU but the extent is unknown, especially because their marine distribution is largely unknown. It is unlikely that exploitation rates will increase due to the trajectory of management. There could also be unaccounted mortality from incidental catch in the groundfish fishery. A relatively high number of fish are taken for hatchery purposes (causing population level impacts to the wild population), which is also included in this category. High levels of uncertainty exist because a suitable CWT proxy does not exist.
6	Human intrusions and disturbance	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	-
6.1	Recreational activities	-	-	-	-	-	Any threat from recreational activities most likely occurs in Boundary Bay.
6.2	War, civil unrest and military exercises	-	Unknown	Unknown	Unknown	High - Low	CN marine distribution and American military exercises are unknown.
6.3	Work and other activities	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	There are stock assessment activities in the watershed that are in direct contact with fish. Fences exist on each river for hatchery convenience. In addition, there could be other activities that occur in the watershed of which we are not aware. Marine mammal rehabilitation groups are known to release rehabilitated seals near the mouth of the Serpentine and Nicomekl rivers.
7	Natural system modifications	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	-
7.1	Fire and fire suppression	-	-	-	-	-	Unlikely threat in this highly urbanized area.
7.2	Dams and water management/use	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	E.g. water extraction, diking for flood control, hydroelectric. Pressure controlled sea dams exist at the mouths of the Serpentine and Nicomekl Rivers. The duration they remain closed during CN migrations is unknown, but intense seal predation on CN at the mouth of the Nicomekl has been observed while dam is closed. Municipalities are upgrading existing sea dams for flood management purposes. Many dikes and culverts exist throughout the DU.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7.3	Other ecosystem modifications	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	Included here are: riprapping, 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). Significant ecosystem modifications have occurred. Habitat has a lot of riprapping and all hydrographs are altered from urban development and flood management - less channelized and complex. Green Crabs exist in Boundary Bay and eat eelgrass.
8	Invasive and other problematic species and genes	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	-
8.1	Invasive non-native/alien species	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Non-native disease are included here. Predation and competition with Spiny Rays. There is a high potential for new invasive species to be introduced and established within the next ten years (Green Crabs, Zebra and Quagga Mussels). We cannot be certain if or when they will arrive, but everyone felt that it was a serious potential threat. Scope and severity will increase over time if and when new invasive species arrive. It is hard to predict.
8.2	Problematic native species	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	Included here are predation (i.e., pinnipeds etc.) and native disease issues. Pinnipeds and birds are significant predators in this DU. Hatcheries could be attracting more seals farther into freshwater. There is now a year round group of seals that prey on Chinook in freshwater. Pinniped predation can also increase when sea dams are closed and other predators can benefit from light pollution coupled with minimal riparian habitat. Parasite load increases faster with increasing temperature - parasite loads are unknown.
8.3	Introduced genetic material	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	Hatchery releases from outside the DU have occurred for over a decade. The genetic difference between this stock and DU1 CN and from domestication are unknown. Some straying occurs: CWT from outside the DU have been reported. Future, out-of-DU introductions is uncertain. The low abundance of this population also increases the threat severity because there is less genetic diversity and resilience.
9	Pollution	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	-
9.1	Household sewage and urban waste water	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	Untreated storm drains. Can be acute on smaller systems and result in die offs of juvenile Chinook (D. Hussey). This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. **From discussion with Tanya Brown:** Tanya felt it was 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 definitely 100%, any fish will be exposed to pollutants, but there is still lots of uncertainty about the impacts. Hesitant to assign one category, because she doesn't feel we have the information to support a specific severity. Most concerned about PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides. Offshore migrates might have more impacts from mercury. In **DU1** habitat, it is common for people to dispose of chemicals and tire compounds and other wastewater to enter the water, causing fish kills. Large aquifers can buffer these effects, while large rainfall events can exacerbate them from stormwater runoff. The situation is unlikely to improve. There is uncertainty about future impacts because it depends on the toxicity of chemicals released (e.g. caustic soda in Cheakamus R).
9.2	Industrial and military effluents	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	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). Sewage and gas lines cross creeks.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.3	Agricultural and forestry effluents	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	A relatively large agricultural footprint still exists in this DU. Farming occurs right to the edge of DU habitat, causing no buffer with pesticides and other chemicals.
9.4	Garbage and solid waste		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Included here are microplastics, abandoned nets/lost nets. Microplastic impacts are pervasive in scope and definitely a threat, but the severity for CN is unknown.
9.5	Air-borne pollutants	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Ubiquitous contaminant impacts, with an unknown severity. Everyone agreed there were population level effects.
9.6	Excess energy	-	Unknown	Unknown	Unknown	Unknown	Excess light pollution from streetlights, walkway lights, and buildings creates a 24/7 period for predation (avian and aquatic) to occur. A lack of riparian habitat can reduce refugia options for CN.
10	Geological events	-	Unknown	Pervasive (71-100%)	Unknown	Unknown	-
10.1	Volcanoes	-	Unknown	Pervasive (71-100%)	Unknown	Unknown	Volcanic disturbances (Mt. Baker) is likely to occur, but the timing and severity are unknown.
10.2	Earthquakes/tsunamis	-	Unknown	Pervasive (71-100%)	Unknown	Unknown	Earthquakes and tsunamis are likely to happen in this DU, but the timing and severity are unknown.
10.3	Avalanches/landslides	-	-	-	-	-	Unlikely threat in this highly urbanized area.
11	Climate change and severe weather	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	-
11.1	Habitat shifting and alteration	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	Included here are: sea level rise, the blob 2.0; ocean acidification, marine survival and all associated aspects. This category could be as low as 1% or as high as 70% over the next 3 generations. Future ocean conditions are uncertain. It is possible 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). **DU1:** Tidal area is diked and loss of intertidal marsh has profound effect on underyearling CN - which is worsening with climate change.
11.2	Droughts	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Drought is a threat to Little Campbell R - unsure if caused by water management or drought itself.
11.3	Temperature extremes	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	This DU spends so little time in freshwater. Marine temperature extremes are recorded and scored under 11.1 with changing ocean conditions, blob etc.
11.4	Storms and flooding	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	Significant bank erosion is happening because rainfall events flow through the main channel since historic channels areas have been blocked for urban flood control. Storm events can scour the streams and these systems have difficulty retaining gravel.

Table 87. Threat Calculator for DU6.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential and commercial development	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	-
1.1	Housing and urban areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	**Lower Fraser:** There has been significant development in the Lower Fraser, but 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 adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. 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 already. **DU6:** The spawning habitat in Maria Slough is unlikely to be developed for housing purposes. Although there is new development on Seabird Island, no in-water work is occurring.
1.2	Commercial and industrial areas	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	**Lower Fraser:** Pervasive was selected because adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. There is a possibility that new commercial and industrial developments will occur from an increasing population density in the Lower Fraser. Please note that these threats are only the direct results from new footprints of industrial activities and do not address previous development. **DU6:** Commercial and industrial development in DU6 is unlikely.
1.3	Tourism and recreation areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	**Lower Fraser:** Pervasive was selected because adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. Many marinas and boat launches exist throughout the lower Fraser, but their severity on CN is unknown. **DU6:** It is unknown if tourism and recreation areas will increase in Maria Slough.
2	Agriculture and aquaculture	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	-
2.1	Annual and perennial non-timber crops	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	**Lower Fraser:** Blueberry farms and greenhouses exist in the Lower Fraser. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses. They are likely to be placed further back from the river, but 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, but 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 (D. Hussey). **DU6:** Corn fields exist within DU6 habitat.
2.2	Wood and pulp plantations	-	-	-	-	-	None
2.3	Livestock farming and ranching	-	-	-	-	-	**Lower Fraser:** There are cattle ranching and dairy farms in the lower Fraser. **DU6:** There is a dairy farm in Maria but whether cattle trample within Chinook habitat is unknown.
2.4	Marine and freshwater aquaculture	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	**Fish Farms:** Fish farms exist, but the impact of the footprint is unknown and expected to be low. Potential fish farm threats from disease/ sea lice/ introduced genetics are scored elsewhere. **Hatchery Fish:** Competition from hatchery is scored here. New unpublished information suggests that the age 2 survival of Chinook is associated with their early marine growth rate and any competition from conspecifics will impact their survival. Cowichan hatchery has also seen reduced survival with increased hatchery releases (C. Parken). Hatchery fish comprise ~40% of salmon in the ocean (Ruggerone and Irvine 2018), and hence could present significant competition. The impact addresses hatchery fish in general

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
							and it is difficult to tease apart the impacts from within-DU and out-of-DU enhancement. These fish migrate further in the ocean and will encounter more hatchery stocks along the shelf. They also have an ocean-type life history (60-150 days freshwater residence), so within-DU hatchery competition is likely less intense.
3	Energy production and mining	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
3.1	Oil and gas drilling	-	-	-	-	-	None
3.2	Mining and quarrying	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	This category pertains to the direct impact to aquatic habitat. **Lower Fraser:** Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser where this DU rears. It should occur in the dry river bed, but it can change the depth and velocity of the habitat and make it less suitable for juvenile Chinook. However, the system is highly dynamic and continuously changes and stabilizes after the extraction. It is possible that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if we don't take that into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. This threat could increase in the future due to the growing demand for gravel, flood protection and dike set back. There is high uncertainty and there will be inter-annual variation. **DU6:** In 2014, gravel extraction was permitted in the Fraser River around Seabird Island from mid-Feb to mid-March. Future gravel extraction here is uncertain.
3.3	Renewable energy	-	-	-	-	-	None – Solar/wind/tidal energy only: hydroelectric is scored under dams and H2O management use.
4	Transportation and service corridors	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
4.1	Roads and railroads	-	-	-	-	-	Past threat. Unlikely future road development will occur here.
4.2	Utility and service lines	CD	Medium - Low	Restricted (11-30%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	**DU6:** Water and utility lines will require servicing in the future, which will occur in spawning habitat. This could affect all individuals in this population (single spawning site), but is restricted in scope because work is likely to happen during a single year. The impact could be negligible if done correctly; if done improperly, spawning habitat could be drained (high uncertainty ranking).
4.3	Shipping lanes	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Dredging for shipping lanes is included here. **Lower Fraser:** This has the potential to impact juveniles (depending on when it is done). Dredging shouldn't occur during times critical to salmon, but resulting jetties impact hydrology and can funnel fish (higher impact for subyearling CN) from estuarine areas into the Strait of Georgia (missing the estuary). This is hard to quantify; it was suggested that 10-20% of fish are affected. A ~2m wash from tugboats could be problematic in shallower areas. The Lower Fraser is an 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 it does occur). There is a high proportion of tide marsh habitat with booms and the impact on tide marsh habitats is significant.
4.4	Flight paths	-	-	-	-	-	Not likely a threat
5	Biological resource use	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	-
5.1	Hunting and collecting terrestrial animals	-	-	-	-	-	Not likely a threat
5.2	Gathering terrestrial plants	-	-	-	-	-	Not likely a threat

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.3	Logging and wood harvesting	-	-	-	-	-	Physical log boom impacts are scored under shipping (4.3) and sedimentation is scored under pollution (9.3). **DU6:** Logging does not occur within stream habitat in this DU.
5.4	Fishing and harvesting aquatic resources	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity refers to the percent decline in the population, not how many fish are caught (so if you don't have a decline there is no impact). Sufficient quantitative data does not exist for this DU. Data suggests that significant fishing has occurred on South Thompson CN (because they are a productive stock), which are comigrants of DU6 CN. Maria CN likely hold in the Fraser mainstem while they wait for favourable flow conditions in Maria Slough, which might increase their exposure to fisheries. Area F troll has become less of an impact because it is shifted in time. Terminal fisheries have increased. Data lacks for the impact of recreational fishing, subsistence fishing, unmonitored fisheries, and bycatch on this DU.
6	Human intrusions and disturbance	-	Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	-
6.1	Recreational activities	-	Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	This threat is scored based on the potential for jet boats to suck up fish or strand them from wakes. A negligible proportion of this DU is likely exposed to jetboats. Jetboat activity would occur in the Lower Fraser since Maria Slough is unnavigable in a jetboat.
6.2	War, civil unrest and military exercises	-	Unknown	Unknown	Unknown	High - Low	**Marine:** No Department of National Defence (DND) activities are known to occur in freshwater. In the marine environment, Chinook pass near Nanoose Bay, but any impacts/severity is completely unknown. There may be other military exercises of which we are not aware. Protest fisheries have occurred in BC and have the potential to continue in response to future fisheries closures, but fish mortality would be considered under 5.4.
6.3	Work and other activities	-	Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	**DU6:** There are stock assessment activities in the watershed that are in direct contact with fish. In addition, some work occurs in the estuary for research purposes. Only a handful of fish are sacrificed.
7	Natural system modifications	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	-
7.1	Fire and fire suppression	-	-	-	-	-	Unlikely threat. If a fire occurred, bucketing is more likely to happen from the Fraser mainstem.
7.2	Dams and water management/use	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	Addresses water extraction, diking for flood control, hydroelectric. **Lower Fraser:** After they emerge, Chinook Fry are using lower Fraser habitat from March to June (critical period). Diking has restricted CN from many backchannels, sloughs, off-channels, and ephemeral habitats. Sumas Lake represents a significant loss of habitat. Most of these impacts are historical impacts and future dike developments will likely be adjustments to the current dikes. 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). **DU6:** Dredging at Seabird Island occurs for flood control. An application was considered for ongoing gravel dredging in 2021 and onward. Additionally, fish must swim through culvert to access habitat and there has been talk about adding water control structures in downstream end to address flooding concerns.
7.3	Other ecosystem modifications	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	Included here are: riprapping, impacts to food webs and prey of Chinook (e.g. mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). **Lower Fraser:** As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This likely increases river velocity on the edges and reduces cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser side channels and sloughs. In addition, there has been significant change in catchment surfaces in the lower mainland, which has an unknown impact. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Snow Geese in the Lower Fraser are also chewing up marsh habitat. Green Crabs modify nearshore habitats and eelgrass beds, which are important to salmon. **DU6:** Canary Reed Grass is a credible threat in DU6; there are points on the

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
							spawning channel that are overwhelmed by it. It is not currently impeding migration but it has the potential to do so. It is also affecting other native plants in riparian habitat. Pumpkinseed has recently arrived in Maria Slough as well. High uncertainty exists with severity because the invasive species populations and their associated impacts in Maria Slough are not well-studied.
8	Invasive and other problematic species & genes	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
8.1	Invasive non-native/alien species	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	**Lower Fraser:** There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years. Their arrival is uncertain, but they are thought to be a serious potential threat. Scope and severity will increase over time if and when new invasive species arrive. **DU6:** There are high levels of predation on juvenile Oregon Spotted Frogs in DU6, which may have the same predators as juvenile CN. Invasive Spiny Rays are a pervasive issue in Maria Slough and compete with CN.
8.2	Problematic native species	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Included here are predation (i.e., pinnipeds etc.) and native disease issues. **Lower Fraser:** More seals exist in freshwater, but they could still be within historical levels. Their distribution has likely shifted because hatcheries are attracting seals further into freshwater and a year-round rookery of seals now prey on CN in freshwater. **DU6:** During low water years, CN could be exposed to more predation (seals and otters) if they are waiting for favourable flows in Maria Slough. Northern Pike minnow have a significant population in Maria, but their effect on CN is not well defined. Parasites were not discussed.
8.3	Introduced genetic material	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Scored as unknown because conflicting opinions existed about the genetic impacts that hatchery practices have on this small, integrated population. One side felt that hatchery enhancement is critical because of low population levels; the other side felt that the reduced fitness of hatchery fish will further impair the recovery of this small population. No consensus was reached. All hatchery releases have been fish from within the DU, but the genetic impacts of broodtake and domestication are unknown. It was recommended that population geneticists provide feedback.
9	Pollution	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	-
9.1	Household sewage and urban waste water	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Also includes untreated storm drains. Can be acute on smaller systems and result in die offs of juvenile Chinook (D. Hussey). This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. **From discussion with Tanya Brown:** Limited research has occurred in BC about pollution impacts on Chinook, but there has been some in Washington. The scope is definitely 100%, any fish passing through the lower Fraser will be exposed to pollutants, but uncertainty about the impacts exist and there is therefore hesitancy to assign to one category. We know there is a negative effect, but severity is hard to pinpoint. There are some ongoing studies that examine many contaminants in the Fraser estuary (household/industrial/historical). Tanya's lab is hoping to be able to identify the different pollution effects, including microplastics, and how they change with the different ocean migration routes. Most concerned about PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. Offshore migrates might have more impacts from mercury.
9.2	Industrial and military effluents	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	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). **Lower Fraser:** Effluents exist in the Lower Fraser, but their effects on CN are not well-studied.
9.3	Agricultural and forestry effluents	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	**Lower Fraser:** Many log booms (including bark debris), runoff/sedimentation from mills, and log sorts, and agricultural runoff from pesticides exist in the Lower Fraser. **DU6:** In the Maria Slough, there is concern that runoff from manure spraying could affect water quality and nutrient loading - which are likely emphasized since water is relatively stagnant.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.4	Garbage and solid waste	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Included here are microplastics, abandoned nets/lost nets. Microplastic impacts are pervasive in scope and definitely a threat, but the severity for CN is unknown.
9.5	Airborne pollutants	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Ubiquitous contaminant impacts, with an unknown severity. Everyone agreed there were population level effects.
9.6	Excess energy	-	Unknown	Unknown	Unknown	Unknown	Noise impacts and excess light energy are scored here - both are unknown.
10	Geological events	-	Unknown	Pervasive (71-100%)	Unknown	Unknown	-
10.1	Volcanoes	-	Unknown	Pervasive (71-100%)	Unknown	Unknown	Volcanoes exist in the region, but the timing and severity of eruptions is unknown.
10.2	Earthquakes/tsunamis	-	Unknown	Unknown	Unknown	Unknown	Earthquakes could occur in the region and tsunamis could affect DU6 CN, but the scope, timing and severity of these events is unpredictable.
10.3	Avalanches/landslides	-	-	-	-	-	**DU6:** A recent fire occurred on a steep slope within DU6 habitat, but is far from Maria Slough itself. Increase sedimentation could result from the sluffing but it is unlikely to have a large impact.
11	Climate change and severe weather	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	-
11.1	Habitat shifting and alteration	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	Included here are: sea level rise, the blob 2.0; ocean acidification, marine survival and all associated aspects. This category could be as low as 1% or as high as 70% over the next 3 generations. Future ocean conditions are uncertain. It is possible 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	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	**DU6:** Maria Slough can be vulnerable to drought in the fall, which is exacerbated by relatively little water storage and catchment area; however, there is a lot of groundwater.
11.3	Temperature extremes	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	**DU6:** The standing water in Maria Slough can make it more prone to high water temperatures (14-15 degrees Celsius in mid-May and 20+ in the summer are not unusual).
11.4	Storms and flooding	-	Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	**DU6:** Maria Slough is not prone to scour because there are big marshy areas that absorb high rain and flows.

Table 88. Threat Calculator for DU13.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential and commercial development	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	-
1.1	Housing and urban areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	**Lower Fraser:** There has been significant development in the Lower Fraser, but 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 adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. 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 already. **DU13:** There are docks near the Eagle R and houseboats in Shuswap Lake. The prospect of urban expansion in other areas is unknown.
1.2	Commercial and industrial areas	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	**Lower Fraser:** Pervasive was selected because adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. There is a possibility that new commercial and industrial developments will occur from an increasing population density in the lower Fraser. Please note that these threats are only the direct results from new footprints of industrial activities and do not address previous development. **DU13:** Commercial and industrial development in DU13 is unknown.
1.3	Tourism and recreation areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	The interactions between recreation and CN are largely unknown. **Lower Fraser:** Pervasive was selected because adults and juveniles will encounter any new developments as they migrate through the lower Fraser. Many marinas and boat launches exist throughout the lower Fraser, but their severity on CN is unknown. **DU13:** Shuswap Lake has considerable tourist traffic and infrastructure. Recreation is also increasing in the Eagle and Perry rivers.
2	Agriculture and aquaculture	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
2.1	Annual and perennial non-timber crops	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	**Lower Fraser:** Blueberry farms and greenhouses exist in the Lower Fraser. Most of the agricultural area is behind dikes already. There is intensification in the lower Fraser from fields to greenhouses. They are likely to be placed further back from the river, but 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, but 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 (D. Hussey). **DU13:** Intense agriculture occurs in the lower Eagle R and it is expanding in the upper Salmon R.
2.2	Wood and pulp plantations	-	-	-	-	-	None
2.3	Livestock farming and ranching	-	Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	**DU13:** Cattle can enter river and streams, especially in the Salmon R.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
2.4	Marine and freshwater aquaculture	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Fish Farms: Fish farms exist, but the impact of the footprint is unknown and expected to be low. Potential fish farm threats from disease/ sea lice/ introduced genetics are scored elsewhere. Hatchery Fish: Competition from hatchery is scored here. New unpublished information suggests that the age 2 survival of Chinook is associated with their early marine growth rate and any competition from conspecifics will impact their survival. Cowichan hatchery has also seen reduced survival with increased hatchery releases (C. Parken). Hatchery fish comprise ~40% of salmon in the ocean (Ruggerone and Irvine 2018), and hence could present significant competition. **DU13:** Not all populations are affected within DU habitat - Salmon R is currently the only enhanced population (since 1993). This DU has a stream-type life history. If fry are released, competition might increase for wild CN during the freshwater fry life stage from within-DU and out-of-DU hatchery releases.
3	Energy production and mining	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
3.1	Oil and gas drilling	-	-	-	-	-	None
3.2	Mining and quarrying	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	This category pertains to the direct impact to aquatic habitat. **Lower Fraser:** Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser where this DU rears. It should occur in the dry river bed, but it can change the depth and velocity of the habitat and make it less suitable for juvenile Chinook. However, the system is highly dynamic and continuously changes and stabilizes after the extraction. It is possible that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if we don't take that into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. This threat could increase in the future due to the growing demand for gravel, flood protection and dike set back. There is high uncertainty and there will be inter-annual variation. This DU has multiple freshwater rearing strategies, so CN that rear in the Lower Fraser will be disproportionately affected.
3.3	Renewable energy	-	-	-	-	-	None
4	Transportation and service corridors	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
4.1	Roads and railroads	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	**DU13:** Doubling of the TCH intersects Salmon R (mouth), Eagle R (along multiple intersections), and South Thompson (rearing). All 4 populations have encountered TCH expansion, which is why it's pervasive. Railroad is particularly problematic on the Eagle R where CP railway can entrain juveniles and restrict usable upstream habitat during periods of low water for adults. Uncertainty exists because we are unsure how effectively TCH expansion is mitigated. Expansion of the railway is unknown.
4.2	Utility and service lines	-	Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	**Lower Fraser:** CN encounter TMX in the Lower Fraser and at its intersection with the Thompson. Issues with TMX could affect the migration corridor and rearing habitat.
4.3	Shipping lanes	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Dredging for shipping lanes is included here. **Lower Fraser:** This has the potential to impact juveniles (depending on when it is done). Dredging shouldn't occur during times critical to salmon, but resulting jetties impact hydrology and can funnel fish (higher impact for subyearling CN) from estuarine areas into the Strait of Georgia (missing the estuary). This is hard to quantify; it was suggested that 10-20% of fish are affected. A ~2m wash from tugboats could be problematic in shallower areas. The Lower Fraser is an 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 it does occur). There is a high proportion of tide marsh habitat with booms and the impact on tide marsh habitats is significant. **DU13:** Grounding effects from log booms is unlikely because Shuswap L is not tidal.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4.4	Flight paths	-	-	-	-	-	None
5	Biological resource use	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	-
5.1	Hunting and collecting terrestrial animals	-	-	-	-	-	Not likely a threat
5.2	Gathering terrestrial plants	-	-	-	-	-	Not likely a threat
5.3	Logging and wood harvesting	D	Low	Restricted (11-30%)	Slight (1-10%)	High (Continuing)	**DU13:** It is reasonable to expect that logging practices (i.e. none in-stream) will not change. A log dump exists on North Shuswap and in the Salmon Arm of Shuswap L. Migrating salmon might pass by them, but the impact would be minimal.
5.4	Fishing and harvesting aquatic resources	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity refers to the percent decline in the population, not how many fish are caught (so if you don't have a decline there is no impact). Sufficient quantitative data does not exist for this DU. These CN migrate before the main South Thompson underyearling population and therefore garner more protection from fishing. Lower Fraser fisheries are not open until mid August, which is after this DU's migration in that area. Although fishing persists in the Salish Sea, all Southern BC Chinook fishing has decreased and is projected to remain low in the future. These scores assume fishing restrictions will not lessen.
6	Human intrusions and disturbance	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	-
6.1	Recreational activities	-	Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	**DU13:** Jetboats, prop boats, jet skis, wakeboard boats, and house boats are numerous in summer months. A negligible proportion of this DU is likely exposed to boat traffic due to the size of the lake.
6.2	War, civil unrest and military exercises	-	Unknown	Unknown	Unknown	High - Low	Marine: No DND activities are known to occur in freshwater. In the marine environment, Chinook pass near Nanoose Bay, but any impacts/severity is completely unknown. There may be other military exercises of which we are not aware. Protest fisheries have occurred in BC and have the potential to continue in response to future fisheries closures, but fish mortality would be considered under 5.4.
6.3	Work and other activities	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	**DU13:** Fences on the Salmon, Scotch and Eagle rivers have had an uncertain impact on CN migration. The Salmon and Eagle river fences are thought to have changed the spawning distribution (R. Bailey). Additionally, jet boating occurs in the Eagle and Perry rivers for stock assessment surveys.
7	Natural system modifications	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	-
7.1	Fire and fire suppression	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	**DU13:** Recent wildfires have occurred in the Salmon and Eagle river drainages. Water was bucketed out of Three Valley Gap, the mouth of the Eagle R, and from Salmon R. Wildfires are expected to persist in the future.
7.2	Dams and water management/use	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	Addresses water extraction, diking for flood control, hydroelectric. **Lower Fraser:** After they emerge, Chinook fry are using lower Fraser habitat from March to June (critical period). Diking has restricted CN from many backchannels, sloughs, off-channels, and ephemeral habitats. Sumas Lake represents a significant loss of habitat. Most of these impacts are historical impacts and future dike developments will likely be adjustments to the current dikes. 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). **DU13:** Water management is particularly problematic for Salmon R. Part of the river runs dry and therefore restricts CN from suitable habitat. The community of Westwold sucks the water table down and parts of the river can run dry for 3 months. Section 88 of the *Water Sustainability Act* was invoked in 2021 to restrict agricultural water use and remained at a level 5 drought. Water extraction in the Salmon R and low levels in Shuswap L cause distributaries to form at its mouth - adult CN swim up what they

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
							think is the main channel and die from stranding. Low water levels can be problematic in Scotch Cr, but unlikely in the Eagle and Seymour rivers.
7.3	Other ecosystem modifications	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	Included here are: riprapping, impacts to food webs and prey of Chinook (e.g. mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). **Lower Fraser:** As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This likely increases river velocity on the edges and reduces cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser side channels and sloughs. In addition, there has been significant change in catchment surfaces in the lower mainland, which has an unknown impact. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Snow Geese in the Lower Fraser are also chewing up marsh habitat. Green Crabs modify nearshore habitats and eelgrass beds, which are important to salmon.
8	Invasive and other problematic species & genes	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
8.1	Invasive non-native/alien species	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	**Lower Fraser:** There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years. Their arrival is uncertain, but they are thought to be a serious potential threat. Scope and severity will increase over time if and when new invasive species arrive. **DU13:** Perch, bass, Pumpkinseed, and other non-native sportfish species pose a threat. Efforts to eradicate Spiny Ray fishes have occurred in Shuswap L.
8.2	Problematic native species	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Included here are predation (i.e., pinnipeds etc.) and native disease issues. **Lower Fraser**: More seals exist in freshwater, but they could still be within historical levels. Their distribution has likely shifted because hatcheries are attracting seals further into freshwater and a year-round rookery of seals now prey on CN in freshwater.
8.3	Introduced genetic material	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Hatchery enhancement has only occurred in the Eagle (end 1993) and Salmon Rs (continuing). No out-of-DU transplants have occurred. CN are inspected at the Salmon R fence for external marks (although mark quality varies between years).
9	Pollution	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	-
9.1	Household sewage and urban waste water	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Also includes untreated storm drains. Can be acute on smaller systems and result in die offs of juvenile Chinook (D. Hussey). This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. **From discussion with Tanya Brown:** Limited research has occurred in BC about pollution impacts on Chinook, but there has been some in Washington. The scope is definitely 100%, any fish passing through the lower Fraser will be exposed to pollutants, but uncertainty about the impacts exist and there is therefore hesitancy to assign to one category. We know there is a negative effect, but severity is hard to pinpoint. There are some ongoing studies that examine many contaminants in the Fraser estuary (household/industrial/historical). Tanya's lab is hoping to be able to identify the different pollution effects, including microplastics, and how they change with the different ocean migration routes. Most concerned about PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. Offshore migrates might have more impacts from mercury. **DU13:** House boats likely dump sewage into Shuswap L. Vehicles (incl. transport trucks) launch into the Eagle R off TCH.
9.2	Industrial and military effluents	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	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). **Lower Fraser:** Effluents exist in the Lower Fraser, but their effects on CN are not well-studied.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.3	Agricultural and forestry effluents	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	**Lower Fraser:** Many log booms (including bark debris), runoff/sedimentation from mills, and log sorts, and agricultural runoff from pesticides exist in the Lower Fraser.
9.4	Garbage and solid waste	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Included here are microplastics, abandoned nets/lost nets. Microplastic impacts are pervasive in scope and are definitely a threat, but the severity for CN is unknown.
9.5	Air-borne pollutants	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Ubiquitous contaminant impacts, with an unknown severity. Everyone agreed there were population level effects.
9.6	Excess energy	-	Unknown	Unknown	Unknown	Unknown	Noise impacts and excess light energy are scored here - both are unknown.
10	Geological events	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	-
10.1	Volcanoes	-	-	-	-	-	None
10.2	Earthquakes/tsunamis	-	-	-	-	-	None
10.3	Avalanches/landslides	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	**DU13:** Silt bluffs can occasionally fail, but they quickly wash away. A recent slide in the Eagle Pass shut the TCH. Avalanches in the Eagle Pass are also common.
11	Climate change and severe weather	B	High	Large (31-70%)	Serious (31-70%)	High (Continuing)	-
11.1	Habitat shifting and alteration	BD	High - Low	Pervasive (71-100%)	Serious - Slight (1-70%)	High (Continuing)	Included here are: sea level rise, the blob 2.0; ocean acidification, marine survival and all associated aspects. This category could be as low as 1% or as high as 70% over the next 3 generations. Future ocean conditions are uncertain. It is possible 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	B	High	Large (31-70%)	Serious (31-70%)	High (Continuing)	**DU13:** Droughts are a significant concern in the Salmon R, but not in Eagle R, Scotch Cr, or Seymour R. Spawners migrate on the descending limb of freshet, but low water levels can impair or restrict migration. Droughts and poor water management can produce similar results. Salmon R remains at a level 5 drought.
11.3	Temperature extremes	BC	High - Medium	Large (31-70%)	Serious - Moderate (11-70%)	High (Continuing)	**DU13:** Temperature extremes are problematic in the Salmon R. Scotch Cr and Seymour R have riparian habitat, mossy areas, and many cedars, so they are unlikely to experience high temperatures. The Perry R, a major tributary of the Eagle R, is glacial fed and effective riparian habitat can cool the Eagle R drainage, which buffers warm temperatures. Three Valley and Gryffin lakes are capable of being heatsinks and can release warm water once they stratify. The shape of the Eagle Valley, however, suggests there is an inordinate amount of groundwater and thermal refugia. In the Salmon R, temperatures can reach mid 20s and are exacerbated by low water levels. Fish kills have been reported in the Salmon R in response to high temperatures. Uncertainty exists because the frequency and severity of heat domes are unknown.
11.4	Storms and flooding	CD	Medium - Low	Large (31-70%)	Moderate - Slight (1-30%)	High (Continuing)	**DU13:** The Eagle and Salmon Rs are prone to scouring. The Eagle R has potential for rain on snow events. All interior systems can be vulnerable to large snowpack and warm spells.

Table 89. Threat Calculator for DU15.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential and commercial development	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	-
1.1	Housing and urban areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	**Lower Fraser:** There has been significant development in the Lower Fraser, but 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 adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. 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 already. **DU15:** Residential development in Nicola watershed and Louis is unlikely. Big Sky is a new development in the lower Deadman R; it will be high on a bank, has a community plan, is likely to use existing accesses (roads, electrical conduits, lines, etc.).
1.2	Commercial and industrial areas	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	**Lower Fraser:** Pervasive was selected because adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. There is a possibility that new commercial and industrial developments will occur from an increasing population density in the lower Fraser. Please note that these threats are only the direct results from new footprints of industrial activities and do not address previous development. **DU15:** Commercial and industrial development in DU15 is unknown.
1.3	Tourism and recreation areas	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	The interactions between recreation and CN are largely unknown. **Lower Fraser:** Pervasive was selected because adults and juveniles will encounter any new developments as they migrate through the Lower Fraser. Many marinas and boat launches exist throughout the lower Fraser, but their severity on CN is unknown. **DU15:** The expansion of tourism and recreation areas in DU15 is unknown.
2	Agriculture and aquaculture	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
2.1	Annual and perennial non-timber crops	-	-	-	-	-	**Lower Fraser:** Blueberry farms and greenhouses exist in the Lower Fraser. Most of the agricultural area is behind dikes already. There is intensification in the Lower Fraser from fields to greenhouses. They are likely to be placed further back from the river, but 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, but 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 (D. Hussey).
2.2	Wood and pulp plantations	-	-	-	-	-	None
2.3	Livestock farming and ranching	-	Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	**DU15:** A significant agricultural footprint exists within this DU and future development plans are unknown. Cattle trampling: occurs in Louis Cr and Deadman R, unlikely in Bonaparte R due to depth, possible in the Coldwater R, Spius Cr, and Nicola R but cows are typically up on the range when CN are spawning and are moved around throughout the season.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
2.4	Marine and freshwater aquaculture	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Fish Farms: Fish farms exist, but the impact of the footprint is unknown and expected to be low. Potential fish farm threats from disease/ sea lice/ introduced genetics are scored elsewhere. Hatchery Fish: Competition from hatchery is scored here. New unpublished information suggests that the age 2 survival of chinook is associated with their early marine growth rate and any competition from conspecifics will impact their survival. Cowichan hatchery has also seen reduced survival with increased hatchery releases (C. Parken). Hatchery fish comprise ~40% of salmon in the ocean (Ruggerone and Irvine 2018), and hence could present significant competition. **DU15:** All populations except Louis Cr have CN hatchery releases. The competitive effects that hatchery CN pose on wild CN in this DU is unknown. The Pacific Salmon Strategy Initiative (PSSI) will construct new hatcheries, but their locations are unknown. There are, however, preliminary discussions to build a hatchery on the Coldwater R.
3	Energy production and mining	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
3.1	Oil and gas drilling	-	-	-	-	-	None
3.2	Mining and quarrying	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	This category pertains to the direct impact to aquatic habitat. **Lower Fraser:** Gravel extraction, often to be argued as part of flood protection, is occurring in the lower Fraser where this DU rears. It should occur in the dry river bed, but it can change the depth and velocity of the habitat and make it less suitable for juvenile Chinook. However, the system is highly dynamic and continuously changes and stabilizes after the extraction. It is possible that the current gravel bed load is an artifact of historical placer mining in the Fraser, and if we don't take that into account in the gravel budget, there could be excess removal of gravel from this section of the Fraser. This threat could increase in the future due to the growing demand for gravel, flood protection and dike set back. There is high uncertainty and there will be inter-annual variation. This DU has multiple freshwater rearing strategies, so CN that rear in the Lower Fraser will be disproportionately affected. **DU15:** Substantial mining occurs in the Nicola drainage, but the footprint is not in the river. Many recreational placer claims exist, with some holders using excavators to dig in the river/streambed.
3.3	Renewable energy	-	-	-	-	-	None
4	Transportation and service corridors	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
4.1	Roads and railroads	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	**DU15:** Salvage logging after the significant wildfires will likely increase the forestry road network within this DU.
4.2	Utility and service lines	-	Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	**Lower Fraser:** CN encounter TMX in the Lower Fraser and at its intersection with the Thompson. Issues with TMX could affect the migration corridor and rearing habitat. **DU15:** TMX crosses the Coldwater R; instream work has occurred because adjacent rock could not be drilled. The Coldwater R has(d) to be temporarily diverted, but mitigation plans are supposed to offset impacts.
4.3	Shipping lanes	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Dredging for shipping lanes is included here. **Lower Fraser:** This has the potential to impact juveniles (depending on when it is done). Dredging shouldn't occur during times critical to salmon, but resulting jetties impact hydrology and can funnel fish (higher impact for subyearling CN) from estuarine areas into the Strait of Georgia (missing the estuary). This is hard to quantify; it was suggested that 10-20% of fish are affected. A ~2m wash from tugboats could be problematic in shallower areas. The Lower Fraser is an 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 it does occur). There is a high proportion of tide marsh habitat with booms and the impact on tide marsh habitats is significant.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4.4	Flight paths	-	-	-	-	-	Not likely a threat
5	Biological resource use	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	-
5.1	Hunting and collecting terrestrial animals	-	-	-	-	-	Not likely a threat
5.2	Gathering terrestrial plants	-	-	-	-	-	Not likely a threat
5.3	Logging and wood harvesting	D	Low	Large - Restricted (11-70%)	Slight (1-10%)	High (Continuing)	**DU15:** A considerable amount of salvage logging is likely to occur in the Coldwater R, Deadman R, and (lower) Nicola R. Current practices leave a riparian buffer, but this may be challenging to achieve in severely burnt areas. Uncertainties exist about salvage logging restrictions and how this will affect future generations.
5.4	Fishing and harvesting aquatic resources	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Stock productivity - use the reasonable range of stock productivity to estimate severity. Severity refers to the percent decline in the population, not how many fish are caught (so if you don't have a decline there is no impact). In the last several years, the exploitation rate has declined for Fraser CN (monitored exploitation rate = <5%). Monitored fisheries occur after these CN spawners pass through the lower Fraser. FSC fishing with rod and reel can occur in upstream areas, particularly at the confluence of the Lower Thompson and Nicola rivers and cause significant impacts. In years with prolonged low water, CN accumulate at the mouth of the Nicola R, increasing exposure to fisheries. In the Deadman R, a no-fishing bylaw exists. In the Bonaparte R, most fishing occurs at the fishway. The recreational fishery targeting Jack Chinook starts later in the year to avoid impacts to this stock group.
6	Human intrusions and disturbance	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	-
6.1	Recreational activities	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	**DU15:** Recreational activities occur within the Coldwater R. In the upper part, quads and motorbikes are driven through the riverbed - occurs during 2-3 summer months when the early Coldwater CN (adults and juveniles) are present and could displace their habitat use. The Rockin' River music festival occurs each summer on the Coldwater R. There have been numerous incidents of festival participants trampling Coldwater R habitat and rearranging streambed to bathe in pools. Recreational activities are thought to be negligible in the Deadman R, Bonaparte R, and Louis Cr.
6.2	War, civil unrest and military exercises	-	Unknown	Unknown	Unknown	High - Low	Marine: No DND activities are known to occur in freshwater. In the marine environment, Chinook pass near Nanoose Bay, but any impacts/severity is completely unknown. There may be other military exercises of which we are not aware. Protest fisheries have occurred in BC and have the potential to continue in response to future fisheries closures, but fish mortality would be considered under 5.4.
6.3	Work and other activities	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	**DU15:** A fishway with a trap exists on the Bonaparte R, but it provides access to upstream habitat and therefore is unlikely to have a negative impact. A long standing mark recapture program is used to enumerate Nicola R CN, but effects are negligible (<1%) (Cowen et al. 2011). Roving surveys are conducted in Louis Cr and could possibly trample CN redds.
7	Natural system modifications	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	-
7.1	Fire and fire suppression	-	Unknown	Large (31-70%)	Unknown	High (Continuing)	**DU15:** The recent intense wildfires necessitated bucketing from Coldwater R, Deadman R, and Nicola R. Tributaries could have experienced altered conditions, such as increased water temperature and low dissolved oxygen, in hot wildfire zones, creating thermal barriers or inhospitable conditions. These effects are unknown.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7.2	Dams and water management/use	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	Addresses water extraction, diking for flood control, hydroelectric. **Lower Fraser:** After they emerge, Chinook fry are using lower Fraser habitat from March to June (critical period). Diking has restricted CN from many backchannels, sloughs, off-channels, and ephemeral habitats. Sumas Lake represents a significant loss of habitat. Most of these impacts are historical impacts and future dike developments will likely be adjustments to the current dikes. 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). **DU15:** Spius Cr, Coldwater R, Louis, and Nicola R are all drought sensitive systems. Water extraction is a significant issue. Some streams are redirected to satisfy water extraction. Low flows cause significant challenges to population viability; evidence suggests that the volume of water in the Nicola in August is associated with stock productivity and affects both juveniles and adults. The DFO habitat program has evidence of dropping water levels stranding fish once irrigator pumps are activated (only one water license can have a significant effect). Voluntary restrictions are present on the Coldwater R.
7.3	Other ecosystem modifications	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	Included here are: riprapping, impacts to food webs and prey of Chinook (e.g. mysids), invasive plants that modify habitat, changes in hydrology from human landscape changes (including both development and forest harvesting). **Lower Fraser:** As of 2015, 50% of the lower Fraser was riprapped, which is a large conversion from natural riparian bank to hard surface. This likely increases river velocity on the edges and reduces cover and foraging habitat for Chinook fry. Invasive plants are prevalent in the lower Fraser side channels and sloughs. In addition, there has been significant change in catchment surfaces in the lower mainland, which has an unknown impact. Invasive plants are prevalent in the lower Fraser in side channels and sloughs. Snow Geese in the Lower Fraser are also chewing up marsh habitat. Green Crabs modify nearshore habitats and eelgrass beds, which are important to salmon. **DU15:** Wildfires have significantly modified the ecosystem, resulting in flashy systems.
8	Invasive and other problematic species and genes	BC	High - Medium	Large (31-70%)	Serious - Moderate (11-70%)	High (Continuing)	-
8.1	Invasive non-native/alien species	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	**Lower Fraser:** There is a high potential for new invasive species to be introduced and established in the lower Fraser within the next ten years. Their arrival is uncertain, but they are thought to be a serious potential threat. Scope and severity will increase over time if and when new invasive species arrive. **DU15:** Invasive perch exist in the Nicola drainage and Spiny Rays are present in Chaperon L, Douglas L, and Nicola L. Their arrival in Nicola R is imminent since passage is possible through the dam. Smallmouth Bass are likely to colonize in the Nicola drainage as well.
8.2	Problematic native species	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Included here are predation (i.e., pinnipeds etc.) and native disease issues. **Lower Fraser:** More seals exist in freshwater, but they could still be within historical levels. Their distribution has likely shifted because hatcheries are attracting seals further into freshwater and a year-round rookery of seals now prey on CN in freshwater. River Otters can also prey upon CN.
8.3	Introduced genetic material	BC	High - Medium	Large (31-70%)	Serious - Moderate (11-70%)	High (Continuing)	All populations except Louis Cr have been heavily enhanced for multiple generations. The PNI is high - nearly all fish in the Nicola R have some degree of hatchery ancestry. Effects of domestication and altered allele frequencies are pronounced here, which can be problematic since natural selection exerts relatively high pressure on this DU (compared to coastal systems). Broodtake procedures have been recently altered to better represent diversity in this population (e.g. run timing), but past broodtake might have led to unwanted effects.
9	Pollution	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	-
9.1	Household sewage and urban waste water	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Also includes untreated storm drains. Can be acute on smaller systems and result in die offs of juvenile Chinook (D. Hussey). This pollution section is from untreated storm drains, pharmaceuticals, home and personal care products etc. **From discussion with Tanya**

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
							Brown: Limited research has occurred in BC about pollution impacts on Chinook, but there has been some in Washington. The scope is definitely 100%, any fish passing through the lower Fraser will be exposed to pollutants, but uncertainty about the impacts exist and there is therefore hesitancy to assign to one category. We know there is a negative effect, but severity is hard to pinpoint. There are some ongoing studies that examine many contaminants in the Fraser estuary (household/industrial/historical). Tanya's lab is hoping to be able to identify the different pollution effects, including microplastics, and how they change with the different ocean migration routes. Most concerned about PCBs, PCDs, metals, household pharmaceuticals and personal care products, and pesticides in the lower Fraser. Offshore migrates might have more impacts from mercury. **DU15:** Treated sewage from the City of Merritt flows into the Nicola R. Septic fields also serve most rural properties in this DU. Current efforts are underway to assess water quality on the Nicola R.
9.2	Industrial and military effluents	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	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). **Lower Fraser:** Effluents exist in the Lower Fraser, but their effects on CN are not well-studied.
9.3	Agricultural and forestry effluents	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	**Lower Fraser:** Many log booms (including bark debris), runoff/sedimentation from mills, and log sorts, and agricultural runoff from pesticides exist in the Lower Fraser. **DU15:** Sediment avulsions occur from forestry activities. Massive sediment has fallen through Bonaparte R and Guichon Cr. In 2017, 500 000 cubic meters of sediment flowed through Guichon Cr, profoundly changing the pool riffle run structure. Wildfires and logging are thought to worsen sedimentation. Sediment can change hydrology and reduce the amount of interstitial space where fish seek cooler water.
9.4	Garbage and solid waste	-	Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Included here are microplastics, abandoned nets/lost nets. Microplastic impacts are pervasive in scope and are definitely a threat, but the severity for CN is unknown.
9.5	Airborne pollutants	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	High (Continuing)	Ubiquitous contaminant impacts, with an unknown severity. Everyone agreed there were population level effects.
9.6	Excess energy	-	Unknown	Unknown	Unknown	Unknown	Noise impacts and excess light energy are scored here - both are unknown.
10	Geological events	-	Unknown	Unknown	Unknown	High (Continuing)	-
10.1	Volcanoes	-	-	-	-	-	None
10.2	Earthquakes/tsunamis	-	-	-	-	-	None
10.3	Avalanches/landslides	-	Unknown	Unknown	Unknown	High (Continuing)	**DU15:** Natural landslides are difficult to discern from those caused from logging, road expansion, wildfires and climate change. Bank stability along CN migration path, timing of landslide, scope of landslide, and the amount of time required to mitigate a landslide are all unknown.
11	Climate change and severe weather	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	-
11.1	Habitat shifting and alteration	BD	High - Low	Pervasive (71-100%)	Serious – Slight (1-70%)	High (Continuing)	Included here are: sea level rise, the blob 2.0; ocean acidification, marine survival and all associated aspects. This category could be as low as 1% or as high as 70% over the next 3 generations. Future ocean conditions are uncertain. It is possible 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). **DU15:** The impact of wildfires, worsened by climate change, have significantly altered this habitat.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
11.2	Droughts	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	**DU15:** All streams are vulnerable to drought - the effects of which are exacerbated by water withdrawals.
11.3	Temperature extremes	BC	High - Medium	Pervasive (71-100%)	Serious - Moderate (11-70%)	High (Continuing)	Stream temperatures will continue to rise to critical levels (>18C) based on current projections (Porter et al. 2013). These increases in stream temperatures are expected to affect the entire population (i.e., the scope is pervasive). This impact is expected to be continuing into the future. However, the severity of this is unknown because of limited data (Riddell et al. 2013). **DU15:** All streams are temperature sensitive. Thermal barriers exist in the Nicola R during the CN spawning migration and are eased by groundwater upwelling.
11.4	Storms and flooding	CD	Medium - Low	Large (31-70%)	Moderate - Slight (1-30%)	High (Continuing)	**DU15:** Spius Cr and Coldwater R are vulnerable to rain on snow events because of their mountainous headwaters.

APPENDIX F. RESEARCH NEEDS

This section provides a summary list of research needs identified during this RPA process, many of which were discussed in detail in the threats assessment. In some cases, there is developing and ongoing research in these areas through various organizations, academia, and different levels of federal and provincial governments.

F.1. FRESHWATER HABITAT

- There is a need to expand our knowledge of fine-detailed Chinook habitat use in the mainstem of the Fraser River. Surveys in the mainstem of the lower Fraser River (e.g. near Agassiz) have identified this as important rearing habitat for many Fraser Chinook DUs. There is some, albeit limited knowledge of habitat use in the mainstem Fraser, but there is more opportunity to gain a better understanding of life history and the temporal and spatial aspects of habitat use/occupancy.
- Previous studies have reported physiological limitations of SBCC for turbidity that are lower than levels observed in some systems known to contain Chinook Salmon. This has likely led to an under-estimation of freshwater habitat use, particularly within the Fraser drainage, and future research should aim to investigate both the physiological limits of turbidity and habitat use in turbid systems for SBCC.
- There is a growing body of information indicating that climate change will lead to an earlier spring freshet, which can impact migration and affect the quantity, availability and quality of freshwater rearing habitats. Considerable research could help understand the implications of changes in timing and duration of the spring freshet.
- There have been massive losses in forest cover in the Fraser River and Boundary Bay drainages through logging, wildfires, and pest infestations. Studies are required to investigate alternate reforestation strategies to address optimizing watershed rehabilitation and restoration, while taking into account climate change, fire and pest resilience and future fibre supplies.
- Research is needed to better characterize SBCC freshwater distribution and suitable habitat supply at the DU level. Element 14 of the RPA aims to provide advice on the status of habitat *supply* and *demand,* and to inform discussion about whether habitat availability is currently limiting population growth. This element was not addressed in the RPA, and will require considerable study of fry dispersal, behaviour, densities, and survival. This information can then be used to coordinate habitat preservation and/or restoration efforts for SBCC.
- Historical development in the lower Fraser River has led to losses in off-channel and stream habitat, and reductions in floodplain connectivity has likely reduced the freshwater carrying capacity for SBCC. Research is therefore needed to understand the potential mitigation effects of reconnecting off channel habitat, particularly in the lower Fraser River.
- Research is needed to gain a better understanding of spawning levels and spawner distribution at the DU level.
- Effects of log booms on predator behaviour and habitat quality and availability for juvenile Chinook require further research, particularly in the lower Fraser River.

F.2. MARINE HABITAT USE

- There is limited available data on the marine distribution and habitat use of SBCC due to the vast areas that they inhabit in the Pacific Ocean. Much of the available data relate to recoveries in fisheries and little is available in terms of pre-fishery distributions. There are some CWT recovery data available for areas along the Pacific Coast outside of Pacific Salmon Treaty waters, and up into the Bering Sea, however these data are limited and inconsistent over time. While large-scale tagging studies are difficult to approach for a variety of logistical reasons, future research should aim to increase our knowledge of SBCC marine distribution to better manage fishing activities and marine protected areas.
- It would be beneficial to determine if there are "carrying capacity" bottlenecks in the nearshore and distant marine habitats, and what (if anything) could be done to alleviate those constraints on production.

F.3. ABUNDANCE AND LIFE HISTORY PARAMETERS

- Due to a lack of indicator stocks for many SBCC DUs, current productivity, survival, and biological data are limited or non-existent. In addition, abundance estimates for many DUs rely heavily on indices of relative abundance, and in some cases, may not be representative of the DU as a whole. As a result, our current understanding DU-level population trends are highly uncertain for these DUs. Obtaining this information will be difficult due to the logistic challenges associated with developing CWT programs. If possible, through CWT (or other) programs, future research should aim to investigate the following at the DU level:
  - Absolute abundance estimates
  - Stock recruit time series data
  - Freshwater and marine survival
  - Length at age
  - Changes in fecundity
  - Maturation rates
  - Trends in age proportions of returns

F.4. POLLUTION

- The effects of pollution at all life stages was identified as a major knowledge gap for SBCC. There are many sources of contaminants in the Fraser River and Boundary Bay drainages and along the Pacific coast (both current and historic) that impact SBCC, many of which have been shown to have negative effects on various Pacific salmon populations in both Canada and the US. These contaminants were broken into the following categories in Element 8 of the RPA:
  - Household Sewage and Urban Waste Water
  - Industrial and Military Effluents
  - Agriculture and Forestry Effluents
  - Garbage and Solid Waste
  - Airborne Pollutants
- It is critical to understand the numerous and dynamic sources and effects of these contaminates for future SBCC mitigation and recovery planning. Considerable research is needed in order to inventory and prioritize pollution risk and subsequent mitigations, and should be considered at the individual DU-level.

F.5. ENHANCEMENT

- Research is required to identify and address data deficiencies within current enhancement programs to ensure that objectives and protocols are aligned with the conservation strategies and recovery of these DUs.
- Competition between hatchery-origin and wild fish occurs at all life stages and in all habitats, the latter of which has been shown to be limiting in the lower Fraser River and estuary due to extensive historical development. High levels of hatchery production may therefore lead to increased competition for finite and limited resources, particularly for SBCC DUs that have similar life histories to those that receive high levels of enhancement (i.e. ocean-type SBCC). While there are some studies available that attempt to characterize these interactions, further research is needed to determine the risk of hatchery competition in the Fraser River and Boundary Bay drainages, and identify the carrying capacity of their associated estuarine habitats.
- There is a need to investigate the extent of genetic introduction into DUs from outside of those populations. Genes can be introduced by the straying of hatchery fish from other populations or deliberately releasing out-of-DU hatchery fish, both of which have occurred in DU1. The impacts from introduction of genes from hatchery-origin fish, in addition to stock transfers, and the use of stored genetic materials should be thoroughly investigated.

F.6. SHIFTS IN PREDATOR/PREY SPECIES INTERACTIONS

- With rapidly changing climatic conditions, there will likely be a continued shift in predator/prey species composition within both freshwater and marine environments. There is a need to better characterize the changes and understand the implications to future Chinook Salmon production. Examples of this are the changing distribution of zooplankton prey species with warming ocean temperatures and the recent increase of coastal jellyfish populations, both of which could change prey availability.
- The distribution of marine predators of Chinook Salmon may be shifting due to warming ocean temperatures. An example of this is the presence of Salmon Sharks in the Bering Sea, where the onset of colder ambient water temperatures were generally thought to drive some predators out of these cold habitats as winter sets in. There is a need to better understand the abundance and distribution of large predators such as Salmon Sharks, in addition to the magnitude of late ocean mortality of Chinook Salmon from predation by large predators.
- There are significant knowledge gaps in the abundance and population trends of a variety of co-occurring freshwater predators, such as pike minnow, seals, and river otters that may also be contributing to declining trends in abundance. Future research is needed to better our understanding of these predatory interactions for juvenile and adult SBCC, and the magnitude of these effects.
- Further research on the impacts of pinniped predation at various life stages of Chinook Salmon is required.

F.7. INVASIVE SPECIES

- The timing of invasion and establishment of invasive species was identified as a significant knowledge gap for all SBCC DUs, and should be considered in mitigation planning. There are a number of invasive fish species that may have detrimental impacts on juvenile SBCC abundance, including Largemouth and Smallmouth Bass, Yellow Perch, Pumpkinseed, Black Crappie, Bullhead, and Northern Pike, in addition to a variety of non-fish species such as European Green Crab and dressenid mussels (i.e. Zebra/Quagga Mussels). European Green Crab in particular was identified as a major potential threat due to their capacity to alter habitats with abundant aquatic vegetation such as eelgrass meadows, which are critical components of juvenile Chinook rearing habitat. While some research is ongoing through provincial and academic organizations in BC, there is a need to clarify a process and platform to better quantify the current distributions and population status of these invasive species, and to determine the levels of risk they pose to SBCC through predation and competition.

- Research is needed to investigate the impacts of pinniped (in particular Harbour Seals, Stellar Sea Lions, and California Sea Lions) predation on SBCC, particularly for low-abundance DUs in which predation effects could be significant. There has been increasing pressure in recent years to reduce pinniped numbers by conducting a cull; however, further research is needed to understand the indirect effects of conducting a cull in addition to other factors that influence ecosystem function such as food web relationships, shifting prey/predator distributions, and hatchery practices. Further to this, with our limited understanding of both Pacific Salmon and pinniped population dynamics, we have little capability in determining whether removals would produce the intended effect.

F.8. DISEASE

- Disease prevalence and intensity is difficult to study in wild salmon populations due to the extensive geographic range they inhabit, and because fish mortality is generally not observed and carcass recovery can be difficult. However, there are opportunities to investigate disease in migrating adult salmon returning to spawning grounds, and to improve upon monitoring and detection protocols for disease. Future research should aim to better characterize the linkages between disease transmission and frequency in SBCC populations with the many stressors these stocks are facing, such as climate change and increasing frequency of drought and periods of low flows.
- All DUs have been shown to migrate through Discovery Island and Johnstone Strait where there is a high probability that they are in contact with active fish farms. Research is required to understand their exposure to the farms, which could be facilitated by acoustic tracking studies.

F.9. FISHING

- Chinook Salmon from some SBCC DUs are caught in fisheries outside the Pacific Salmon Treaty waters; however, there is little in the way of specific accounting for these impacts as some fisheries are without formal CWT monitoring programs or effective alternatives.
- There is a need to collect more and better encounter data from non salmon-targeted fisheries and distant fisheries such as the Gulf of Alaska Pollock fishery and mid-water trawl fisheries for Hake off US/Southern BC coast.
- Recently, concerns surrounding the potential impacts of mass-marking programs and the implementation of mark-selective fisheries have been raised, as injured and/or stressed wild salmon can be subject to substantial mortality following release. The impacts from mark-selective fisheries should be investigated for SBCC DUs, and compared to the benefits of the information provided and possible alternatives.
- Considerable research is needed to better characterize harvest rates for SBCC both at the MU and DU level. The current paucity of CWT-indicator programs for the Spring and

Summer 5.2s has resulted in a lack of information on age- and fishery- specific harvest rates. Developing DU-specific encounter rate information, for both retention and non-retention fisheries would be very valuable.

- There is considerable uncertainty surrounding illegal fishing activity in both the freshwater and marine environments, in addition to fisheries that intercept SBCC as bycatch. Research is needed to investigate the impact these activities have on SBCC, particularly at the DU-level, and to provide information for potential mitigations.

F.10. MITIGATION MEASURES

- Considerable research is needed to investigate the feasibility and potential effectiveness of mitigation measures that may benefit SBCC. In Element 16 of the RPA a broad inventory of mitigation measures that may benefit SBCC was discussed, using examples from both within the Fraser River, Boundary Bay drainages, and distant regions, yet there is a great amount of uncertainty with regards to their applicability or practicality. Due to our limited knowledge of SBCC habitat use and supply (particularly for stream-type SBCC with no stock-recruit data) variable inter-annual environmental conditions, and a large and often inter-related suite of threats and limiting factors that lead to SBCC mortality, there is insufficient information to accurately quantify the benefits of individual mitigation measures at the DU or even MU level. As more research is conducted on the effectiveness of mitigation measures it may be possible in the future to estimate ranges of productivity changes for certain projects.
- There is an enormous amount of variation in habitat type, hydrology, and environmental conditions between streams within the SBCC DUs considered in this RPA, and often major differences exist between watersheds within a single DU. This is particularly challenging for mitigation planning for multiple DUs in which there are a large number of watersheds (i.e. DU13-STh-1.3, DU15-LTh-1.2). Future research on SBCC mitigation should explore DUs on an individual basis to better represent these aggregate populations.

APPENDIX G. EXCERPT FROM WILD SALMON POLICY ASSESSMENT: BENCHMARK CALCULATION METHODS

Provided below is an excerpt from the Research Document that is pending from the 2014 Assessment of Southern British Columbia Chinook Salmon Conservation Units, Benchmarks and Status[46]. The excerpt provided from the report describes the abundance status metric (13.1) and the benchmark calculations (13.2). These exact methods were used to calculate the abundance benchmarks using the updated habitat model provided in the RPA research document.

G.1. WSP STATUS METRICS

G.1.1. Abundances

The (geometric) average spawner abundance in the most recent generation was compared against the lower benchmark, S_{gen}, and an upper benchmark, 85% of S_{MSY}, where S_{gen} is defined as the spawner abundance that will result in recovery to spawner abundances at maximum sustainable yield (S_{MSY}) within one generation under equilibrium conditions (Holt et al. 2009). The upper benchmark (i.e., 85% of S_{MSY}) is a slight deviation from that proposed by Holt et al. 2009 (i.e., 80% of S_{MSY}), and was adopted to be consistent with an agreed benchmark for Chinook Salmon assessment specified in the Pacific Salmon Treaty (PST 2008). Benchmarks (and 90% confidence intervals) were obtained through published stock-recruit parameters where available (CK-01: Okanagan; CK-03: Harrison; CK-22: Cowichan), or otherwise estimated from habitat models of freshwater capacity for rivers where Chinook Salmon spawn (Parken et al. 2006). See section 13.2 for further details on this calculation. In short, S_{gen} is estimated by solving the following equation iteratively:

(3) $$S_{MSY} = \alpha S_{gen} e^{-\beta S_{gen}}$$

G.1.2. Benchmarks for the Relative Abundance Metric

For the majority of southern BC Chinook Salmon CUs, it is not possible to calculate traditional stock-recruit parameters, due to insufficient data. For these cases, a habitat-based approach has been developed to provide comparable estimates of productivity and capacity (Parken et al. 2006), and these can then be used to provide upper and lower abundance benchmarks (as outlined in the previous section).

The habitat model predicts S_{MSY} and S_{REP}, spawner abundances at maximum sustainable yield or replacement, and the associated confidence levels from watershed characteristics (Parken et al. 2006; updated by C. Parken, DFO, unpublished data). Benchmarks were then estimated from S_{MSY} and S_{REP} using the Ricker model:

(4) $$R = \alpha S e^{-\beta \cdot S + \omega}, \omega \sim (N, \sigma_{\omega}^2),$$

[46] Brown, G., Thiess, M.E., Pestal, G., Holt, C.A and Patten, B. In prep. Integrated Biological Status Assessments under the Wild Salmon Policy Using Standardized Metrics and Expert Judgement: Southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) Conservation Units. DFO Can. Sci. Advis. Sec. Res. Doc.

where α is the productivity parameter, β is the capacity parameter, ω is a stochastic term, and σ_{ω}^{2} is the variance of the recruitment anomalies. Using first principles (Ricker 1975) and an approximation for S_{MSY} (Hilborn and Walters 1992), Ricker α and β parameters could then be estimated as:

(5) $$log_e(\alpha) = \frac{0.5 - \frac{S_{REP}}{S_{MSY}}}{0.07}, \text{ and } \beta = \frac{log_e(\alpha)}{S_{REP}}$$

Finally, S_{gen} was estimated by solving Equation (3) iteratively as outlined in the previous section.

For CUs with spawning sites across multiple watersheds, an extra step was required to arrive at CU-level habitat estimates of S_{MSY} and S_{REP}. Prior to estimating S_{gen} as outlined above, joint distributions of S_{MSY} and S_{REP} for the CU were calculated from the individual estimates for all watersheds contributing to the reported escapement time series (i.e. this meant including habitat-based estimates for all persistent, aggregated or extirpated census sites, but not from data deficient or deleted census sites). For each CU, the following non-parametric procedure was used:

6. Generate 10,000 samples of S_{MSY} for each of the *n* contributing census sites in the CU, where

$$S_{MSY,i,j} \sim lognormal\big(median(S_{MSY,i}), std\ error(S_{MSY,i})\big), \qquad i = 1, \dots, n;\ j = 1, \dots, 10\,000$$

The median and standard errors of S_{MSY} for each contributing census site were provided by C. Parken (unpublished data).

7. Estimate the S_{MSY} for the CU ($S_{MSY,CU}$) by summing across the *n* contributing census sites' S_{MSY} estimates for each of the 10,000 random samples (thus generating 10,000 samples of $S_{MSY,CU}$) and calculating the mean and standard deviation of the resulting distribution.

$$S_{MSY,CU_j} = \sum_{i=1}^{n} S_{MSY,i} \quad where\ i = 1, \dots, n; j = 1, \dots, 10\,000$$

$$S_{MSY,CU} \sim lognormal\left(median\left(S_{MSY,CU_j}\right), std\ error(S_{MSY,CU_j})\right)$$

8. S_{REP} was identified as a proportion of S_{MSY}, so in order to maintain this relationship, the point estimate of S_{REP} was determined dependent on the ratio of median S_{REP} to median S_{MSY} for each contributing census site, multiplied by the random sample of S_{MSY}s:

$$S_{REP.ratio_i} = med(S_{REP,i})/median(S_{MSY,i}) \quad where\ i = 1, \dots, n$$

$$S_{REP,i,j} = S_{REP.ratio_i} \cdot S_{MSY,i,j} \quad where\ i = 1, \dots, n\ and\ j = 1, \dots, 10\,000$$

In a manner similar to Step 3, S_{REP} for the CU ($S_{REP,CU}$) was approximated by:

$$S_{REP,CU} \sim lognormal\left(S_{REP,CU_j}, std\ error(S_{REP,CU_j})\right), \qquad j = 1, \dots, 10\,000$$

where $S_{REP,CU_j} = \sum_{i=1}^{n} S_{REP,i},\ i = 1, \dots, n$