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Interior Fraser Coho Salmon Recovery Potential Assessment

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Foreword

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

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ABSTRACT

The Interior Fraser Coho Salmon (IFC) (*Oncorhynchus kisutch*) Designatable Unit (DU) was assessed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2016, and is currently under consideration for addition to Schedule 1 of the *Species at Risk Act*. This Recovery Potential Assessment (RPA) provides descriptions and status of populations, habitat, threats and limiting factors, possible recovery targets and population projections, as well as recommendations regarding mitigation and allowable harm. The initial decline in IFC is attributed to decreased smolt-to-adult survival and lagged fisheries management response; however, subsequent management has halted further decline. The population trajectory since 2005 appears flat, with uncertainty. Quantification of suitable freshwater habitat represents a knowledge gap for IFC. Threats with the highest ranked risk (modifications to catchment surfaces, linear development, and agricultural and forestry effluent) were associated with landscape-level modifications affecting whole watersheds. As well, threats from both anthropogenic and natural factors will be exacerbated by climate change and cumulative impacts. General types of mitigation measures were recommended because a landscape-level approach that may benefit multiple COSEWIC-assessed salmonids and freshwater species is likely the most effective approach, and would require a collaborative effort among multiple government, First Nations, and non-government agencies that is beyond this RPA. The suggested DU-level natural-origin spawner abundance target of a 3-year geometric mean of 36,935 is based on observed abundances that met a distribution goal of 1000 spawners per subpopulation. Projections of growth to the recovery target under different fishing mortality and smolt-to-adult survival regimes was based on a stock-recruit analysis from brood years 1998-2013, but contains several caveats and conditions. Three models, based on different hypothesized population dynamics, were updated from a previous CSAS assessment and their forward projection results were given equal weight and model-averaged. Results indicate that positive population growth and reaching the recovery target under current conditions (average exploitation rate of 12.5% and smolt-to-adult survival of 1.0%) is 41% or “about as likely as it is not likely”. If smolt-to-adult survival continues like current conditions and no impacts to freshwater habitat and egg-to-smolt survival occur, IFC are likely (≥ 66% chance) to have positive population growth at a fishing mortality of 6%; however, the risks imposed by climate change and continued anthropogenic development add notable uncertainty. Therefore, it is recommended that only activities in support of the survival and recovery of the species, which may result in possible mortalities (e.g. stock assessment, research, or mitigation activities), be permitted to ensure positive population growth.

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 kisutch*

Common Name – Coho Salmon (interior Fraser River populations)

COSEWIC Status (Year of Designation) – Threatened (2016), Endangered (2002)

COSEWIC Reason for Designation (2016) – This population experienced declines in excess of 60% in the number of mature spawning individuals in the 1990s because of a reduction in marine survival (as indicated by smolt-to-adult survival), changes in freshwater habitats, and overexploitation, which resulted in a designation of Endangered in 2002. The population increased in abundance from 2005 to 2012 but escapements in 2014 and 2015 were very low. Marine survival rate has deteriorated. There are several threats to the freshwater habitat related to invasive species, drought, increased water temperatures, land use, and increased urbanization. All of these factors were suspected to cause reductions in numbers exceeding 30% over three generations including years in the recent past and the future.

1.2 LISTING AND RECOVERY BACKGROUND

Interior Fraser River Coho Salmon, hereafter, IFC, belongs to the Salmonidae family and spawns (reproduces) in the Fraser River watershed upriver from Hells Gate in British Columbia. The IFC are genetically unique, representing a single DU, and can be genetically distinguished from populations in the lower Fraser River watershed and other areas of Canada and the United States. The IFC occupy about 25% of the range of Coho Salmon within Canada. Coho Salmon are semelparous and anadromous, returning to fresh water from marine waters from August to November and spawn during fall and early winter before dying of senescence. Fry emerge from the gravel the following spring and remain in freshwater for a year or two before migrating to the ocean as smolts. Most of IFC spend 18 months at sea before returning to freshwater to spawn and complete a 3-year life cycle, and about 12% of them have a 4-year life cycle.

The status for IFC has been assessed multiple times recently by both COSEWIC and Fisheries and Oceans Canada (DFO). In 2002, IFC were assessed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (Irvine 2002), however they were declined for listing under SARA in 2006. In response to the COSEWIC designation, DFO assembled a multi-interest team, the Interior Fraser Coho Recovery Team (IFCRT), and a comprehensive conservation strategy was published (IFCRT 2006). In 2013, DFO prepared a pre-COSEWIC report (Decker and Irvine 2013), and subsequently COSEWIC changed the assessment from Endangered to Threatened (COSEWIC 2016). The existence of high (**historic**) and low (**current**) productivity regimes is an important aspect of considering recovery and risks from threats that was highlighted in the pre-COSEWIC report (Decker and Irvine 2013). In 2014, a

Science Advisory Report (DFO 2015a) was created from a peer review meeting on the IFC Salmon Interim Assessment to assess IFC in the context of the IFCRT recovery objectives (IFCRT 2006). Also in 2014, IFC were assessed under the Wild Salmon Policy (WSP) framework, which assessed the DU as five Conservation Units (CU) (DFO 2015a). Three of the CUs were determined to be “Amber” WSP status and two were “Amber/Green” WSP status, based on population dynamics, abundance, distribution, productivity, and their trends in the context of current environmental conditions (Parken et al.[1]). The most recent analysis on IFC by Korman et al. 2019 examined IFC in the context of the Pacific Salmon Treaty and developed management reference points. A full list of documents on IFC can be found in Appendix 1.

There is no formal Recovery Strategy for IFC because it is not listed under SARA, however the IFCRT created a conservation strategy. The conservation strategy identified several short- and long-term recovery goals and objectives, and identified several high-level threats and strategies to mitigate aspects of them (Table 1).

Table 1. Summary of strategies for the recovery of Interior Fraser River Coho Salmon (last updated in 2005).

Threat	Strategy	Anticipated Effect
Harvest	Refine abundance-based harvest management methods to set exploitation caps based on survival and abundance forecasts.	Increase number of spawners.
Harvest and Climate Change	Manage escapement goals to allow Interior Fraser Coho to recover beyond the short term recovery objective.	Increase number of spawners.
Climate Change	Recover all sub- populations so that they will be viable during periods of climate-related low marine and freshwater productivity.	Increase number of spawners.
Habitat Change	Maintain and restore functionality and productivity to as many habitats within each population as is feasible.	Increase survival at all life stages and improve spawning and rearing success.
Habitat Change	Investigate the relationships between habitat and Coho Salmon throughout their life history and range and determine important habitat requirements.	Improve understanding of life history. Increase survival of populations.
Habitat Change	Improve public awareness and increase amount of stewardship.	Increase survival of populations.

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[1] Wild Salmon Policy Biological Status Assessment for Conservation Units of Interior Fraser River Coho Salmon (*Oncorhynchus kisutch*). Parken, C.K. and 20 co-authors. CSAS Working Paper 2013SAL12.

Threat	Strategy	Anticipated Effect
Hatchery Production and Harvest	Hatchery fish may be used as part of the conservation strategy or to assess abundance and/or survival of selected populations or subpopulations.	Maintain ability to assess threats and progress of recovery. Increase successful spawners.
Hatchery Production and Harvest	Develop specific rules for initiation, continuation, and modification of hatchery activities, including the consideration of whether hatchery production should cease once recovery objectives are achieved.	Reduce genetic risk. Revise long-term production goals.
Hatchery Production	Select gametes from the native population so as to minimize the risk of losing genetic information from within a population.	Reduce genetic risk.
Hatchery Production	Return juveniles to the wild as soon as is feasible with juvenile release timing dependant on the conservation strategy chosen.	Reduce competition in freshwater habitat.
Hatchery Production	Annually assess hatchery contribution to the escapement.	Maintain ability to assess threats and progress of recovery.
Hatchery Production and Harvest	Continue to mass mark lower Fraser and Strait of Georgia hatchery releases to encourage the use of selective harvesting of visibly marked hatchery fish.	Increase number of Interior Fraser River wild and hatchery Coho Salmon spawning in the wild. May increase genetic risk.

The IFCRT (2006) also noted that partnership groups were developing more-localized salmon recovery plans. For example, with sponsorship and funding from the Pacific Salmon Foundation and the Pacific Salmon Endowment Fund Society, the Scw’exmx Tribal Council (formerly the Nicola Tribal Association) and the Nicola Watershed Community Roundtable formed a partnership to coordinate the implementation of the Coldwater River Watershed Recovery Plan (Nelson et al. 2001). Up to 2005, the partnership had undertaken three years of recovery implementation activities. With similar sponsorship and funding, the Salmon River Watershed Roundtable partnership had developed a watershed salmon recovery plan for the Salmon River (Salmon River Watershed Society 2004). There are several other local stewardship groups working in the interior Fraser River watershed (Appendix 2).

In response to the decline in abundance and productivity, reductions in exploitation rates (ERs) were instituted beginning in 1989 in both Canadian and American fisheries. Within southern BC, IFC are harvested incidentally by First Nations, commercial, and recreational fisheries in the Strait of Georgia, Johnstone Strait, along the west coast of Vancouver Island, and in the Fraser

River. Since 1989, a series of Canadian fishery management measures have reduced the ER on Coho Salmon populations (Appendix 3). These measures became more extensive over time, with the last large commercial harvest by Canadian fisheries occurring in 1996, with over one million Coho harvested in South Coast fisheries. Beginning in 1997, no Canadian commercial fisheries were permitted to target Coho Salmon; however, a Coho Salmon recreational fishery was continued with a reduced daily retention limit on Coho Salmon. First Nation fisheries were also restricted in the Fraser River and many Interior Fraser First Nations voluntarily ceased Coho Salmon harvesting. The social, cultural and economic implications of these management actions were far reaching throughout Southern BC, affecting both interior and coastal communities.

To support a listing decision for IFC by the Minister, DFO Science has been asked to undertake an RPA, based on the national RPA Guidance. The advice in the RPA may be used to inform both scientific and socio-economic aspects of the decision, development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits or agreements, and the formulation of exemptions and related conditions, as per sections 73, 74, 75, 77, 78 and 83(4) of SARA. The advice in the RPA may also be used to prepare for the reporting requirements of SARA s.55. The advice generated via this process will update and/or consolidate any existing advice regarding IFC.

2 BIOLOGY, ABUNDANCE, DISTRIBUTION, AND LIFE HISTORY PARAMETERS

2.1 ELEMENT 1: SUMMARY OF INTERIOR FRASER COHO BIOLOGY

Coho Salmon, *Oncorhynchus kisutch* (Walbaum 1792), is one of five anadromous and semelparous species of Pacific salmon native to North America (Sandercock 1991). The scientific names derive from the Greek roots for hook (onkos) and nose (rynchos) while the species name kisutch is commonly used in Kamchatka and Alaska (Hart 1973). The English common name for this species is Coho Salmon, but they are also referred to as silver salmon, sea trout, hooknose, or bluebacks, the latter referring to small Coho Salmon caught early in their final marine year (Decker and Irvine 2013). The French common name is Saumon Coho. There are additional names for Coho Salmon in local First Nations’ languages throughout the interior Fraser River watershed including but not limited to: sxeyqs, kwṓx̱weth, sx̣áyqs, xáyeqs, and Dedzikh (COSEWIC 2016).

Adult and juvenile Coho Salmon have several identifiable morphological features. Coho and other Pacific salmon can be distinguished from trout and char in having 12 or more anal fin rays. Adult Coho Salmon can be differentiated from other salmon by the presence of white gums at the base of the teeth in the lower jaw (Scott and Crossman 1973). When black spots occur on the tail fin they usually appear only on the upper lobe. Dimorphism develops as Coho Salmon become sexually mature with males becoming darker and often bright red, the upper jaw develops an elongated hooked snout, and the teeth become enlarged. Females are usually less brightly coloured and show lesser jaw development. In juvenile Coho Salmon the anal fin is sickle-shaped and the front edge is longer than the base. Detailed descriptions of Coho Salmon are provided in Scott and Crossman (1973), Hart (1973), Sandercock (1991), and Pollard et al. (1997).

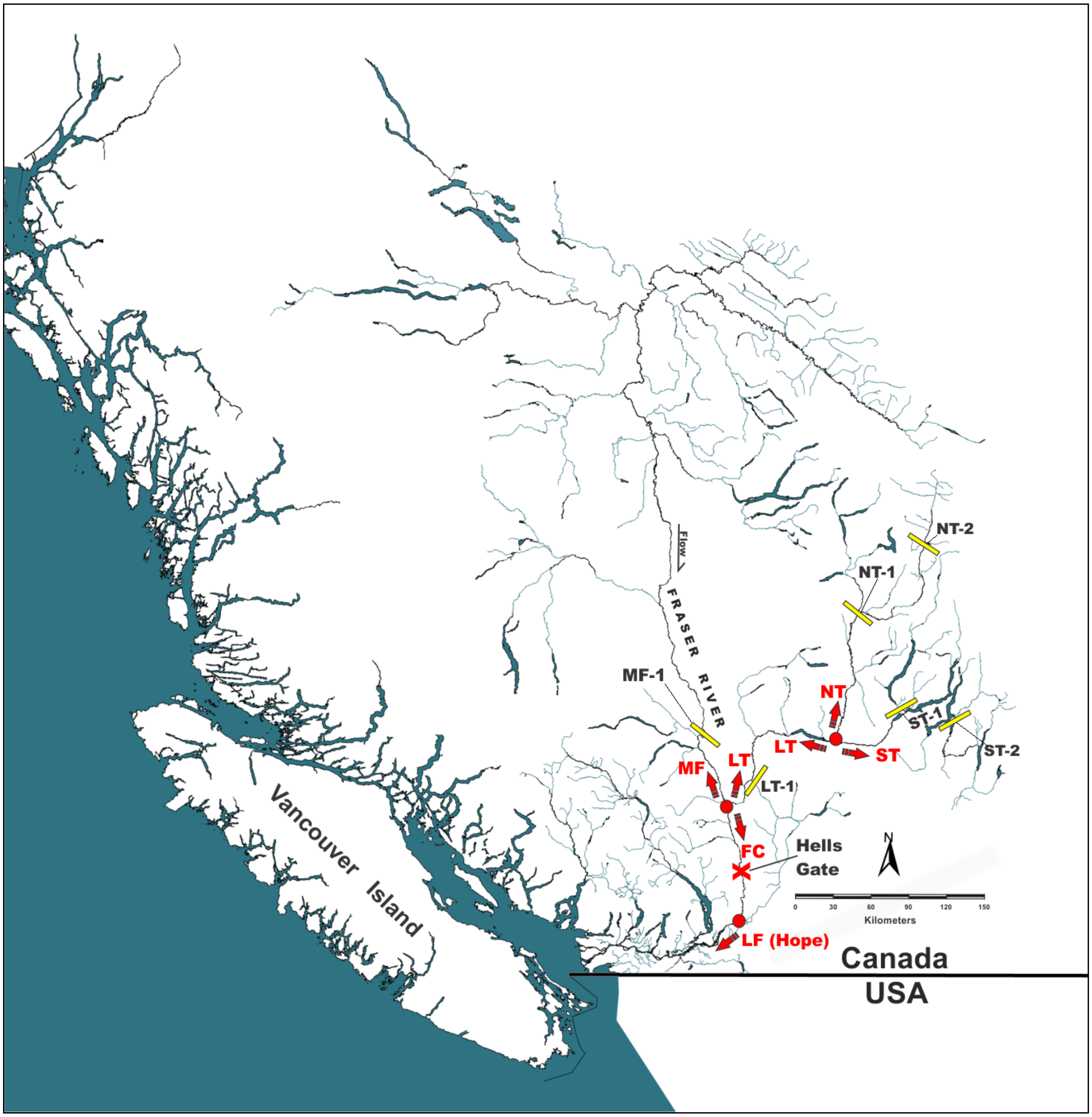

Figure 1. The Fraser River and its major tributaries. Here, the Interior Fraser Coho Salmon DU is considered all of the populations that are upstream of Hells Gate (marked by a red x). Each of the five Conservation Units (CUs) of IFC are separated by red points and text, as is the Lower Fraser (LF). The five CUs are North Thompson (NT), South Thompson (ST), Lower Thompson (LT), Fraser Canyon (FC), and Middle Fraser (MF). There are 1-3 subpopulations within each CU that are denoted by yellow breaks with green text. The ST CU includes the Adams River (upstream of ST 1), Shuswap Lake/Tributaries (between ST 1 & 2), and Middle/Lower Shuswap (upstream of ST 2) subpopulations. The NT CU includes the Lower NT (downstream of NT 1), Middle NT (between NT 1 & 2), and Upper NT (upstream of NT 2) subpopulations. The LT CU includes the Lower Thompson (north of LT 1) and Nicola (south of LT 1) subpopulations. The FC CU is only 1 subpopulation in the IFC DU, which is above Hells Gate. The MF CU includes the Lower Middle Fraser (downstream of MF 1) and Upper Middle Fraser (upstream of MF 1) subpopulations.

The population and spatial structure of IFC was affected by historical glaciation patterns. British Columbia (BC) was almost entirely covered by ice 15,000 years ago (Fulton 1969), followed by a period of global warming (Roed 1995). Anadromous salmon existed in several glacial refugia during the earlier period including the ice-free lower two-thirds of the Columbia River. As the ice retreated, much of the Fraser River drained through the Okanagan watershed, entering the ocean via the Columbia River (Decker and Irvine 2013) because the Fraser Canyon was blocked with ice near Hells Gate (Figure 1). It was during this period that Coho Salmon (and other species) colonized the interior Fraser River watershed from a glacial refugium in the lower Columbia River watershed (Northcote and Larkin 1989). Fish entered by post-glacial lake connections in the Okanagan-Nicola area and by upper mainstem Fraser/Columbia connections. Coho Salmon in the middle and upper Columbia River watershed upstream of the Deschutes River, that may have been genetically similar to Interior Fraser Coho, are now extinct (Nehlsen 1997). The IFC are the only remaining representatives of this genetic group. In contrast to Interior Fraser populations, many salmon populations found in the lower Fraser River watershed colonized along the coast via the sea (Decker and Irvine 2013).

Coho Salmon exhibit spawning system fidelity and as such there are genetically and ecologically distinct populations within the species and within the IFC DU to an extent. Small et al. (1998a, 1998b) provide some evidence for differences within the IFC. A more exhaustive analysis reviewed the population structure of most North American Coho Salmon with a gene diversity analysis and found that the interior Fraser River are discrete from other Coho Salmon populations (Beacham et al. 2011). An updated analysis including more recent genetic data found that Coho Salmon from the North Thompson River drainage clustered together in 67% of dendrograms (Figure 2). The samples from the South Thompson and lower Thompson rivers formed clusters in 64% and 100% of the replicates. The samples from the middle and upper Fraser River systems cluster together in 75% of dendrograms (Figure 2). Coho Salmon from the single location in the Fraser River Canyon (Nahatlatch River) were discrete both from upstream populations and those of the lower Fraser River (Beacham et al. 2011). Due to their genetics, as well as geographic separation, IFC are separated into five Conservation Units (CUs) within the DU; the five CUs are North Thompson, South Thompson, Lower Thompson, Fraser Canyon, and Middle Fraser.

The IFC also differ morphologically and behaviourally from Lower Fraser River and other coastal populations. The IFC have smaller body size than fish from other populations and have also evolved a slightly earlier spawn timing to coincide with interior winter hydrology. Juvenile IFC are more fusiform and have greater stamina compared to coastal populations (Taylor and McPhail 1985a). Differences in juvenile traits were also shown to be at least partially inherited (Taylor and McPhail 1985b).

Figure 2. Neighbour-joining dendrogram of Cavalli-Sforza and Edwards (1967) chord distance for Interior Fraser River Coho Salmon Conservation Units. From the top, the groups are North Thompson (Blue), Middle Fraser (Orange), South Thompson (Green), Lower Thompson (purple), and Fraser Canyon (Nahatlatch_R), surveyed at 15 microsatellite loci. Bootstrap values at major tree nodes denoted by arrows indicate the number of 1000 trees where populations beyond the node clustered together. (Figure originally published in COSEWIC 2016)

Sexually mature Coho Salmon generally return to freshwater in the fall (August/November) and spawn during a protracted period throughout the fall and early winter. Like most salmon, Coho Salmon use olfactory cues to assist in their migration; however, unlike some salmon, IFC have a much lower tributary-level fidelity due to the variable hydrology and immense size and complexity of the CU basins where they return to spawn. The average straying rate of Coho Salmon from Vancouver Island is < 5%, with the average distance that strays travelled being 15.7 km (Labelle 1992). Due to the genetic differences between CUs, the across-CU straying rate of IFC is likely < 5% (Small et al. 1998a, 1998b), but within CU tributary fidelity (i.e. returning to the tributary where they were born) is likely low. Spawning can occur as early as August and as late as March in some populations (Weitkamp et al. 1995, Holtby and Ciruna 2007). The IFC spawning activity peaks in mid-November, and can extend to January. Females construct several redds, successively moving upstream. All Coho Salmon die after spawning. Incubation of their eggs in the redd generally takes 40-50 days or longer depending on water temperature; anywhere from 0-74% of eggs survive and fry emerge from the gravel between March and July (Sandercock 1991).

Juvenile Coho Salmon use and travel over large areas of freshwater, estuarine, and marine habitats. Upon emerging from the gravel, Coho Salmon fry school and can become territorial, with smaller fish displaced downstream or into less desirable habitat. Unlike coastal Coho Salmon, however, there is little evidence of territorial behaviour in the parr life stage for IFC (Chapman 1962, Warren 2010). Major episodes of fry dispersal include spring movements away from spawning sites (Gribanov 1948, Chapman 1962) and pre-winter movements into small tributaries and off-channel habitat (Peterson 1982). The IFC have substantial downstream movements between side channels, tributaries and mainstem river areas when rearing (Shrimpton et al. 2014). Individual IFC may have low site fidelity during the parr-smolt life stages and have a diversity of movement patterns(Shrimpton et al. 2014). For example, large numbers of fry have been captured in side-channel habitats in the North Thompson River that do not support spawning (Scott et al. 1982[2], Stewart et al. 1983[3]). In another study, DNA analysis indicated that 35% of a sample of 1,800 juvenile Coho Salmon collected during the winter from side-channel and off-channel habitat in the Lower Fraser River in 2006-2007 were of Interior Fraser origin (DFO, Fraser River Chinook and Coho Salmon Stock Assessment Division, unpublished data).

Downstream migration into the estuary and ocean generally occurs in the spring as yearlings. A length of 10 cm appears to be the threshold for smoltification and adaptation to saltwater conditions (Sandercock 1991). A small proportion of juveniles may spend two years in fresh water, and for IFC this proportion appears to be affected by the magnitude of the spring freshets connectivity to off-channel rearing habitats. The average residency of juvenile Coho Salmon in the upper portion of the Fraser River estuary ranged from one to two weeks across two years of one study (Atagi 1994) and the average juvenile Coho Salmon in North America spends one month in estuarine habitat before migrating offshore (Arbeider 2018). Some individual Coho Salmon do not undertake extended offshore migration but spend their entire marine existence near their natal stream. Coho Salmon, including the IFC, can migrate widely in the marine environment. There are indications that IFC initially migrate northward along the British Columbia coast to Alaska before moving offshore and counter-clockwise through the Gulf of Alaska (Sandercock 1991). Eventually, IFC return to the onshore areas mainly in BC and Washington, heading towards their stream of origin.

Most IFC spend 18 months at sea, returning to fresh water in the fall to complete the 3-year life cycle. About 12% of IFC have a 4-year life cycle and these fish went to sea in their third year, but still only spent 18 months at sea. Based on a 7,261 fish sample aged from scales, 88% went to sea in their second year (i.e. 1 year old fish), 12% reared in fresh water for an additional one year, and less than 1% were aged as either jacks (precocious mature males) or older than 4 years (DFO Fraser Stock Assessment unpublished data).

Coho Salmon range in length and weight at maturity from 45-70 cm (fork length), and from 2-5 kg, although fish over 12 kg have been caught (Scott and Crossman 1973, Sandercock 1991). The IFC are smaller than most Coho Salmon from other parts of the range of similar age (Sandercock 1991, Weitkamp et al. 1995). Fecundity increases with length and latitude but

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[2] Scott, K. J., M. A. Wheln, L. B. MacDonald, J. D. Morgan, and W. R. Olmsted. 1982. 1981 Biophysical studies of select Chinook and Coho Salmon producing tributaries of the North Thompson drainage, part 1: juvenile salmon investigations. Available from Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Road, Nanaimo, BC, V9T 6N7

[3] Stewart, G. O., R. B. Lauzier, and P. R. Murray. 1983. Juvenile salmonid studies in the North Thompson region of BC, 1982. Available from Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Road, Nanaimo, BC, V9T 6N7.

generally is in the range of 1500-7000 eggs per female (Sandercock 1991). Fecundities for IFC are highly variable and hatchery brood-stock averages are at the lower end of this range (1900-2800), consistent with the generally smaller length of IFC fish.

General research on Coho Salmon (i.e. not IFC specific research) has found that they are primarily insectivorous and piscivorous across their freshwater to marine stages. Juvenile Coho Salmon in streams consume larval and adult insects, primarily of aquatic origin (Dill and Fraser 1984, Nielsen 1992). Juvenile Coho Salmon in coastal Southern BC waters primarily consume juvenile Pacific Herring (*Clupea pallasi*) followed by Sand Lance (*Ammodytes hexapterus*), and crustaceans (euphausiids, amphipods, and megalops larvae) (Prakash 1962). Estuarine diets are an intermediate between freshwater and marine diet (Arbeider 2018). Adult Coho Salmon diets in coastal BC waters are dominated by fish, consisting of Herring, Sand Lance, and other small pelagic fish including Anchovy (*Engraulis mordax*), Surf Smelt (*Hypomesus pretiosus*), Capelin (*Mallotus villosus*), and Sardines (*Sardinops sagax*) (Foerster 1955). Adults also feed extensively on euphausiids and occasionally squid (*Loligo sp.*). Pritchard and Tester (1943, 1944) report Coho Salmon consumed rockfish (*Sebastes sp.*), Sablefish (*Anoplopoma fimbria*), myctophids, Pacific Hake (*Merluccius productus*), Saury (*Cololabis adocetus*), Walleye Pollock (*Theragra chalcogramma*), and other Coho Salmon.

The predator landscape for Coho Salmon changes as they grow and move from fresh water to salt water. Predation on IFC while they reside in fresh water is likely from Bull Trout (*Salvelinus confluentus*), Rainbow Trout (*Oncorhynchus mykiss*), Northern Pikeminnow (*Ptychocheilus oregonensis*), and cottids (*Cottus spp.*) (COSEWIC 2016). Other general freshwater predators include herons (*Ardea herodias*), mergansers (*Mergus merganser*), and mink (*Neovison vison*). Predators in the marine environment include Dogfish (*Squalus acanthias*) and sharks as well as Bonaparte's (*Chroicocephalus philadelphia*) and Glaucous-winged Gulls (*Larus glaucescens*), loons (*Gavia spp.*) and marine mammals such as Harbour Seals (*Phoca vitulina*), sea lions (*Eumatopias jubatus* and *Zalophus californianus*), and Killer Whales (*Orcinus orca*).

Further description of IFC biology can be found in the COSEWIC (2016) and pre-COSEWIC (Decker and Irvine 2013) reports.

2.2 ELEMENT 2: EVALUATION OF RECENT INTERIOR FRASER COHO SALMON ABUNDANCE TRAJECTORY, DISTRIBUTION, AND NUMBER OF POPULATIONS

2.2.1 Distribution and number of populations

The terminology used to describe the "populations" within the IFC DU vary across organizations. There are five CUs in the IFC DU which correspond to the five major Coho Salmon bearing drainages within the interior Fraser River watershed: three within the Thompson River (North, South, and Lower Thompson), and two within the Fraser River (Fraser Canyon and Middle Fraser) (Figure 1). The IFCRT (2006) also identified subpopulations within each CU, which have been assessed by DFO in follow-up management planning activities (Decker et al. 2014). It is important to note that the COSEWIC refers to the CUs as **subpopulations**, which are referred to as **populations** or CUs in other IFC documents (Table 2).

Table 2. Overview of terminology used in different reports with equivalent interpretation (i.e. in the same Delineation Level). For example, all terms used in the 1st Sub-level refer to the 5 major divisions shown in Figure 2. DU = Designatable Unit. MU = Managment Unit. CU = Conservation Unit. IFCRT = Interior Fraser Coho Recovery Team. COSEWIC = Committee on the Status of Endangered Wildlife in Canada. PST = Pacific Salmon Treaty. WSP = Wild Salmon Policy.

Delineation Level	IFCRT / Pre-COSEWIC	PST / WSP	COSEWIC
Broadest (e.g. all systems upstream of Hells Gate)	DU	MU	DU
1st Sub-level (e.g. all systems part of the North Thompson River)	CU	CU	Subpopulation
2nd Sub-level (e.g. systems upstream of the Blue River confluence within the North Thompson River)	Subpopulation	Subpopulation	(no reference of)

Subpopulation delineations are based on the following factors: the presence of natural barriers, the influence of large lakes on downstream discharge and thermal regimes, observations of spawner aggregations under differing discharge conditions, and limited genetic evidence. The Fraser Canyon is the only CU that is not split into two or three subpopulations because most of the spawning occurs within one river. The 11 subpopulations are described in detail in the IFCRT report (2006). Identification of these subpopulations may be important for considering the distribution aspect of a Recovery Target (*5.1 Element 12*). Trends in abundance, however, will only be reported on the CU (population) and DU-levels.

The spatial distribution of IFC depends on the overall distribution of accessible rearing and spawning areas. There are more than 11,775 km of stream habitat within the known range of IFC, with approximately 7,000 km accessible to migrating adult IFC and 3,600 km suitable for spawning (Table 3). These are minimum estimates as, for the most part, they only represent mainstem distances along the major tributaries of the Fraser River and the mainstem distances along the main tributaries to those streams (IFCRT 2006). Although the amount of Coho Salmon utilization of the upper Middle Fraser area is poorly understood, it is important to note that over two-thirds (67%) of the stream area accessible to IFC lies in the upper portions of the Fraser River. The populations with the most data, i.e. those in the Thompson River drainage, occupy less than one-third (31.9%) of the area accessible to IFC. The lack of records on the presence of IFC in many parts of the upper Middle Fraser CU is a major knowledge gap.

The COSEWIC (2016) reported an index of area of occupancy (IAO) for IFC based on the distribution of spawning areas based on a 2x2 km grid. The IAOs were 669 km^2 for the Fraser Canyon CU, 916 km^2 for the Lower Thompson CU, >2000 km^2 for the South Thompson CU, 1612 km^2 for the North Thompson CU, and >2000 km^2 for Middle Fraser River CU. Overall, the extent of occurrence exceeds 20,000 km^2 for the IFC DU.

Table 3. Total mainstem stream lengths and currently accessible habitat for IFC. These values are likely underestimates because they are only mainstem streams were measured, see Appendix 6.

Population region	Total stream length (km)	Percent of total length	Accessible Stream (km)	Percent of total accessible	Suitable for Spawning (km)	Percent of total suitable
Fraser Canyon	104.4	0.9	78.3	1.1	78.3	2.1
Middle Fraser	7,504.1	63.7	4,702.3	67.0	1,754.4	47.7
North Thompson	1,536.4	13.0	844.0	12.0	576.3	15.7
Lower Thompson	1,013.2	8.6	613.3	8.7	585.7	15.9
South Thompson	1,620.6	13.8	781.4	11.1	686.9	18.7
Total	11,778.6	—	7,019.3	—	3,681.5	—

2.2.2 Trends in productivity and abundance

Estimated total pre-fishery returns (those fish of natural- or hatchery-origin returning to their natal stream pre-harvest), removals (e.g. hatchery brood stock), and spawners (both excluding and including hatchery-origin) were provided by DFO Fraser Salmon Stock Assessment (Appendix 4). The IFC spawner abundance data have been systematically uploaded to the New Salmon Escapement Database System (NuSEDS); however, revisions of past spawner estimates have not been consistently updated in NuSEDS. Therefore, the Fraser Stock Assessment data set is the most up-to-date source for the five IFC CUs. Information on data quality and age structure (from 1998 to 2017) was obtained from the same source. A detailed description of the most recent treatments of data can be found in Parken et al.[1] and Appendix 5. Here, only data from 1984-2017 will be used due to changes in assessment over the years based on management priorities and available resources, both in terms of the number of systems surveyed and the extent of coverage.

Lowered smolt-to-adult survival was a major factor that reduced productivity of IFC and is likely inhibiting the DU's ability to recover to historic levels. Decker et al. (2014) noted two distinct periods in the stock-recruitment relationship for IFC (Figure 3a) that are likely driven by a change in smolt-to-adult survival. Productivity was considerably higher for return years 1987-1993 (brood years 1984-1990) than for return years 1994-2017 (brood years 1991-2014). This change corresponds approximately to a 1989-1990 change in marine conditions (Beamish and Bouillon 1993, Irvine and Fukuwaka 2011). A shift is evident in annual smolt-adult survival estimates for IFC hatchery-indicator stocks, with survival for the past 15+ years being much lower than before the regime shift (Figure 3b). Smolt-to-adult survival averaged about 4.8% from brood years 1984-1990, then dropped to 1% in brood year 1992. Smolt-to-adult survival appeared to increase after brood year 1992 but then decreased to 0.3% in brood year 2003. Since the last peak in smolt-to-adult survival around brood years 1997-1999, smolt-to-adult survival has averaged 1.0%. The higher survival and productivity period before brood year 1991 (i.e. 1984-1990) will be referred to as the **historic regime** and the lower survival/productivity period from 1991 onwards will be referred to as the **current regime**.

Estimated ERs (total Canada and the United States) also determine pre-fishery abundances and are essential in defining salmon escapement, i.e. the number of fish that return to the spawning grounds. The ER averaged 66% from 1984-1997 (Figure 3c). With the realization that the number of pre-fishery returns and escapement were declining rapidly in the 1990s, a recovery program was initiated in 1998 and measures were implemented to reduce the ER to below 13% (Decker et al. 2014). The ER has averaged 12.5% since 1998; however, there was a high ER of 32% in 2014.

The IFC are semelparous with an average 3-year life span, giving 3 somewhat independent broodlines. There is one broodline that has recently had much greater abundance than the two others. In order to smooth the observed cyclic dominance, a 3-year running geometric average of the annual escapement and return values is used to describe and analyze underlying trends. When return (the year that adults return and spawn) or brood years (the year that a cohort was laid as an egg) are described in this report that are from a running average, the cited year is the middle-year of a 3-year period (e.g. 2015 includes 2014, 2015, and 2016). Smoothing over cycles with a geometric running mean is recommended for Pacific salmon species with log-normally distributed abundance data (Grant et al. 2011).

The pre-fishery returns (typically referred to as recruits) and natural-origin escapements in the historic (high productivity) regime were much higher than in the current (low productivity) regime. Estimated pre-fishery returns of IFC averaged 5.2 times greater in the historic regime than the current regime. The 3-year running geometric average returns in the historic regime varied between 153,000 and 227,000 with an overall average of 199,000. The 3-year running geometric average pre-fishery returns in the current regime varied between 21,000 and 70,000 with an overall average of 38,000. The average natural-origin escapement was 2.2 times greater in the historic regime that the current regime. The 3-year running geometric average escapement in the historic regime varied between 36,000 and 74,000 with an overall average of 57,000. The 3-year running geometric average escapement in the current regime varied between 17,000 and 43,000 with an overall average of 26,000.

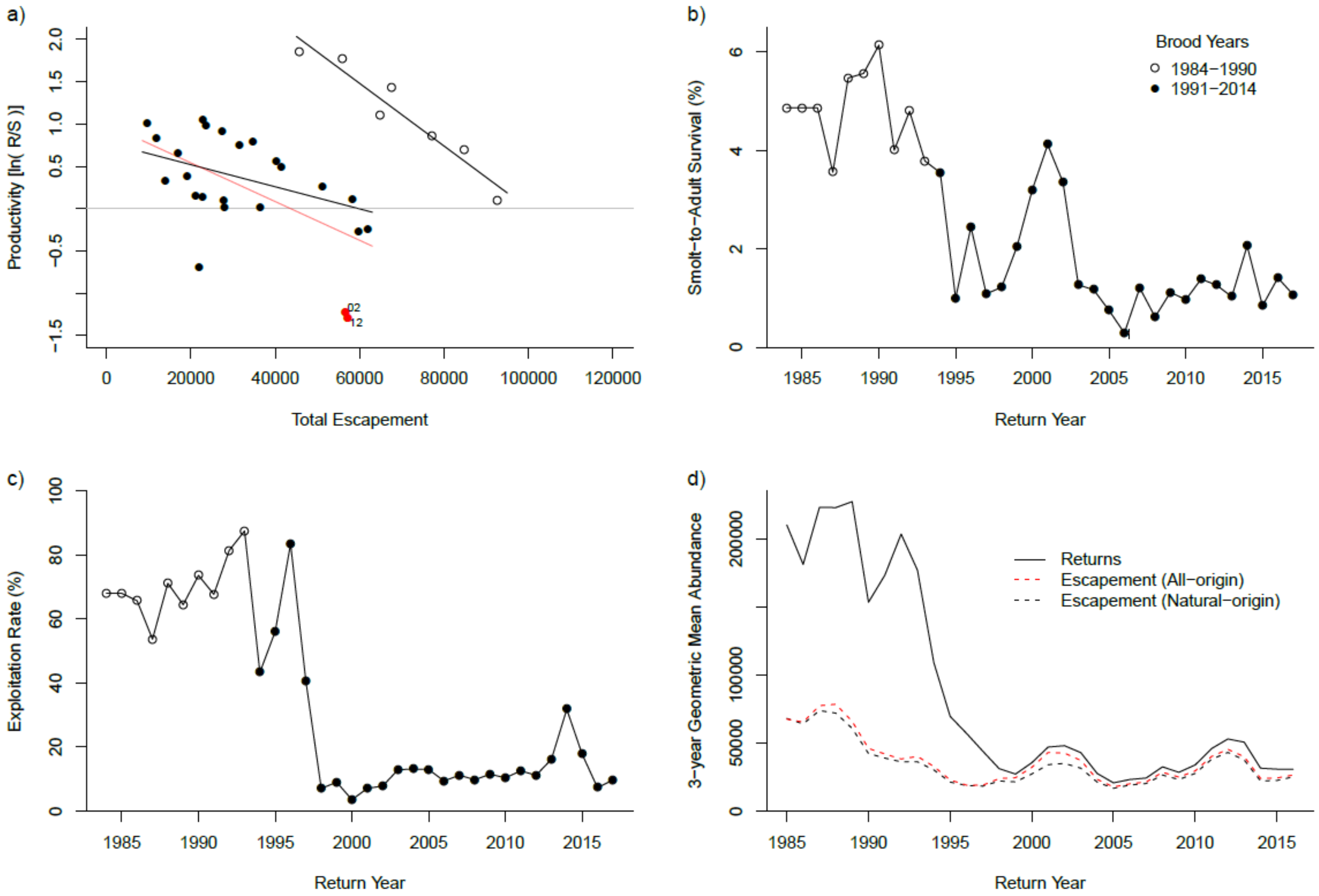

Figure 3. Productivity versus total escapement abundance (a), smolt-adult-survival (b), exploitation rate of adipose present pre-fishery returns (c), and 3-year geometric mean abundance of pre-fishery returns (black solid), total escapement (red dashed), and natural-origin escapement (black dashed) for IFC that span two productivity regimes. Brood years 1984-1990 are open circles, which coincide with the historic regime, and 1991-2013 are filled circles, which coincide with the current regime. In (a), the black lines represent the relation between productivity and total escapement; $R^2 = 0.93$ and 0.19 for the historic and current regimes, respectively, with $p < 0.05$ for each model. The two red points are influential points from brood years 2002 and 2012. The red line is the current regime slope with the influential points included. Data are available in Appendix 4, however, this figure assumes all fish are age 3 to make recent years comparable to years prior 1998 where scale-age data are scarce or absent.

2.2.3 Long term and recent population trajectories

The population trajectories were calculated over two time periods from the slope of natural-log linear regressions of total pre-fishery returns and natural-origin spawners:

1. The entire time series (**long term trend,** 1985-2016)
2. The last 10 years (**recent trend,** 2007-2016)

The former is consistent with International Union for Conservation of Nature (IUCN) guidelines for fluctuating populations with more discrete cycles (IUCN 2014, guideline 4.5.1) and with current salmonid scientific literature (Porszt et al. 2012, D'Eon-Eggertson et al. 2015). The latter is recommended by IUCN and by COSEWIC under general circumstances. For both methods, the percent change in abundance over 10 years was estimated as 100*(exp(10*b)-1) where b is the slope of the respective natural-log linear regression. Therefore, results will be reported as the percent change in abundance in the 10 most recent years based on a population trajectory calculated from either the entire time series (long term trend) or the last 10 years (recent trend). The slope was calculated using generalized least squares models with a first order autocorrelation structure to account for the temporal correlation between return years. All data were smoothed using a 3-year running arithmetic average prior analysis because it was then natural-log transformed. Therefore, the long term trend is estimated from 32 running averages (centered from 1985-2016) and the recent trend from the last 10 running averages (centered from 2007-2016).

The average slope in pre-fishery returns was always negative when estimated from the long term trend, whereas a couple of slopes were positive when estimated from the recent 10-year trend (Figure 4; Table 4). The average percent change in returns in 10 years for the IFC DU was -46.1% as estimated from the long term trend and all but two of the CUs upper 95% confidence intervals (2.5 and 97.5%) were negative. Whereas the average percent change as estimated from the recent 10-year trend in pre-fishery returns for the IFC DU was 18.6%. The Fraser Canyon, South Thompson, and North Thompson CUs had negative average percent changes as estimated by the recent term trend. However, the 95% confidence interval for all CUs in the recent 10-year trend crossed 0, suggesting large uncertainty in the shorter length, recent term return trajectories. Therefore, the returning DU abundance may still be declining when considering the longer data series, while there is larger uncertainty in the trajectory when only considering the recent 10-year trend data.

Most of the average slopes in natural-origin spawner abundance were negative when estimated from the long term trend, whereas a couple were positive from the recent 10-year trend (Figure 4; Table 5). The average percent change over 10 years in spawners for the IFC DU was -20.6% as estimated from the long term trend but the 95% confidence interval crossed 0. Three CUs had confidence intervals cross 0 in the long term trend models, including two CUs that had positive averages. The average percent change as estimated from the recent 10-year trend in spawners for the IFC DU was 16.6% but the lower confidence bound was negative. The Fraser Canyon, South Thompson, and North Thompson CUs had a negative average as estimated from the recent term trend. However, the 95% confidence intervals for all CUs from the recent term trends crossed 0, suggesting uncertainty in the current spawner abundance trajectories. Similar to the returns results, it appears that the spawning abundance in the DU may be declining when considering the longer data series, while there is larger uncertainty in the trajectory when only considering the recent 10-year trend data.

After the addition of 2 years of escapement data since the COSEWIC (2016) report, it is not recommended that a reassessment be completed before the scheduled timeframe (2026). The average percent change in 10 years across the CUs and DU derived from the long-term trend were all very similar to the COSEWIC report, with the 95% confidence interval (CI) of this assessment always overlapping with the COSEWIC averages. The percent change estimates across the CUs and DU derived from the recent term were always lower (i.e. either less positive or more negative) than the COSEWIC averages and the 95% CIs did not always encompass the COSEWIC averages. This may indicate that the DU may be declining more rapidly than when it was assessed by COSEWIC in 2016; however, confidence intervals or statistical error was not reported by COSEWIC, making conclusions difficult. Since the DU average percent change from the recent trend is still positive (but uncertain), it is still likely that the threats associated with IFC and their lowered abundance relative to historic levels would be the main factor in determining that this population is “Threatened”.

Given the mitigating effect of reduced exploitation after 1998, the trend in total pre-fishery returns reflects the impacts from the decline in productivity that occurred after 1989 more accurately than the trend in escapement (Figure 3c, d). The trend in total returns was not reported by COSEWIC (2016).

Table 4. Estimated rate of change and percent change over 10 years in pre-fishery returns for Interior Fraser Coho Salmon Designatable Unit (DU) and Conservation Units (CUs). Slope estimates are presented for the long term and recent 10-year periods from their respective regressions. The remaining columns give the average percent (%) change in abundance over a 10-year period and the 95% confidence interval.

Period	Returning Unit	Slope	% Change	2.5%	97.5%
Long Term	Lower Thompson CU	-0.032	-27.4	-57.1	22.8
	South Thompson CU	-0.065	-47.8	-69.4	-11
	North Thompson CU	-0.071	-51	-65.2	-30.9
	Fraser Canyon CU	-0.108	-66	-76.1	-51.6
	Middle Fraser CU	-0.031	-26.7	-53.7	16.2
	Interior Fraser DU	-0.062	-46.1	-64.1	-19.1
Recent	Lower Thompson CU	0.049	63.8	-26.6	265.8
	South Thompson CU	-5e-5	-0.1	-49.7	98.4
	North Thompson CU	-0.006	-5.7	-52	85.3
	Fraser Canyon CU	-0.055	-42.4	-91.5	289.9
	Middle Fraser CU	0.065	90.7	-15.4	330
	Interior Fraser DU	0.017	18.6	-41.4	140.1

Table 5. Estimated rate of change and percent change over 10 years in natural-origin spawner abundance for Interior Fraser Coho Salmon Designatable Unit (DU) Conservation Units (CU). Slope estimates are presented for the long term and recent 10-year periods from their respective regressions. The remaining columns give the percent (%) average change in abundance over a 10-year period and the 95% confidence interval.

Period	Spawning Unit	Slope	% Change	2.5%	97.5%
Long Term	Lower Thompson CU	0.007	6.9	-27.9	58.5
	South Thompson CU	-0.028	-24.5	-53	21.3
	North Thompson CU	-0.03	-25.9	-43.8	-2.3
	Fraser Canyon CU	-0.067	-48.7	-63.1	-28.8
	Middle Fraser CU	0.012	13	-11.5	44.2
	Interior Fraser DU	-0.023	-20.6	-41.3	7.5
Recent	Lower Thompson CU	0.056	74.3	-22.4	291.5
	South Thompson CU	-0.009	-8.4	-53.1	78.9
	North Thompson CU	-0.007	-6.9	-52.1	80.9
	Fraser Canyon CU	-0.058	-43.8	-91.4	269.4
	Middle Fraser CU	0.063	88	-10.9	296.9
	Interior Fraser DU	0.015	16.6	-41.2	131.2

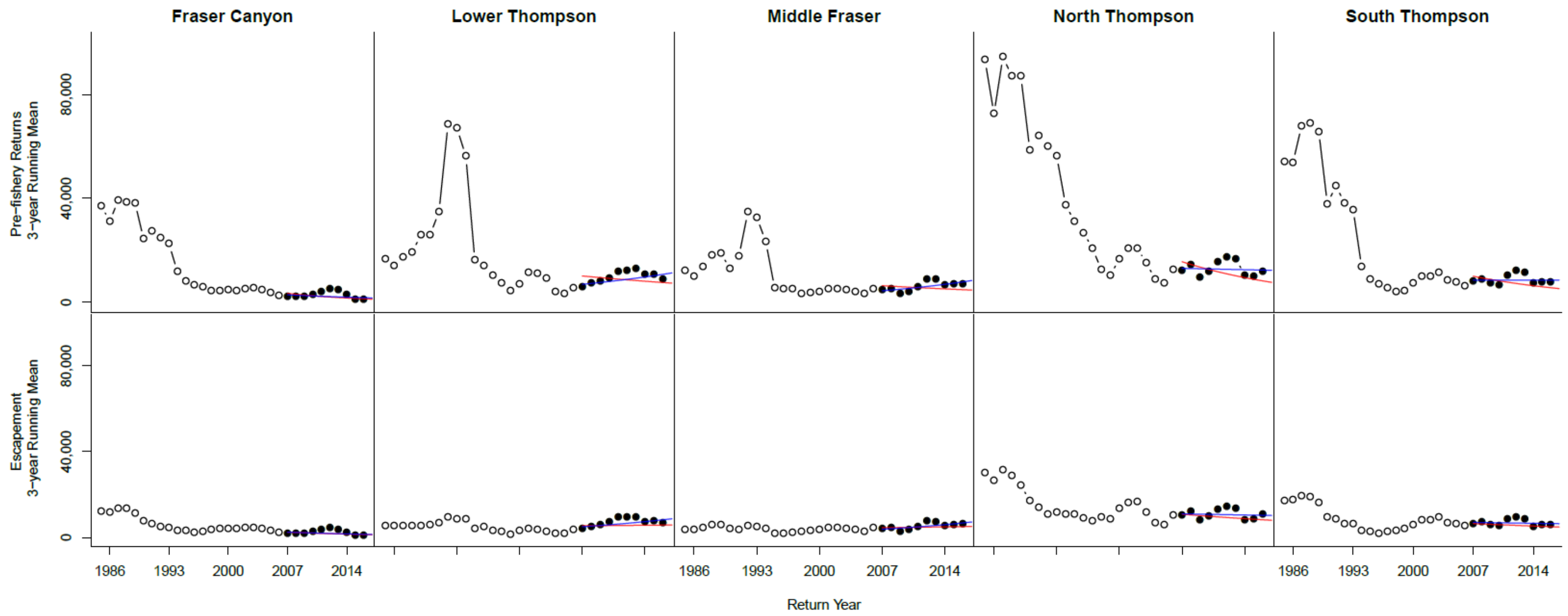

Figure 4. Linear Trend in Interior Fraser Coho Salmon CU pre-fishery returns (top row) and natural-origin escapement (bottom row).The red and blue lines are the mean slope over the recent 10 years (filled circles) from a generalized least squares model with first order autocorrelation derived from the entire time series (long term trend) and last 10 years (recent term trend), respectively. Note that the average recent 10-year trend slope is always more positive than the long term trend slope.

2.3 ELEMENT 3: ESTIMATES OF THE CURRENT OR RECENT LIFE-HISTORY PARAMETERS FOR INTERIOR FRASER COHO.

Important life-history parameters, listed in Table 6, were discussed in the prior Elements section. In most cases, up-to-date and consistent data for the current productivity regime are reported, including data from 1998 to 2018. Most data are from the DFO stock assessment program with the exception of fecundity data provided by the Salmonid Enhancement Program (SEP). Several parameters are also split across specific demes where there are only data from a specific location, whereas other estimates are only available at the DU-level.

There are several sources of uncertainty and underlying assumptions in many of the estimates. The age-at-maturity data and generation time are based on scale aging methods from scales collected from senesced adults. There are generally few scale samples from individuals (~100) collected per CU per year and not every CU-year has data. Scale quality and the consistency of the aging is also determined by the level of decomposition of the fish and the experience of the data collector, both of which can introduce bias.

The sex ratio data are only based on adults whose sex was identified post-mortem by stream-walk (dead-pitch) surveyors. Sex that was determined from live fish at fish fences was not used. Sex-ratio calculations performed on deceased fish assumes that there is an equal detection probability across sex, which is an unlikely assumption for some field programs. For example, there is decrease in the time-series proportion of males in Louis Creek whereas there is no trend evident at the Eagle River and Lemieux Creek.

Fecundity data provided by SEP were quality screened to only include data from fish that were “fully spawned” as the percentage of eggs recovered from “partially spawned” fish was unclear. Fecundity is estimated volumetrically and assumes that egg size has not changed through time.

Smolt-to-adult survival is estimated from hatchery reared fish that have been coded-wire tagged (CWT). This method assumes that sufficient CWTs are recovered on spawning grounds to estimate smolt-to-adult survival with a reasonable level of precision and that hatchery-origin fish have a comparable smolt-to-adult survival as natural-origin fish. For Lower Fraser Coho, Parken et al.[1] found that wild Coho Salmon smolts have higher survival than hatchery Coho Salmon smolts on average.

Total ER has many assumptions and potential sources of uncertainty. The methods used to estimate ER are described in the Fisheries Regulation Assessment Model (FRAM) (Model Evalution Workgroup: MEW 2008) and model assumptions have previously been discussed by the Pacific Salmon Commission Coho (PSC) Technical Committee (PSC 2013a).

Both the recruits per spawner and the spawners per spawner estimates (Table 6) are based on the age distribution reconstruction outlined in *5.2 Element 13* and Appendix 9. These estimates have the same uncertainties as the ER data and scale age data as well as several assumptions about covariation between CUs.

The spawner data itself also contain unrepresented observation and statistical error. Escapement estimates can be influenced by environmental conditions, which are not entirely represented and several escapement estimates are infilled for systems based the methods described in English et al. (2007). The general treatment of the spawner and recruitment data can be found in Parken et al.[1] or Appendix 5.

*Table 6. Life-history parameter's average estimates at the DU, CU, or Deme-level with their standard deviations (SD) and data timeframe. The first four parameter averages and SDs are calculated from annual point estimates weighted by sample size. The four latter parameters averages and SDs are calculated from annual point estimates with no weighting. *Note that this range is 1 SD above and below the mean from a log-normal distribution.*

Parameter (measurement)	DU, CU, or Deme	Estimate	SD	Data Timeframe
Age at Maturity (Percent Age 3)	DU Aggregate	88.3	1.3	2000-2017
	Lower Thompson	83.6	3.5	
	South Thompson	86.6	2.8	
	North Thompson	93.4	5.1	
Generation Time (Years)	DU Aggregate	3.12	0.018	2000-2017
	Lower Thompson	3.16	0.04	
	South Thompson	3.13	0.023	
	North Thompson	3.06	0.014	
Sex Ratio (Percent Males)	DU Aggregate	49.1	5.5	1998-2017
	Eagle River (ST)	49.6	6.3	
	Lemieux Creek (NT)	48.4	3.2	
	Louis Creek (NT)	49.1	6.2	
Fecundity (Eggs per Female from hatchery brood-stock)	DU Aggregate	2315	523	1998-2018
	Coldwater River (LT)	2287	468	
	Spius Creek (LT)	1916	402	1998-2003
	Deadman River (NT)	2222	456	1998-2014
	Eagle River (ST)	2785	583	1998-2018
	Salmon River (ST)	2280	465	
Smolt to Adult Survival (Percent from hatchery smolts)	DU Aggregate	1.0	0.7-1.6*	2000-2013
Exploitation Rate (Percent)	DU Aggregate	12.5	5.7	1998-2017
Recruits per Spawner (age distribution corrected)	DU Aggregate	1.30	0.70	1998-2013
	Fraser Canyon	1.20	0.94	

Parameter (measurement)	DU, CU, or Deme	Estimate	SD	Data Timeframe
	Lower Thompson	1.42	1.11	
	Middle Fraser	1.56	1.03	
	North Thompson	1.36	0.84	
	South Thompson	1.48	1.07	
Spawners per Spawner (age distribution corrected)	DU Aggregate	1.15	0.64	1998-2013
	Fraser Canyon	1.05	0.81	
	Lower Thompson	1.25	0.99	
	Middle Fraser	1.37	0.91	
	North Thompson	1.2	0.76	
	South Thompson	1.31	0.97	

3 HABITAT AND RESIDENCE REQUIREMENTS

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

The definition of habitat for IFC includes spawning grounds and nursery, rearing, food supply, migration, and any other areas on which the DU depends, directly or indirectly, in order to carry out its life processes. This broad definition means that essentially anywhere that IFC occur is considered to be Coho Salmon habitat. The IFC require adequate freshwater and marine habitats to survive and reproduce. An overview of habitat properties can be found in Table 7; however, most of these properties are derived from coastal Coho Salmon and specific habitat properties for IFC represents a substantial knowledge gap

3.1.1 Spawning and egg incubation habitat

Spawning occurs over a wide variety of habitats and the overall abundance of spawning habitat is not generally thought to be limiting (IFCRT 2006). The one known exception is within the Nahatlatch River.

As Coho Salmon spawn in fresh water and juveniles normally spend one full year there before migrating to the sea, their survival depends on having adequate habitat in fresh water as well as in the ocean. The distribution of spawning habitat for Coho Salmon is usually clustered within watersheds, often at the heads of riffles in small streams, and in side channels of larger rivers. Females generally construct nests, called redds, in shallow (30-cm) areas where the gravel is around or less than 15-cm diameter and has good circulation of well-oxygenated water (Sandercock 1991). The exact sizes of gravel that are used across the range of streams for IFC is unknown and additional monitoring effort is needed to quantify this property. Low or high flows, freezing temperatures, siltation, predation, and disease can reduce egg survival. Winters can be severe in the interior Fraser River watershed and winter stream flow and temperature may play a critical role in spawning site selection (Decker and Irvine 2013). Interior Fraser streams also generally experience declining discharges during the fall and winter as temperatures drop below freezing at higher elevations creating a risk of redds dewatering and freezing if spawning occurs too early. Spawning occurs in the fall and winter, and in lake-headed streams where temperatures and discharge are relatively stable (Decker and Irvine 2013) and non-lake headed streams with more variable temperatures and discharge. Coho Salmon are known to have differing temperature tolerances (Sandercock 1991) and the exact range of temperatures that IFC eggs, across their CUs, can survive is unknown and required additional research.

The hyporheic zone (Boulton et al. 2002) can be important areas for spawning site selection. McRae et al. (2012) found that groundwater moderates ambient stream temperatures and IFC select spawning micro-sites with groundwater upwelling. Groundwater also appears to influence spawning distribution at larger spatial scales with fish congregating in side channels with abundant groundwater off the main stems of larger streams such as the North Thompson River (IFCRT 2006). Therefore, features that may affect the hydrology of groundwater can also indirectly provide important habitat properties for Coho Salmon. The porosity of soil, density and type of vegetation, and gradient all have important interactions that determine groundwater flow and temperature (Naiman et al. 1992); it is important to consider the direct habitat requirements of species as well as indirect processes that shape them.

3.1.2 Fry and Juvenile Rearing Habitat

Following emergence, fry disperse from spawning sites (Chapman 1962) and move into small tributaries and off-channel rearing habitat. In the interior Fraser River watershed, fry emergence corresponds with periods of high discharge, and fry likely colonize flooded habitats created by the spring freshets. Major episodes of fry dispersal include spring movements away from spawning sites (Gribanov 1948, Chapman 1962) and pre-winter movements into small tributaries and off-channel habitat (Peterson 1982). Fry densities are generally higher in pools than in riffles in small streams and usually with gradients less than 3% (Decker and Irvine 2013). Data collected during a multi-year (2001-2011) survey of juvenile Chinook Salmon (*O. tshawytscha*) and Steelhead (*O. mykiss*) in the lower Thompson River system suggest that Coho Salmon fry reared mainly in small tributaries, and were largely absent from mainstem habitats in larger streams (Decker et al. 2012[4]).

Structurally complex habitats (large organic debris and large substrate), and habitats with slow moving water are both necessary to ensure high overwinter survival of young Coho Salmon (Solazzi et al. 2000). Groundwater ponds and channels and other types of off-channel habitats often support large numbers of overwintering Coho Salmon fry in Interior Fraser streams (Swales and Levings 1989, Bratty 1999).

Generally Coho Salmon use lakes less frequently than streams and there is a lack of information of IFC specifically. Fry have been recorded in near-shore regions of lakes in the interior Fraser River watershed, including some very large lakes (e.g., Shuswap Lake, Quesnel Lake; Brown and Winchell 2004), although the extent of use and the potential productive capacity of these lakes are unknown. The IFC fry appear to prefer lake habitats that are protected from wave action such as backchannels, alcoves, and sloughs, often in close

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[4] Decker, A. S., J. Hagen, and R. G. Bison. 2012. Annual distribution and abundance of steelhead parr in the lower Thompson River basin during 2001-2011 in relation to spawner abundance and habitat characteristics. Report Prepared for British Columbia Ministry of Natural Resource Operations, Kamloops BC, and the Habitat Conservation Trust Foundation, Victoria, BC. Available from Robert Bison at MNRO, Kamloops Region (Robert.Bison@gov.bc.ca).

proximity to the mouths of natal streams, as opposed to exposed shorelines (Brown 2002, Brown and Winchell 2004).

There is also evidence that, similar to some Interior Fraser Chinook Salmon populations (Murray and Rosenau 1989), substantial numbers of Coho Salmon fry from the Interior Fraser rear in non-natal streams for at least part of their freshwater residence. For example, large numbers of fry have been captured in side-channel habitats in the North Thompson River that do not support spawning (Scott et al. 1982, Stewart et al. 1983). In another study, DNA analysis indicated that 35% of a sample of 1,800 juvenile Coho Salmon collected during the winter from side-channel and off-channel habitat in the lower Fraser River, near Agassiz, in 2006-2007 were IFC, with fish originating from all five IFC CUs (DFO, Fraser River Chinook and Coho Salmon Stock Assessment Division, unpublished data).

3.1.3 Juvenile freshwater outmigration habitat

After one or sometimes two years in fresh water, juvenile IFC migrate down the Fraser River in the spring and early summer and enter the Strait of Georgia. Tagging indicates that it takes from 10-16 days to migrate from the interior to the lower Fraser River (Chittenden et al. 2010). Coho remain in the highly developed estuary of the Fraser River at Vancouver for an unknown period and many spend their first summer in the Strait of Georgia (Beamish et al. 2010), leaving in October/November (Chittenden et al. 2009).

3.1.4 Ocean rearing habitat

The IFC spend the remainder of their 18-month ocean residence primarily in coastal waters of the North Pacific (Weitkamp and Neely 2002, Weitkamp 2012). Habitat requirements of juvenile Coho Salmon in the Fraser River estuary and the Strait of Georgia are poorly understood. The belief is that early ocean residence is a critical period for Pacific salmon (Peterman 1987, Pearcy 1992), and that subsequent survival to maturity is determined during the first few months resident in the Salish Sea (Beamish et al. 2004, 2010). Early marine survival of Coho Salmon may be influenced by numerous interacting factors including sea temperatures, the timing of ocean-entry, spring plankton blooms, food availability, predator abundance, abundance of other competitor juvenile salmonids and generally favourable ocean conditions reflected in periods of negative Pacific Decadal Oscillation and absence of El Niño Southern Oscillation events (Beamish et al. 2004, LaCroix et al. 2009, Araujo et al. 2013).

3.1.5 Adult Freshwater Migratory Habitat

Adult IFC require habitat that permits them access to holding and spawning areas within the drainage. Adult Coho require freshwaters of sufficient depth and velocity for migration. In addition, water temperatures must be within an acceptable range and refuge or holding areas are required.

Under certain conditions, water velocities in the Fraser River near Hells Gate in the Fraser Canyon, and in the area referred to as Little Hells Gate in the North Thompson River (Figure 1) could impede upstream passage of IFC. Further research could investigate whether these two areas are important habitat. For all five IFC CUs and for the Upper North Thompson subpopulation to recover or survive, passage through Hells Gate and Little Hells Gate, respectively, needs to be unobstructed.

Table 7. Overview of habitat requirements for Coho Salmon by life stage. Most attribute values are taken from reviews of habitat requirements by Groot and Margolis (1991) and Bjornn and Reisser (1991). Notably, few studies on the habitat requirements of IFC have been published.

Life Stage	**Function**	**Feature(s)**	**Attributes**	**References**
Reproductive adults and embryos	Spawning, incubation	Redds are often constructed at the heads of riffles in small streams, and in side channels of larger rivers areas where the gravel is less than 15 cm diameter and has good circulation of well-oxygenated water. Groundwater can be important for some populations.	Particle size range: 1.3-10.2 cm Spawning water depth: > 18 cm Velocity: 0. 3-1.09 m/s DO_2: 7-12 mg/L Temperature: 4.4-13.3℃ Mean redd area: 2.8 m^2 Redd depth range:15-30 cm	Bjornn and Reisser 1991
Fry and juvenile rearing	Feeding, cover	Often found in side channels and small streams with cover. As juveniles grow they move from shallow habitats such as stream margins, side channels, and backwaters to deeper pool habitat (Rosenfeld et al. 2000). Non-natal streams and littoral zones of lakes channels may also be used for rearing.	Preferred temperature range: 12-14℃ DO_2: 5-12 mg/L Turbidity: <25 NTU Cover: high amounts of overhanging vegetation and undercut banks Gradient: <3% Pool size range: 50-250 m^2 Pool density: >1500 m^2/km Large woody debris density: >100 pieces/km	Reviewed in Groot and Margolis 1991; Sharma and Hilborn 2001
Juvenile freshwater outmigration	Outmigration, feeding	Large rivers, non-natal tributaries, estuaries	Largely unknown	-
Juvenile - Ocean rearing	Feeding	Coastal waters	Largely unknown - Lower annual sea-surface temperatures linked to higher marine survival	Beamish et al. 2010
Adult – freshwater migration	Upstream migration	Large rivers	Temperature range: 7.2-15.6℃ Water depth: >18 cm Velocity: <2.44 m/s	Bjornn and Reisser 1991

3.1.6 Update of status of knowledge gaps and suggested research

The IFCRT (2006) suggested several research actions that would identify important habitat properties; however, few of them have been fulfilled (Table 8). As noted prior, this element represents a large gap in IFC specific knowledge.

Table 8. Studies suggested by IFCRT to identify important habitat for IFC. The study columns and duration are from Table 5 of IFCRT (2006). The status column has been added by the authors of this report to highlight the continued need for them.

Study	Duration	Status
Map spawning and rearing habitat in the areas used by the Fraser Canyon Coho Salmon population; determine proportions that are within the Nahatlatch River. (Applicable to all CUs)	2 years	To be done
Quantify the relationships between river discharge, velocity, and depth and Coho Salmon passage success at Hells and Little Hells gates.	2 years	To be done
For each Coho Salmon life history stage, characterized the habitat features that support essential life history attributes of IFC	2 years	Partially complete (Warren 2010)
Determine the amount and configuration of habitat features including stream flow requirements, required to support each IFC DU and sub-population at or above the recovery objectives.	3 years	To be done
Determine the amount and configuration of habitat features currently available for each IFC DU and sub-population.	4 years	To be done
Map the habitat required to meet population recovery objectives.	5 years	To be done
Compare the habitat available with the habitat required for each IFC sub-population with the objective of determining the need for additional important habitat.	5 years	To be done
Develop an age-structured model and carry out population viability analyses to evaluate relationships among combinations of habitat, marine survival and fishery exploitation rates to estimate probabilities of population extinction, decline, survival, or recovery	5 years	To be done
Map ephemeral streams and assess the importance of ephemeral areas to Coho Salmon rearing and over-wintering behaviour.	4 years	To be done
Assess the importance of groundwater levels during winter low water and summer drought periods.	4 years	Partially complete (McRae et al. 2012)

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

3.2.1 Freshwater Habitat Distribution

The IFC spawn upstream of Hells Gate in the Fraser Canyon and are widespread throughout the Thompson River Watershed and Fraser Watershed north of the Thompson River confluence (Figure 1). The distribution in the Middle Fraser and Fraser Canyon areas are less well known. Coho Salmon are known to occur as far upstream as the Nechako River in the Upper Middle Fraser subpopulation area, but there are several major Upper Middle Fraser watersheds where Coho Salmon presence is probable but has not been confirmed. The extent of Coho Salmon possibly contracted after the landslides in Hells Gate in 1914 like Pink Salmon extent did (Ricker 1989); therefore, suitable habitat may be unoccupied as IFC may not have expanded their distribution to the pre-1914 extent. Most of the rivers and tributaries on the maps presented below have sections that contain the habitat properties described in Element 4. Some systems have had an assessment on the extent of “useable” habitat, though this assessment’s methods have not been found nor published (Appendix 6). Additional information on habitat properties in some systems can be found in the Community Mapping Network database; however, this information is general and stored in many layers, making it time intensive to acquire and use.

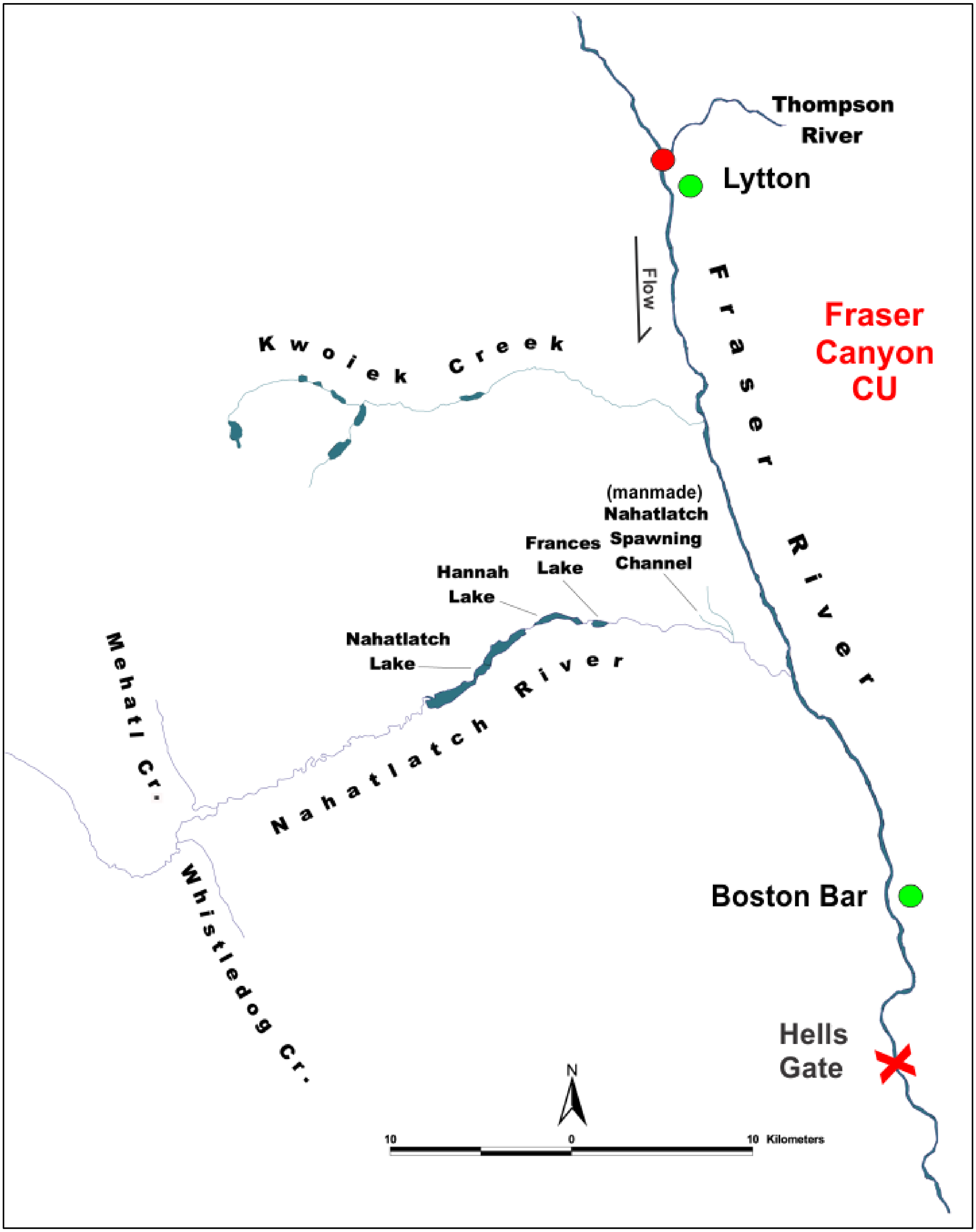

Figure 5. Major and minor tributaries of the Fraser Canyon Conservation Unit. The IFC DU occurs upstream of Hells Gate. Green dots denote cities and red dots at river forks denote breaks between CUs. Note that these markings will be used for Figure 6-Figure 11.

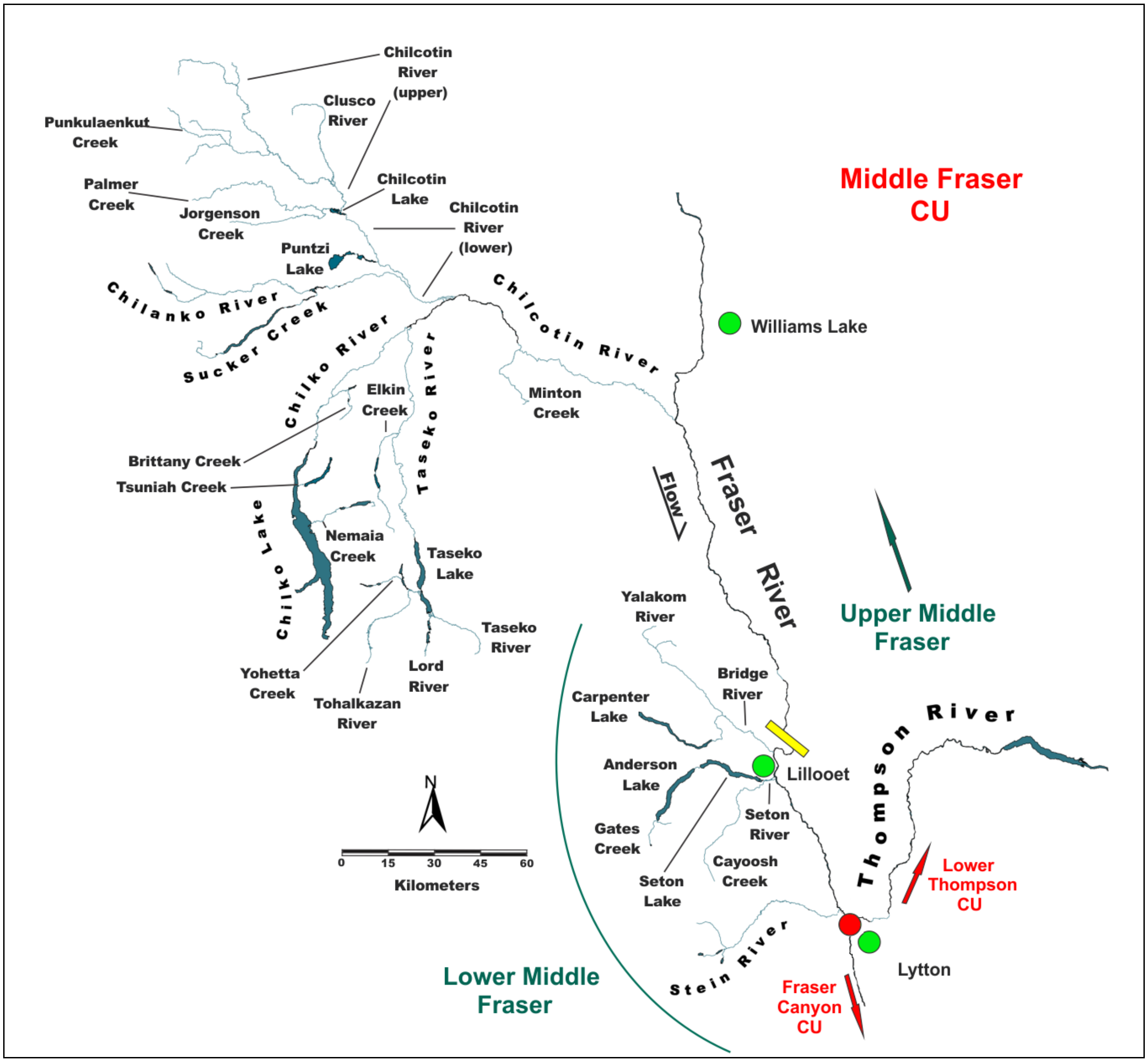

Figure 6. Major and minor tributaries of the Middle Fraser Conservation Unit. The yellow bar represents the break between subpopulations, which are written in green text (note that these symbols will be used in Figure 7-Figure 11). The Upper Middle Fraser subpopulation continues (this is 1 of 3) in Figure 7 and Figure 8.

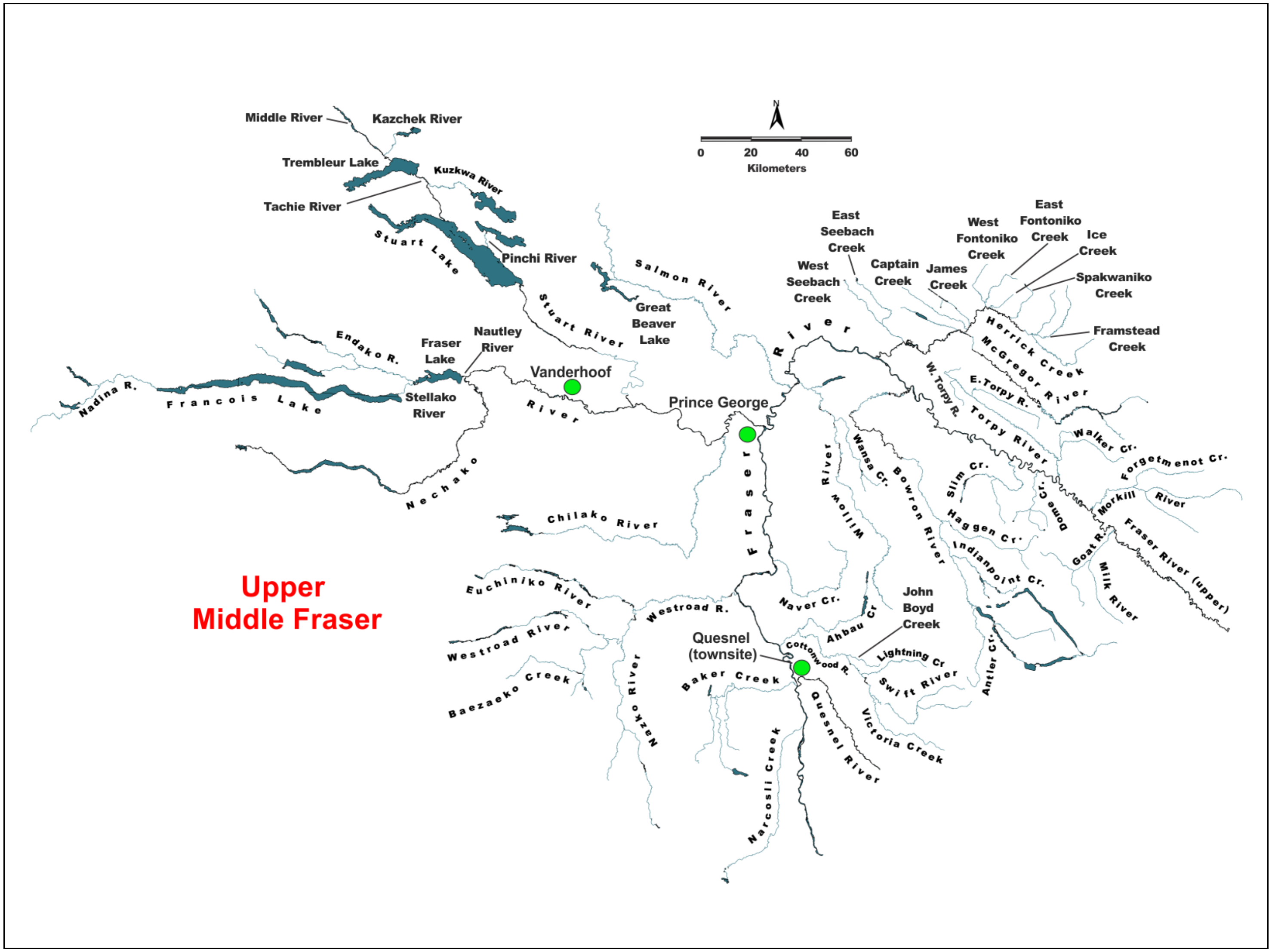

Figure 7. Major and minor tributaries of the Upper Middle Fraser subpopulation, continuation 2 of 3.This area represents the largest unknown section of likely usable habitat. Coho Salmon have been observed in some of these systems, such as Westroad River and tributaries, Nechako River, Kuzkwa River, Kazchek Creek, and Bowron River (unconfirmed); however, there is no regular or formal surveys of most streams.

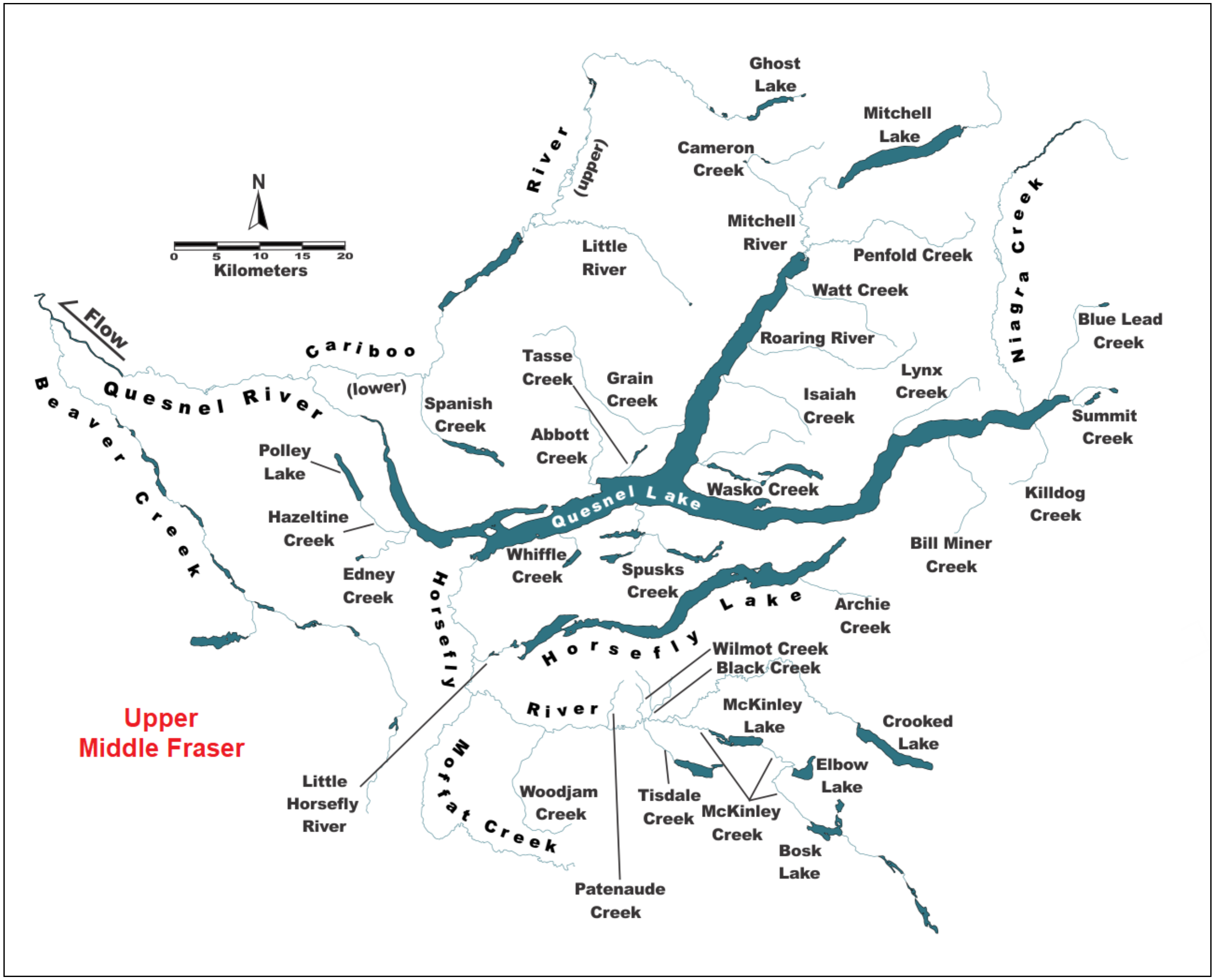

Figure 8. Major and minor tributaries of the Upper Middle Fraser subpopulation, continuation 3 of 3.This area represents a large section of likely usable habitat. Several of these systems are monitored but many of the shorter streams have not been assessed.

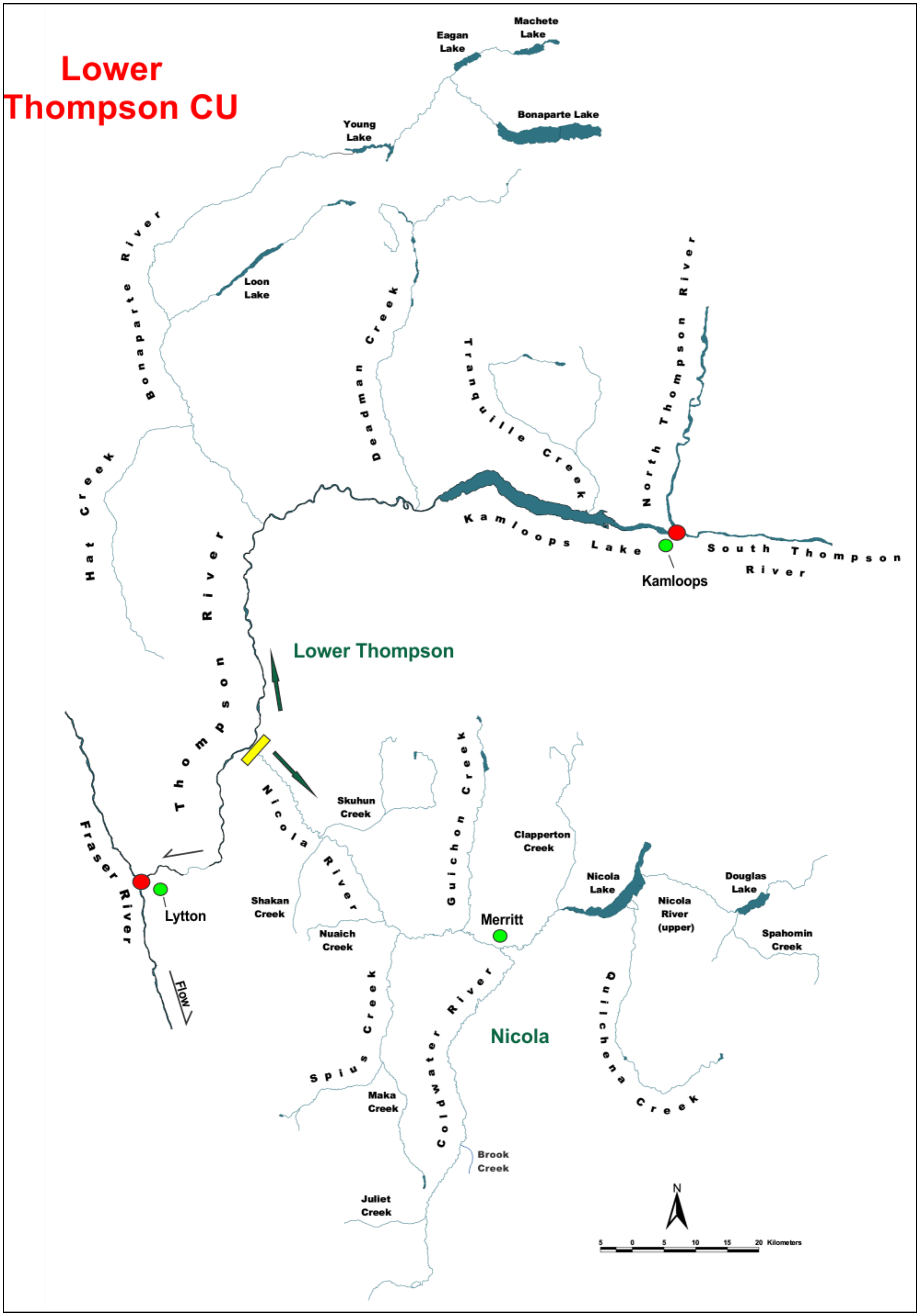

Figure 9. Major and minor tributaries of the Lower Thompson Conservation Unit. Refer to Figure 6 and Figure 7 for description of symbols.

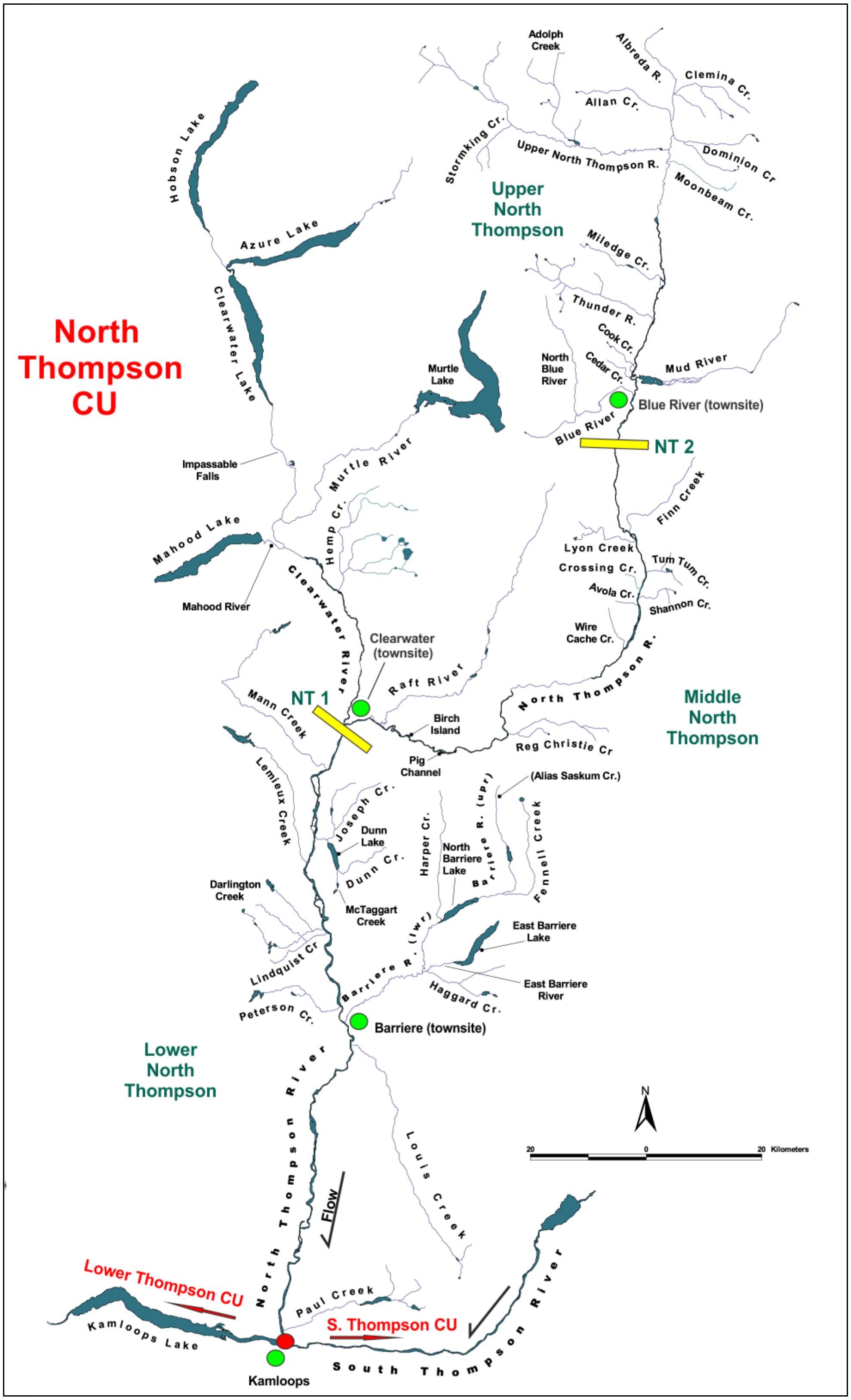

Figure 10. Major and minor tributaries of the North Thompson Conservation Unit. Refer to Figure 6 and Figure 7 for description of symbols.

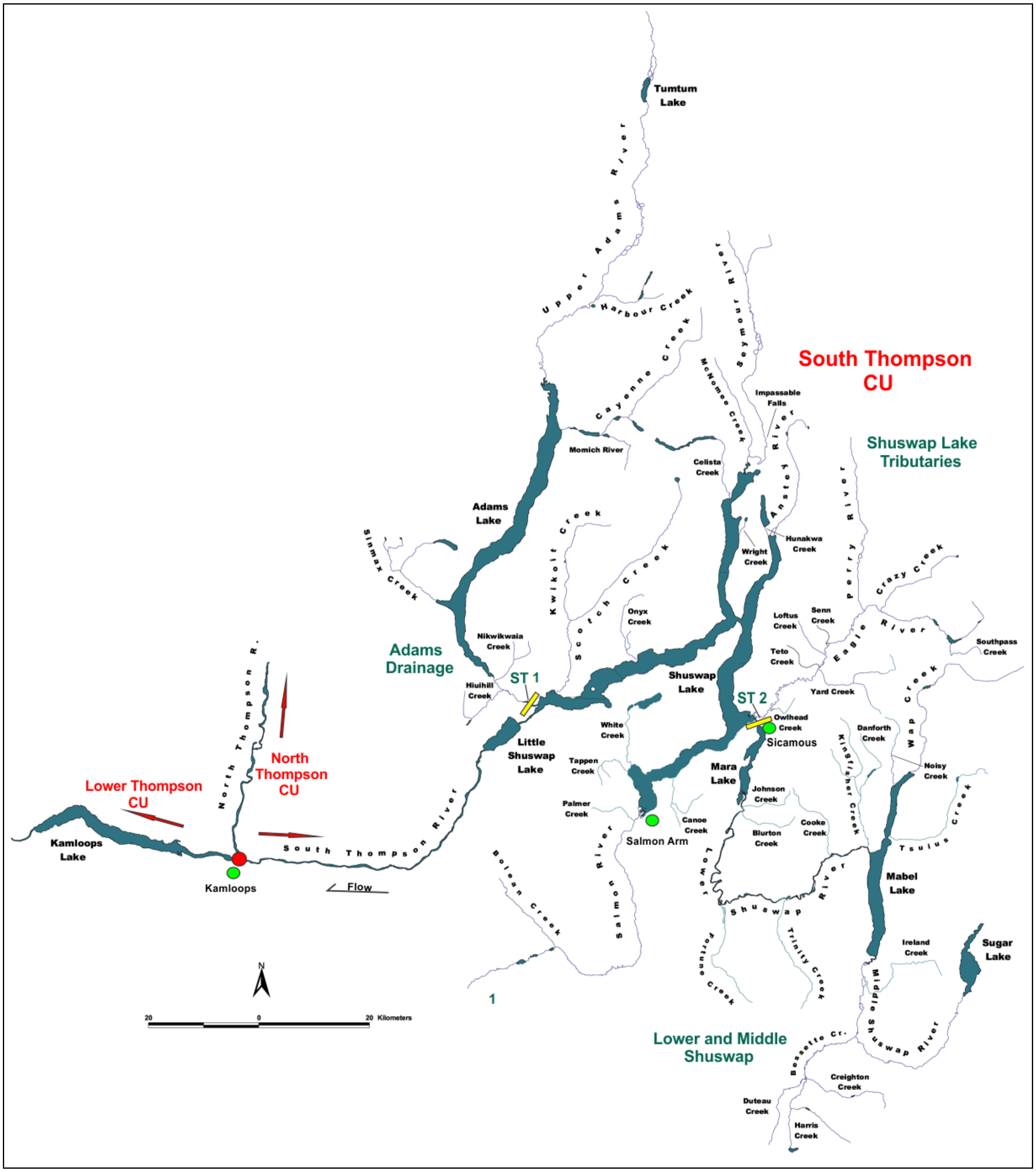

Figure 11. Major and minor tributaries of the South Thompson Conservation Unit. Refer to Figure 6 and Figure 7 for description of symbols.

3.2.2 Marine Distribution

As aforementioned, marine habitat properties are largely unknown, but the marine distribution of IFC habitat is thought to be primarily along the coast of British Columbia and Washington. Smolts enter the Fraser River estuary and then use the Salish Sea (Beamish et al. 2004, 2010) during their initial months. Subsequently, the hypothetical distribution of adult IFC has been inferred from CWT recovery data (Weitkamp and Neely 2002). Just under half (on average) of adult IFC caught are off of the West Coast of Vancouver Island, with slightly more caught in the southern half. Many (nearly half) IFC caught are in the Strait of Georgia and Puget Sound, including the Juan de Fuca Strait. There are also some (typically <10%) IFC that are caught in Southeast Alaska, Northern and Central British Columbia, Washington, and Northern Oregon. However, the full marine range of IFC is unknown because fishing does not occur in all parts of the Northeastern Pacific, and only hatchery-origin individuals have been used to create the known information.

3.3 ELEMENT 6: PRESENCE AND EXTENT OF SPATIAL CONFIGURATION CONSTRAINTS

3.3.1 Hydroelectric Dams and Landslides

The IFC DU has not been heavily affected by hydroelectric development. However, reduced stream flow, changes to the natural hydrography, impacts to IFC rearing and spawning habitat, and impacts to smolt passage from hydroelectric developments in the Bridge and Seton watersheds (Middle Fraser CU) and the Middle Shuswap River (South Thompson CU). Landslides or other impacts have produced blockages of IFC migration routes. The Hells Gate was a natural constriction of the Fraser River, however in 1914 the construction of the Canadian Northern Railway triggered a landslide that obstructed the passage up upstream migrating salmon, including the IFC DU. Little Hells Gate in the North Thompson River is a natural constriction in the North Thompson River that is downstream of all spawning locations for the Upper North Thompson subpopulations (IFCRT 2006). In June 2019, a recent landslide near Big Bar on the Fraser River north of Lillooet was discovered. The landslide initially created a five-metre waterfall and work was undertaken to reduce the impact of the slide. Based on the magnitude of the obstruction, salmon migrating upstream were impeded from naturally proceeding beyond the landslide. The majority of IFC spawn in areas below the Big Bar slide site but one subpopulation (Upper Middle Fraser) spawns above the slide. Hells Gate and Little Hells Gate may act as temporary barriers to upstream migrating IFC at certain flows (IFCRT 2006). The impact of the Big Bar slide has not yet been fully assessed. Natural or human alterations of channel morphology at these or other critical locations represent future threats to IFC CUs.

3.3.2 Floodplain Connectivity

Loss of off-channel and small stream habitat in the lower Fraser River, as a result of flood control and agricultural development, represent likely reductions in freshwater carrying capacity for IFC. Most of the streams in the lower Fraser River valley are classified as threatened or endangered due to draining of wetlands for agriculture and residential development, dyke construction for flood control, installation of hanging culverts, riparian zone degradation, disconnection of seasonally flooded habitats, draining of wetlands, and pollution (FRAP 1998, Langer et al. 2000, Brown 2002, Rosenau and Angelo 2005). An estimated 70% of wetland habitats have been isolated from the lower Fraser River floodplain by dyke systems (Birtwell et al. 1988). Detailed descriptions of impacts to habitat for specific IFC subpopulations are found in Fraser River Action Plan (FRAP) reports (e.g. Harding et al. 1994; DFO 1998a; DFO 1998b), and the IFCRT report (Appendix 4 of IFCRT 2006) and in Element 8 of this report. Future assessments would benefit from a detailed summary and mapping of known barriers in freshwater throughout the lower and interior Fraser River.

3.4 ELEMENT 7: EVALUATION OF THE CONCEPT OF RESIDENCE AND DESCRIPTION FOR COHO 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 2015b). Redds, i.e. spawning nests constructed by Pacific salmon and other fish species, are considered residences because they meet the following criteria:

1. individuals (not a population) make an investment (e.g., energy, time, defense) in the redd and/or invest in the protection of it;
2. the location and features of the redd contribute to the success of a life history function (i.e., breeding and rearing);
3. the redd is a central location within an individual’s larger home range, with repeated returns by the species to complete a specific life function; and
4. 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 2015b). Coho 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 2011).

Redd habitat for Coho Salmon is usually clustered within watersheds, often at the heads of riffles in small streams, and in side channels of larger rivers. Females generally construct redds in shallow (30 cm) areas where the gravel is less than 15 cm diameter and has good circulation of well-oxygenated water (Sandercock 1991). In the interior Fraser River watershed, where winter temperatures are more severe than in coastal areas, there is indication that winter stream flow and temperature play a critical role in spawning site selection. Whereas average discharge is higher in winter compared to summer in coastal streams, Interior Fraser streams generally experience declining hydrographs during the fall and winter as temperatures drop below freezing at higher elevations. This creates a risk of redds dewatering and freezing if spawning occurs too early. Some IFC may have adapted to these conditions by selecting spawning sites in lake-headed streams where temperatures and discharge are relatively stable. Groundwater also plays a critical role in spawning site selection in the hyporheic zone.

4 THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF INTERIOR FRASER COHO SALMON

4.1 ELEMENT 8: THREATS TO SURVIVAL AND RECOVERY

This report follows the definition of threats found in the “Guidance on assessing threats” Science Advisory Report (DFO 2014a). A threat is “any human activity or process that has caused, is causing, or may cause harm, death, or behavioural changes to IFC, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur; a human activity may exacerbate a natural process” and be deemed a threat. This is important to consider in the context of Element 10, Limiting Factors. Activities that increase either the variability or negative effects of natural processes are described below.

Between the two COSEWIC assessments for IFC and the IFC Conservation Strategy (Irvine 2002, IFCRT 2006, COSEWIC 2016), previous threats were generally categorized as:

excessive exploitation, degradation of freshwater habitat, changes in marine survival (as indicated by smolt-to-adult survival), climate change, degradation in estuary and marine habitat, hatchery production, non-native species, parasites and disease, and human population growth. These threats continue to be important and the severity and immediacy of most have not decreased substantially since the original assessment, other than exploitation, which has been reduced from historical rates.

The threat categories are based on the IUCN-CMP (World Conservation Union–Conservation Measures Partnership) unified threats classification system (Salafsky et al. 2008, COSEWIC 2012), 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 (2014a) *Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk*, to the extent possible in the context of limited data and information on threats to IFC within Canadian waters (Table 9; DFO 2014b). For IFC, a working group initially assessed threats to IFC using the IUCN-CMP threat assessment method used by COSEWIC (Appendix 7). One IUCN-CMP category was subsequently expanded to improve the applicability to aquatic species in general and salmonids in particular, category 7.3 (Other ecosystem modifications). The threat assessment was reviewed by the author group using the DFO standardized assessment method (DFO 2014a) after the initial COSEWIC-style assessment by a larger working group (see Appendix 7 for more details).

Climate change and hatchery salmonids are threats that could have been considered in multiple categories. To avoid multiplying the magnitude of the threats they posed to IFC, their threat risk was considered in *4.3 Element 10: Natural factors that will limit survival and recovery* because they exacerbate several natural limiting factors. For example, climate change and the presence of hatchery salmon exacerbate natural processes such as sever weather, competition, predation, and disease transmission. However, climate change and hatchery salmonids will also be discussed in *4.1.9 Other threats that exacerbate limiting factors* because of their anthropogenic drivers.

Anthropogenic climate change and severe weather events that are exacerbated by climate change will be discussed here as a threat under - *Climate Change* but the associated threat risks are specifically assessed within, and will also be discussed here as a threat under *4.1.9 Other threats that exacerbate limiting factors - Hatchery Salmonids.*

The concept of cumulative effects in the context of IFC is discussed in *4.1.10 Cumulative Impacts.* Cumulative effects were not given a threat risk in the DFO assessment framework but their possible level of impact was considered (to an extent) by the COSEWIC assessment (Appendix 7).

The following sections are associated with Table 9 and represent the rationale used to arrive at Likelihoods of Occurrence, Levels of Impact, Causal Certainties, and Threat Occurrences, Frequencies, and Extents. Definitions of the levels of the aforementioned aspects can be found in DFO (2014b) and Appendix 7. Categories in the text are organized by the order that they appear in the COSEWIC threats list and not by Threat Risk Level. In Table 9 these threats are organized by their Threat Risk Level.

4.1.1 Livestock farming & ranching

Livestock, particularly cattle, have the potential to directly disturb, alter, damage, and destroy redds. Within the Interior Fraser watershed, the South Thompson (e.g. Lower Shuswap, Bessette), North Thompson (Louis, Dunn, Lemieux), Lower Thompson (Nicola), and Middle Fraser (Quesnel, Horsefly, Chilcotin) CUs have a large proportion of stream length that is adjacent to pasture. Cattle may only enter stream sections where the bank gradient is low;

however, riparian buffer zones and fencing can deter livestock from entering or crossing streams. Therefore, while livestock may enter IFC systems, their direct DU-level effects are likely low.

4.1.2 Mining & quarrying

Mining activity occurs in many areas of the interior Fraser River watershed, and it consists mainly of placer mining (gold), hard-rock or open-pit mining (copper, molybdenum, and gold), and sand and gravel quarries. Of these types of mining, placer mining results in the most significant direct impacts on salmon habitat (Smith 1940). Placer mining involves mechanical dredging, sifting, washing, and re-deposition[5] of fluvial substrates and stream side deposits, primarily in search of gold. Distribution of placer mining activity in the interior Fraser River watershed is concentrated in the eastern tributaries of the Fraser River including the Bridge River, the area from Williams Lake to Hixon, as well as in the Fraser River mainstem.

Placer mining has occurred in portions of the mainstem Fraser River and its eastern tributaries since the 1850s, and was generally unregulated until the mid-1970s. Historical mining practices resulted in significant long-term negative effects on fish habitat. Hydraulic mining, stream channel diversion, suction dredging, and discharge of mine tailings into streams were responsible for 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 place mining. Placer mining operations have improved over time from an environmental standpoint, but the productivity of fish habitat for some IFC subpopulations remains affected by present-day placer operations and historical practices.

Both placer and open-pit mining activities have the potential to increase, especially in the Quesnel and Cariboo River watersheds due to speculated mineral and metal deposits. These activities may seriously impact local fish populations and fish habitat, primarily through the introduction of deleterious substances to sediments. Both types of mining operations are regulated under provincial jurisdiction as well as the *Fisheries Act*. Routine monitoring and participation of habitat protection staff from DFO's Fish and Fish Habitat Protection Program during mine development and operational stages is required to ensure local habitat impacts are minimized or avoided.

4.1.3 Transportation and Service Corridors

The primary threats from transportation and service corridors in aquatic environments occur during construction, modification, and maintenance. Behavioural modifications and mortality in redds from human activity or displacement of sediments (Bisson and Bilby 1982) are the primary threats considered when assessing these categories. A lack of maintenance may also cause impacts; for example, gravels may become redistributed from unnatural bank stabilization or streamside pipes and cover redds or displace juvenile fish. It should be noted that only construction in-stream is considered here. Armouring, bank stabilization, and changes in connectivity from general linear feature development are assessed in the section *Linear development*. Threat frequency and extent were identified as recurrent and narrow, respectively, because these activities often occur sporadically and would typically affect a small fraction of

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[5] Impacts and threats from re-deposition of sediments found within the bankfull area (the top of the floodplain) due to anthropogenic activities are considered within that activity's threat category. Impacts and threats from sedimentation caused by activities above the bankfull area are considered in *4.1.8 Pollution/contaminants.*

the entire DU. These categories were all scored as low impact because the direct in-stream impacts of construction, modifications, and maintenance is likely minimal at the DU-level and even at the CU-level.

Roads & railroads

The construction of road and railroad river crossings over streams is often avoided due to economic costs; however, the density of these infrastructures and their maintenance increases with human population density. Culvert and bridge construction on smaller tributaries may have the largest impacts because rivers often need to be blocked or diverted during construction, which would have the largest impacts on behaviour. Any given tributary consists of a small proportion of the total DU, and the frequency of construction and maintenance could limit any chronic behavioural impacts.

This threat does not include behaviour or habitat impacts associated with general linear development and habitat alterations, see *4.1.6 Natural Systems Modifications*.

Utility & service lines

There are two pipelines alongside IFC habitat. The Trans Mountain pipeline, which transports crude and refined oil products, runs the length of the North Thompson CU, part of the Lower Thompson CU (i.e. the Coldwater River), and along the lower Fraser River. This line is proposed to be twinned and construction may impact IFC by displacing sediment that can alter juvenile behaviour and adversely change stream morphology. Construction of lines across streams is not done during seasons when redds are present; however, existing lines may also displace sediment periodically due to changed stream morphology, which could destroy redds. The Westcoast Transmission System Pipeline, which transports natural gas, parallels the Fraser River beginning at Prince George, is diverted away from the river near Williams Lake, then follows the Trans Mountain pipeline route along the Coldwater River and lower Fraser River.

This threat does not incorporate the risk of pipeline spills, which is assessed in the *Industrial & military effluents* section.

Shipping lanes

Direct impacts of ship traffic on salmon are unknown, but the maintenance of shipping lanes via dredging could have potential effects on salmon populations. The changes in turbidity may alter foraging and predator avoidance abilities (Gregory 1993, Gregory and Northcote 1993), which could then affect juvenile IFC survival. Dredging for shipping lane traffic is most prominent in the Lower Fraser River, which is a migratory route for all adults and smolts. Historic dredging was also evident in the South Thompson and Little rivers to accommodate shipping traffic from Savona to Enderby in the early 1900s, which may have affected spawning and rearing habitat quality and quantity. The IFC juveniles may rear in the lower Fraser River up to 12 months so there will likely be some impact to an unknown proportion of the DU but since the entire DU migrates past possible dredging activities, the threat extent was identified as a conservative “extensive”.

4.1.4 Food, Social, and Ceremonial; Recreational; and Commercial Fisheries

Fisheries in Canada and the United States (US) impact IFC. The data and modelling associated with IFC ERs represent the total ER on IFC, which include the threat of Canadian and US fisheries. When the IFC Management Unit (equivalent to DU) is in a low status category, under the Pacific Salmon Treaty, the US and Canada have an ER cap of 20% (maximum of 10% each). However, domestic considerations may result in ERs that are lower (and on rare occasion higher) than the ER cap. There are three management categories for Canadian fisheries: 1) First Nations Food, Social and Ceremonial (FSC), 2) Recreational and 3) Commercial (including First Nations Economic Opportunity).

Fishing activities are linked in both management and how ERs are estimated, thus will be discussed as a whole. Fisheries were assigned low-medium threat risk, which is higher than what would be described based on ER analysis alone (e.g. the average ER rate is 12.5%) and the current population trajectory; however, the uncertainty around estimating encounters and post-release mortality rates associated with each activity warrant a precautionary and uncertain level of associated impact. Given substantial overlap in run-timing among the IFC CUs, and the absence of CU-specific estimates of ER, mortality from most fisheries (other than terminal) are treated as an equal threat for all IFC CUs. The subsequent discussion describes sources of uncertainty to explain why the level of impact from fishing activities, and by extension the management categories, ranges from low to medium.

The 1998 risk assessment for Thompson River Coho Salmon (Bradford 1998) concluded that fishing mortality played a significant role in the initial decline of IFC. It was highlighted that ERs in the early 1990s were not reduced quickly enough or sufficiently to compensate for declines in productivity that were the result of a significant decrease in marine productivity, which has since been described as the historic (higher) productivity and current (lower) productivity regimes (Decker et al. 2014). For example, fishing caused the direct mortality of approximately 68% of the total returning adult population in the early 1990s (Figure 3c). Bradford (1998) suggested that IFC escapements would have been 2-10 times greater in the late 1990s had exploitation been reduced to sustainable levels beginning in the earlier part of that decade.

In contrast, ERs have been reduced substantially since 1998 (Figure 3c), which reduced the overall rate of decline for IFC (Walters et al. 2018). Yet, in the current (lower) productivity regime (see Element 2), productivity was below replacement in some years (Figure 3a), which resulted in ERs increasing the magnitude of negative population growth for those years. Since the average productivity of IFC has been > 1 recruit/spawner since 1998 (Table 6), management of ER represents a conservation tool for promoting positive population growth, and for minimizing negative population growth when productivity is less than replacement.

A recent retrospective analysis for the IFC CUs investigated how the total IFC DU abundance could have changed under different ERs (Korman et al. 2019). The retrospective analysis demonstrated that the average observed ER of approximately 12% resulted in modelled escapements of 6% and 21% higher than escapements resulting from modelled ERs at 20% and 30%, respectively; however, there was recognition of a large amount of uncertainty in the analysis. Korman et al. (2019) suggested that the majority of variation in escapement since 1998 may be driven by variation in smolt-to-adult survival rates or other unexplained residual variation.

An important consideration for determining the threat level (and certainty) from fishing activities is that estimation of ERs has become less reliable since 1998. Changes in the fisheries management regulations and low fishery sampling rates for Coho Salmon have reduced the quantity and quality of CWT data, the main fishery evaluation technique since the mid 1970s for Coho Salmon. Reduced CWT release numbers combined with lower Coho Salmon survival and exploitation have reduced the number of CWTs that could be sampled from fisheries and escapements. The number of smolts marked with CWT has decreased slightly since 1998; however, the number of fry marked with CWT dropped from an average 540,000 in the 1980s to 0 in 1999. The quantity and quality of IFC CWT data have been affected by the reduced numbers of CWT released combined with low smolt-to-adult survival and low fishery sampling rates (below Pacific Salmon Commission and Mark Recovery Program guidelines). These and other factors have led the Pacific Salmon Commission (PSC) Coho Technical Committee to estimate the ER for IFC from the Fishery Resource Allocation Model (FRAM) instead of from CWT data collected by sampling fisheries and escapements.

With the implementation of mark-selective fisheries (targeting adipose-fin-clipped fish), there are very few directed fisheries on wild/natural-origin Coho Salmon during IFC co-migration. A few fisheries for wild Coho Salmon exist in some US fisheries, small harvests in terminal areas, and in a few years of early and late-season FSC fisheries before and after the majority of the IFC migration. The majority of fishing-related mortality of natural-origin IFC in licensed fisheries is now due to incidental mortality on released unmarked (mainly natural-origin) Coho Salmon in mark-selective fisheries that target other species and are regulated as Coho Salmon non-retention.

These circumstance cause additional uncertainty due to possible underreporting of Coho Salmon releases to creel surveyors that has been noted in a number of independent studies (Bijsterveld et al. 2002, Babcock et al. 2003, Diewert et al. 2005, Vélez-Espino et al. 2010). When Coho Salmon are reported as released, fishers often do not record and cannot recall clip status.

There is also uncertainty introduced in incidental mortality accounting. Incidental mortality includes sources such as drop off, depredation, accidentally landed Coho Salmon, and release mortality, which is collectively known as fisheries-related incidental mortality (FRIM) (see Patterson et al. (2017) for definitions). With the exception of post-release mortality, all other forms of IFC incidental mortality are calculated as five percent of the total IFC encounters (MEW 2008) despite variability in measured rates. With respect to IFC post-release mortality, fixed gear-specific rates are applied despite research into post release mortality rates showing variability across temperatures, handling technique, gear specifications, and locations (Patterson et al. 2017). Depending on the bycatch levels of CWT IFC indicators in non-Coho retention fisheries by gear type and environmental conditions, there could be a relatively large IFC post-release mortality that is unaccounted for in CWT ER calculations.

ER estimates for IFC may also be biased low if there is unlawful or unlicensed fishing anywhere along the route of IFC migration. Unlawful exploitation is not estimated nor accounted for in CWT ER calculations.

Overall, the reduction of fishery monitoring and head returns, uncertainty in Coho Salmon release rates and FRIM rates as well as unauthorized harvest have likely introduced an unquantified bias into the CWT IFC ER time series. Of further consequence was the introduction of Coho Salmon mark-selective fisheries, which significantly compromises the function of CWT indicator stocks to represent the wild Coho Salmon ER due to the differential impacts on clipped and unclipped Coho Salmon. Hatchery raised CWT indicator stocks are always adipose-fin clipped, which makes them vulnerable for retention in mark-selective fisheries where non-clipped wild Coho Salmon would be released.

The issues caused by lower quality fishery monitoring and CWT sampling and more mark selective fisheries for Coho have led to an increased reliance on post season ER modelling using FRAM and the Fraser River Decay Spreadsheet to estimate fisheries ER outcomes on IFC. Unbiased modelled ER depends on a number of assumptions. These assumptions include accurate representation of IFC timing through fisheries, unbiased catch and release estimates and unbiased escapement estimates (PSC 2013a). These assumptions are likely violated by the same factors that compromise the CWT program: licenced but unmonitored fisheries (Pacific Salmon Commission Coded Wire Tag Workgroup: PSCCWTW 2008), unlicensed fisheries activity that is unquantified, reliance on fisher release reports which are repeatedly found to be underestimated (Bijsterveld et al. 2002, Babcock et al. 2003, Diewert et al. 2005, Vélez-Espino et al. 2010), and uncertainty in the quantification of FRIM (Patterson et al. 2017). Also, the use of a 1986-92 CWT fisheries distribution dataset to inform FRAM on IFC marine distribution, despite changes to ocean conditions, also likely introduces unquantified error or bias into the ER modelling exercise. Because the modelled impacts result in estimates of all IFC mortalities in fisheries, the denominator in the ER calculation is no longer a single returning CWT population, but instead is the entire IFC DU. This results in the introduction of potential bias through errors in the IFC escapement estimates which are again unquantified.

Many salmon fisheries, including those directed at harvesting other salmon species, are currently limited in time and area to prevent incidental harvest of IFC; however, uncommon fisheries opportunities that exploit large returns of another species may result in higher ERs on IFC than originally planned for. For example, an estimated ER of 32% in 2014 occurred with the relaxation of the overall ER target from 13% to 26% on IFC. The resulting combined US and Canadian ER was approximately 6% higher than the management cap ER on IFC. Upon further review by the PSC Coho Technical Committee during their periodic review exercise in 2018, the original 32% ER was found to be 36%, which is 10% higher than was planned. This new ER rate of 36% does not include any adjustments for underestimates of FRIM rates nor corrections to angler reported underestimates of release data in fisheries other than Fraser River gill nets.

Even though sources of uncertainty exist, they are not represented in the planning tools used to manage fisheries. Current planning tools rely on assumptions of stationarity through time with regard to IFC mortality as a function of effort as well as IFC distribution and stationary catchability coefficients. Changes over time in these relationships are likely, though not understood nor examined regularly.

4.1.5 Human Intrusions & disturbance

Recreational Activities

Threats from recreational activities include any human activity that alters, destroys, or disturbs habitats and species with non-consumptive objectives. This threat does exclude non-consumptive, catch-and-release fishing for recreation, which is represented in the previous section. For aquatic species like Coho Salmon, any recreational activity that disturbs their aquatic habitat is included here such as boats and their wake, any off-road vehicle (e.g. ATV, dirt bikes) or horse entering a stream, and even pets such as dogs entering streams. There is a relatively low likelihood of recreational activities crushing redds due to the late fall spawning times and overwinter incubation period, where cold temperatures and freezing lakes deter the majority of recreational activity in aquatic habitat. It is recognized, however, that recreational hunting activity (which may use ATVs to increase access) during the fall and early winter would have the most overlap with redd occurrence and it is likely that at least some redds or juveniles would be disturbed. This is why the likelihood of occurrence was ranked as a more conservative likely than unlikely. The frequency of occurrence would be intermittent (or “recurrent”) and likely affect a very restricted proportion of the entire DU. In general, most recreational activities would not result in direct mortality of IFC; however, the potential for recreational activities to impact redds, which can disproportionately affect productivity, resulted in this categories level of impact to be listed as “unknown”.

Science Activities

Research and assessment methods can cause mortality of salmon, but there is likely small to no population effect for several reasons. Primary research may lead to mortality of IFC (e.g. Raby et al. 2015), however, such research is not usually a recurring annual endeavour and samples (possible mortalities) are usually very small. Assessment methods are designed to minimize any influence on the spawning population. Finally, the mortality associated with the test fisheries at Albion, Cottonwood, Whonnock, Qualark, and Thompson River combined has never been greater than 0.5% of the total return of IFC. Thus science activities represent a known low level of impact that only impacts a small proportion of the IFC DU (“narrow” extent) on a recurring annual basis.

4.1.6 Natural Systems Modifications

Fire & fire suppression

Forest fires are becoming more frequent as a result of climate change, historic forestry practices, mountain pine beetle and other pest infestations, pathogens, and incidences of human initiated fires (Mote et al. 2003, Wang et al. 2015). The immediate (direct heating from flames) and lasting effect (removal of riparian stream cover) of a forest fire is increased stream temperatures that can affect the behaviour and physiology of juvenile salmon (Beakes et al. 2014). Additionally, fire suppression tactics such as aerial bucket scooping can directly capture juvenile Coho Salmon. Occasionally back-hoes and other heavy machinery are required to dig ditches and ponds in aquatic systems to accommodate the aerial water-bucket, thus resulting in habitat destruction and suspended sediments. Construction of emergency access to water for pump trucks and equipment can also have localized effects on habitat, suspended sediments, and fish behaviour. The impacts from these threats do not always reach IFC in space and time (hence a “restricted” and “recurrent” extent and frequency, respectively), and there is likely a low DU-level of impact from fire and fire suppression although fires are expected to continue to occur, and have had massive impacts at small scales (e.g. Elephant Hill fire impacts on the Bonaparte River).

Fire and fire suppression (e.g. vegetation clearing to create fireguards/breaks or access roads) greatly modifies the landscape and can affect hydrological regimes (Springer et al. 2015), but the impacts from this threat are assessed in *Modifications to catchment surfaces.*

Dams & water management/use

Threats associated with dams and water management/use include changes to water flow patterns and volumes (hydrology), sediment transport, and the in-river footprints of structures. Water extraction for agricultural irrigation is pervasive for most IFC CUs (with the possible exception of the Fraser Canyon CU). Few systems have large dams but recently proposed low-head Run of River (RoR) hydro projects could present a threat for IFC. Individually activities that extract or impede water may not have large impacts, but cumulative impacts in combination with a changing environment increase the uncertainty of the level of impact. For these reasons, this category was ranked as having a low-medium level of impact that may continuously affect IFC freshwater habitat and a large proportion of both juveniles and adults.

The largest potential threat from agricultural practices is the extraction and storage of surface and ground water, which may be particularly impactful in naturally semi-arid environments, and basins with alluvial sediments (Stanford and Ward 1993). Many IFC CUs spawn and rear in naturally semiarid areas (e.g. in the South Thompson, Lower Thompson, and southern part of the North Thompson CUs). These areas also have high demands for water extraction for crop irrigation during summer low flow periods, frequently resulting in lower flows and high water temperatures (Rood and Hamilton 1995, Walthers and Never 2000). High water temperatures and lower flows can lead to increased juvenile mortality, reduced juvenile habitat capacity, and potentially prevent adults from accessing spawning habitat in the fall (Rosenau and Angelo 2003).

In previous reports, the area of greatest concern around water extraction centered on the licensing and utilization of water. Historically, Land and Water British Columbia had low levels of monitoring despite several watersheds with low flow issues and related negative impacts on fish and fish habitat (Rosenau and Angelo 2003). Threats from water use will increase with population size and the associated demands on water and agriculture. There is also a risk of illegal or unmonitored ground- and stream-water extraction. Finally, as climate change continues to cause drought conditions, threats may be further exacerbated.

Large hydroelectric dams can have several negative effects on salmon but they are currently minimal and concentrated in the Interior Fraser Watershed. 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). The alteration in hydrology can also alter thermal regimes which can have potential evolutionary consequences on downstream populations that are affected by selecting for delayed spawning or slower developing embryos (Angilletta et al. 2008). There is a series of hydroelectric dams that affect the Lower Middle Fraser subpopulation on the Bridge and Seton river systems. The Terzaghi dam, built in 1948, is a barrier to salmon migration as it does not have a fish passage facility. The footprint of Carpenter Reservoir, created by Terzaghi Dam, removed spawning and rearing habitat (The Fish & Wildlife Compensation Program: FWCP 2017), and the footprint of the Seton Dam removed spawning habitat. The Terzaghi Dam system involves a water diversion from the Bridge River to Seton Lake, which has reduced the Bridge River volume and habitat capacity for rearing juvenile IFC. Although the Seton Dam is passable by Coho Salmon and several enhancements have been built upstream as mitigation, juveniles continue to be entrained during the spring outmigration (FWCP 2017). Upstream tributaries from the Seton Dam include Portage Creek and Gates Creek. There is also a hydroelectric dam on the middle Shuswap River in the Shuswap River subpopulation (South Thompson CU), the Wisley Dam. Currently, suspended sediment load and deposition from dam operations are being monitored by the Okanagan Nation Alliance to assess their possible impacts on downstream habitat.

Future hydroelectric development in BC is a complex issue that involves both Federal and Provincial governments. No major hydro developments are expected within the watersheds supporting IFC; however, the British Columbia Provincial Government has developed a framework to facilitate the development of independent power projects on stream tributaries to the Fraser River. Independent power projects are often built as RoR dams that, individually, often have smaller in-river impacts than large hydro projects (Anderson et al. 2014). Although the in-river impacts RoR of individual projects may be less, their cumulative impacts to hydrology and from associated linear development to support them may increase their level of impact (Gibeau et al. 2016). Several projects exist in the Interior Fraser Watershed: Scuzzy Creek (Boston Bar Hydro), Kwoeik Creek, Cayoosh Creek (Walden North), Bone Creek, and Hystad Creek. Future projects are possible but their locations are unknown.

Other ecosystem modifications

The COSEWIC/IUCN classification included a general “other ecosystem modifications” category, which does not adequately highlight differences in the types of ecosystem modifications that impact salmonids and IFC. This category has been split into three that allow for their relative threat levels on IFC to be described. The subsequent categories are Modifications to catchment surfaces, Linear development, and Invasive plants modifying habitats.

Modifications to catchment surfaces

The threats associated with modifications to the catchment surface include: altered temperature and flow regimes as the result of vegetation clearing or increases in impervious surfaces. Activities that result in modified catchments include: forestry and pine beetle- or other pest-induced forestry, forest fires (also association with pine beetle effects and historic forestry practices), agriculture, and urban and rural/industrial development. The impacts of several of these activities have been correlated to declines in IFC productivity (Bradford and Irvine 2000) and their impacts in a changing climate are likely high but uncertain. The level of impact from modifications to catchment surfaces was identified as medium to high to capture both the uncertainty and the possible cumulative impact of all of the aforementioned activities. The “high” end of the level of impact range was assigned because impacts to temperature, flow, and hydrology affect egg-to-smolt survival (Lawson et al. 2004), which may highly influence population growth and productivity (Evans and Dempson 1986, Bradford 1995). Altered sediment transport as a result from forestry and agriculture is assessed in *Agricultural & forestry effluents*.

The IFCRT (2006) qualitatively ranked the current/historic impacts of forestry, agriculture, and urban and rural development (as well as linear development, water use, and mining) at the subpopulation-level in section 1.5.3 of their report. Forestry was typically identified as having had the highest levels of impact, followed by agriculture and then urban and rural development. An ongoing analysis on the percent area used for each land use activity within each CU identified a similar trend. Assuming this trend continues into the future, the relative contribution to the level of impact of modifications to catchment surfaces from each of the aforementioned activities is first from forestry followed by agriculture and then urban and rural development.

Forestry development (e.g. harvesting and replanting) on crown land, as well as private land logging, is a major resource activity throughout the IFC DU and may have several impacts to hydrology. Extensive logging (e.g. clear-cut logging) within a watershed may lead to reductions in Coho Salmon carrying capacity through degradation of the stream channel stability and riparian habitat, increased summer stream temperatures, and altered seasonal hydrographs by altering run-off dynamics (Meehan 1992). Current forestry practices aim to leave riparian areas on salmon-bearing streams intact using a no-harvest buffer area alongside the stream, but historically, clear-cut logging to stream banks resulted in increased stream temperatures from increased irradiation from solar radiation (Brown and Krygier 1970). Seasonal hydrographs may be more variable or peak flows may shift due to the reduction in vegetation that typically moderates run-off and infiltration rates (Meehan 1992, Winkler et al. 2017). Additionally, replanting after forestry, for example with monocrops of Douglas Fir (*Pseudotsuga menziesii*), may alter flows by increasing evapotranspiration rates and reducing stream flow relative to the original older, mixed conifer forest that could have been present pre-logging (Perry and Jones 2017).

In the Thompson River watershed, Bradford and Irvine (2000) did not find a significant relationship between the proportion of recent land logged and the annual change in recruitment, but they suggested impacts from logging likely occurred 50-100 years ago. They proposed that the impacts from historic forestry were large, such that recent forestry impacts would appear to be subtle. Recent research in a coastal system found that impacts from forestry-related watershed alterations may take decades to fully develop (Tschaplinski and Pike 2017). The study (Tschaplinski and Pike 2017) also initially found elevated productivity related with the increased river temperatures but suggest that increased river temperatures would have negative impacts in semi-arid environments, such as the interior Fraser River watershed.

Forestry activity within the interior Fraser River watershed is pervasive, though some areas are more heavily logged due to accessibility or salvage practices. The Fraser Canyon and Adams River subpopulations are the most significantly impacted by historic and continuing forestry practices, followed by tributaries of the Nicola River. The recent mountain pine beetle infestation in the interior Fraser River watershed has also exacerbated logging intensity in important spawning drainages occupied in the South and Lower Thompson, and Middle Fraser CUs. To address salvage of insect infested trees, the annual allowable cut was raised in a number of watersheds within the geographic range of IFC. The resulting increase in the amount of area harvested over a shorter period of time may create much greater impacts than typical forestry management, especially in combination with climate-change accelerated spring warming. Large scale channel destabilizations have been observed recently in several Interior watersheds following extensive clear cutting to salvage beetle killed timber. Forest harvesting is also currently occurring in the headwaters of many watersheds, which may result in an increase in stream temperatures and their variability (Macdonald et al. 2003). Such destabilizations increase the risk of watershed-wide changes in hydrology and stream morphology that could have pervasive impacts on IFC.

As noted in the *Fire & fire suppression* section, forest fires are becoming more frequent as a result of climate change, historic forestry practices, pine beetle infestation, and incidences of human initiated fires (Mote et al. 2003, Wang et al. 2015). The impacts of forest fires are similar to forestry in how they alter flow and temperature regimes, but their impacts can be worse for several reasons. Wildfires do not follow forestry management rules and can remove all vegetation, including riparian vegetation (i.e. not keeping a buffer zone). In addition to fire removing vegetation, fire breaks in the vegetation are also created as a form of 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), as noted in *Fire & fire suppression.* The loss of vegetation also results in changes to the natural hydrological cycle by modifying runoff and evapotranspiration dynamics (Springer et al. 2015). Secondly, severe fires have the potential to create hydrophobic soils by burning all organic content (Letey 2001). A greater prevalence of hydrophobic soils may yield an increase in the frequency and magnitude of bank erosion from high volume run-off events. Recolonization rates by plants may also be reduced relative to forestry impacted areas from severe burns, which prolongs the impacts of the modified catchment. Widespread intense fire activity in 2017 and 2018 resulted in the creation of areas of hydrophobic soils that are totally denuded of vegetation and prone to severe erosion. Recently affected IFC systems include the Bonaparte River and the Westroad River watersheds.

Agriculture is well established throughout most of the interior Fraser River watershed and the lower Fraser River. Crop production and livestock operations predominantly occur in the valley bottoms on private lands while livestock summer grazing takes place on crown lands, often at higher elevations. While the overall percentage of farmland in each watershed may be relatively low, agricultural activities are typically concentrated along stream corridors where impacts to stream habitat have and may occur. Loss of surrounding forest and riparian vegetation is evident along streams due to land clearing for crop production, buildings, or grazing activities. Threats to IFC due to forest clearing for agriculture align with those from forestry. Where riparian clearing occurs, it may also result in wider and shallower streams, increased water temperatures through irradiation, reduced cover, increased erosion, and altered stream substrates; all of which can have an impact on spawning and rearing habitats and migration routes. Within the interior Fraser River watershed, the Nicola River, lower Thompson, several North Thompson subpopulations, and Middle and Lower Shuswap subpopulations are the most impacted by agricultural activities. Additionally, because the entire population migrates through and a proportion of juveniles rear in the lower Fraser River (where there is extensive agricultural development), there is a possibility that all IFC individuals are affected by agriculture to some degree.

The impacts of bank destabilization combined with the resulting sedimentation and landslide risks associated with logging, forest fires, and agriculture are incorporated into the threat levels of *Agricultural & forestry effluents* and *Landslides*. The combined impacts from changes in hydrology and irradiation from these activities is estimated to be medium-high. There is uncertainty in the assessment of this category because it is difficult to quantify the continued cumulative impacts of historical forestry and agricultural practices and the vast amount of habitat alteration that has and continues to occur in this watershed. Additionally, this category includes the threat of changes to hydrology from urban and industrial development, which has similar effects as vegetation removal but is compounded with permanent changes to landscape permeability.

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 hydrology 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). Drastic changes in flow regime can result in bedload movements that destroy redds, strand fish, and change behaviours such as migration and foraging. Roads, particularly highways and forest service roads, may also intercept shallow groundwater flow paths and amplify run-off effects where they cross streams (Trombulak and Frissell 2000); these effects are particularly evident in smaller stream systems where forest service roads are likely to cross. Bradford and Irvine (2000) found a negative correlation between annual change in recruitment 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 such development, this type of activity is not directly under the control of any single government body. A lack of integrated planning can produce urban, rural, and industrial developments that create site-specific but also cumulative alterations in stream hydrology with increased peak or decreased low flows and produce degraded water quality from urban storm-water runoff. Pollution and contaminants, however, are assessed in *4.1.8 Pollution/contaminants*.

Linear development

Linear development includes straightening and channelization of streams, often modifying natural landscapes with riprap, dykes, culverts, bridges, and floodgates, which are associated with the protection of agriculture, industrial, and urban development. In particular, utility lines and services such as highways, railroads, electric transmission lines, and pipeline developments often follow valley bottoms and may span large sections of rivers that require armouring to protect the developments. This category was identified as having a medium level of impact because linear development is expected to continue with increasing human population growth and economic development and because its impacts will affect egg-to-smolt survival.

Overall, linear development activities have resulted in a reduction of the complexity, diversity, and connectivity of fish habitat. Riprapping and channelization has been shown to reduce the abundance of juvenile Coho Salmon (Knudsen and Dilley 1987), likely because the habitat becomes less “desirable” due to changes in cover from predators and stream velocity. Riprap can also reduce shading from the riparian zone and contribute to warmer stream temperatures (Massey 2017). Additionally, there is often an associated reduction in the overall amount of habitat after channelization due to a reduction in stream length originally produced by bends and forks (Chapman and Knudsen 1980). Also, important rearing habitats (e.g. side channels, off-channel habitat, ponds, and wetlands) can be cut off following linear development. For example floodgates and dykes installed along the lower Fraser River, because of the tidal influences or flood protection, can block access to rearing habitat (Scott et al. 2016), which may have historically been used by juvenile IFC. 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).

Within the IFC subpopulations, the Upper Middle Fraser and Middle North Thompson have had the greatest amount of linear development impacts; however, habitats within the lower Fraser have been impacted to the greatest degree. Most of the streams in the lower Fraser River valley are classified as threatened or endangered due to draining of wetlands for agriculture and residential development, dyke construction for flood control, riparian zone degradation, and pollution (FRAP 1998, Langer et al. 2000, Brown 2002, Rosenau and Angelo 2005). An estimated 70% of wetland habitats have been isolated from the lower Fraser River floodplain by dyke systems (Birtwell et al. 1988). Sumas Lake is one example of potential habitat for juvenile IFC that has been lost. In 1924, Sumas Lake was drained and converted to farmland, which consisted of 3,600 ha of open water and 8,000 ha of marshland and sloughs that may have had the potential to support 230,000 overwintering juvenile Coho Salmon (Brown 2002).

“Other” development pressures that are not necessarily *linear* also occur along lakeshores. Lakeshore recreational development-related activities (e.g. filling, dredging, sewage disposal, removal of gravel and cobble, removal or alteration of riparian vegetation, installation of water intakes) threaten important nursery areas along the foreshore areas utilized by rearing IFC. Within the interior Fraser River watershed, the greatest impacts are in the Middle and Lower Shuswap rivers and Shuswap Lake subpopulations.

Invasive plants modifying habitat

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

4.1.7 Invasive & other problematic species & genes

Invasive non-native/alien species

At a global scale, the invasion of non-indigenous species is recognized as one of the most important threats to native species abundance and biodiversity (Rahel et al. 2008, Gallardo et al. 2016). Invasive fish species can permanently reduce abundance and diversity of native fishes through competition, predation, or introduction of new pathogens (Cambray 2003), and are one of the leading threats to freshwater fish species in Canada (Miller et al. 1989, Dextrase and Mandrak 2006, Rahel et al. 2008). Region-specific assessments of distribution (Runciman and Leaf 2009) and biological risk (Bradford et al. 2008a, 2008b, Tovey et al. 2008) have been completed in the past for several invasive fishes in British Columbia including Yellow Perch (*Perca flavescens*), Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), Northern Pike (*Esox lucius*), Pumpkinseed (*Lepomis gibbosus*) and Walleye (*Sander vitreus*). These species became established in British Columbia as a result of natural dispersal in transboundary watersheds via introductions to Washington and Idaho, deliberate introductions by government agencies in Canada as recently as the 1980s, and unauthorized introductions in recent years. Eastern Brook Trout (*Salvelinus fontinalis*), a non-indigenous salmonid, are also widely distributed in British Columbia, as a result of introductions by government agencies beginning in the 1920s (McPhail 2007), but there is no documentation of significant impacts on IFC from Brook Trout, and coastal Coho Salmon appear likely to outcompete Brook Trout based on lab studies (Thornton 2015).

Yellow perch and Smallmouth Bass are the two most widely established invasive species in the interior Fraser River watershed and likely pose the greatest threat. The presence of Yellow Perch had been confirmed in nine lakes and three streams in the South Thompson watershed (South Thompson CU; Runciman and Leaf 2009); two of which are also used by IFC. However, management actions taken to eradicate Yellow Perch were implemented in recent years, with successful eradications in most of the Thompson watershed (The Ministry of Forests, Lands, Natural Resource Operations and Rural Development: FLNRORD 2016). There is still a well established Yellow Perch population in Douglas Lake that is directly connected to Nicola Lake and River system, placing it at the highest risk of invasion from perch. Smallmouth Bass were confirmed in two small lakes in the South Thompson watershed, and throughout the Beaver Creek drainage in the Quesnel River watershed (Middle Fraser CU), including six small, connected lakes and Beaver Creek itself (Runciman and Leaf 2009). Coho Salmon are known to use the lower reaches of Beaver Creek. To date, the presence of Northern Pike or Walleye has not been confirmed in the interior Fraser River watershed, while Largemouth Bass and Pumpkinseed have both been confirmed in an isolated three-lake drainage in the South Thompson watershed (Runciman and Leaf 2009).

The risk of widespread establishment in the Thompson and middle Fraser watersheds is moderate to high for Yellow Perch and high for Smallmouth Bass based on high habitat suitability within a substantial portion of each watershed. Range expansion may be facilitated by their ability to migrate considerable distances and utilize streams as well as lakes (Bradford et al. 2008a, Tovey et al. 2008), but the proximity of established populations of each species is still tens of kilometers or more in most cases. The risk of deliberate unauthorized introductions by anglers may be the more prominent risk. Despite the apparent absence of Largemouth Bass and Walleye, the risk of establishment in the Thompson and middle Fraser River watersheds is also considered moderate to high for these species based on the same factors listed for the previous two (Bradford et al. 2008b, Tovey et al. 2008). The risk of establishment of Pumpkinseed and Northern Pike is estimated to be moderate to low, based on lower habitat suitability (Bradford et al. 2008b).

The ecological consequences (i.e., risk to the aquatic ecosystem as a whole) resulting from widespread establishment of each of these six species was estimated to be moderate to high for large lakes and high to very high for small lakes (Bradford et al. 2008a, 2008b, Tovey et al. 2008), but these studies did not specifically address the direct risk to IFC. Coho Salmon are known to rear in both small and large lakes in the interior Fraser River watershed, usually in backchannels, sloughs and alcoves near natal streams (Brown 2002, Brown and Winchell 2004), but whether these habitats are critical for Coho Salmon is uncertain because IFC appear to rear primarily in streams and off-channel habitats associated with streams (Elements 1 & 4). However, Smallmouth Bass, Walleye and Northern Pike commonly occupy fluvial habitats in addition to lakes, and Largemouth Bass to a lesser extent (Bradford et al. 2008b, Tovey et al. 2008).

Unlike the interior Fraser River, the lower Fraser River has well established populations of many invasive fishes throughout its tributaries and mainstem (MOE 2015). As all juvenile IFC migrate through the lower Fraser River and some rear there, invasive species represent a risk to the entire population. The impact on IFC has not been quantified and the lack of expertise in this category during the assessment resulted in the level of impact being identified as unknown. Detailed and extensive research would be required to calculate the impact of invasive species on IFC and there are too many uncertainties to assign a threat risk currently.

Introduced genetic material

The COSEWIC/IUCN definition of this category includes “human altered or transported organisms or genes” (COSEWIC 2012), which encompasses enhancement and hatchery practices in the case of salmonids. Enhancement and hatchery practices often change genetic diversity (typically through reduction) in hatchery-origin fish by producing cohorts from smaller gene pools and exposing them to different selective (and unnatural) pressures found in hatchery environments (Gardner et al. 2004, Grant 2012). Hatchery-origin fish then interbreed with wild stocks, potentially reducing productivity, modifying behaviour, and limiting population adaptability in future generations due to the reduction of genetic diversity (Waples 1991, Gardner et al. 2004). There is a growing body of empirical evidence suggesting that there are progressive, intergenerational declines in fitness in wild populations when hatchery-origin fish are present (Fleming 2002, Berejikian and Ford 2003, Gardner et al. 2004, Grant 2012). Waples (1999) outlines how risks posed by hatcheries can never be fully avoided, even with best management practices. Waples (1999) also suggests that hatcheries/enhancement can have conservation benefits in populations that are already small and possibly suffering from depensatory effects. Therefore, excessive and even moderate numbers of hatchery-origin adults interbreeding with wild fish places genetic diversity and fitness of the wild IFC at risk but enhancement may be required if populations are at risk of or already have been extirpated.

Across IFC populations, enhancement of Coho Salmon using hatchery-origin fish typically falls within one of four objectives. The first objective is conservation enhancement, used in systems where Coho Salmon are deemed to be well below carrying capacity or are highly at risk of extirpation or extinction. Examples of this are the hatchery programs on the Deadman River in the lower Thompson, and on the Salmon River in the South Thompson. The second objective is assessment enhancement, where releases of coded wire tagged fish provide information for assessment of fishery ERs, smolt-adult survival, enhancement program performance measurement, program efficiency and optimization, effects of enhanced salmon on wild salmon populations, international treaty support, domestic fisheries planning and stock assessment support. Examples of this are the hatchery programs on the Coldwater River and the Eagle River. The third objective is enhancement for stewardship purposes, where small-scale hatchery supplementation is part of a strategy to increase community stewardship. The enhancement work undertaken by North Thompson Indian Band on Dunn Creek is a stewardship project. The final objective is education enhancement that involves classroom incubator-type projects and releases of small numbers of fry as part of a program to enhance awareness of salmon in elementary school children.

Since its inception in the 1980s, the scale of hatchery production of IFC has been fairly modest relative to that in other parts of Southern British Columbia (e.g., Strait of Georgia, lower Fraser River) and in the US Pacific Northwest (IFCRT 2006). Earlier studies (Bradford and Irvine 2000, Irvine 2002, IFCRT 2006) concluded that enhancement demonstrated a relatively minor effect on overall abundance trends for the IFC DU. Previous reports noted however, that the Lower Thompson CU was dominated by hatchery-origin fish (60% of escapements in 1998-2000; Irvine 2002), as were several enhanced streams in the North Thompson and South Thompson CUs (IFCRT 2006). The potential historic loss of genetic diversity may have detrimentally affected the Lower Thompson subpopulations, for which the effects are difficult to reverse. More recently, releasing juveniles as fry has stopped, resulting in lower proportions of hatchery fish among IFC in freshwater rearing habitat and, to an extent, spawning habitat (hatchery smolts are still produced). The proportion of hatchery-origin fish in the Lower Thompson CU has steadily declined since 1998 while the other CUs have typically had less than 20% hatchery origin or none at all (Figure 12, Appendix 4). The mean proportion of hatchery fish in escapements for the most recent generation (return year 2016) was 3.4% compared to 16.8% at the time of the first COSEWIC assessment for the IFC aggregate (return year 2000; Irvine 2002). The proportion of hatchery fish in escapements to the IFC since the first COSEWIC assessment (since return year 2006) has been, on average, 2.6 times less than return years 1998-2005. British Columbian hatchery practices are changing recently to consider the adverse effects of enhanced fish on wild fish (Withler et al. 2018), but effects from historical practices that were unmonitored may be pervasive and even the best management practices can't alleviate all genetic impacts of hatchery fish (Waples 1999). Accordingly, this category's impact level was ranked with uncertainty (low-medium).

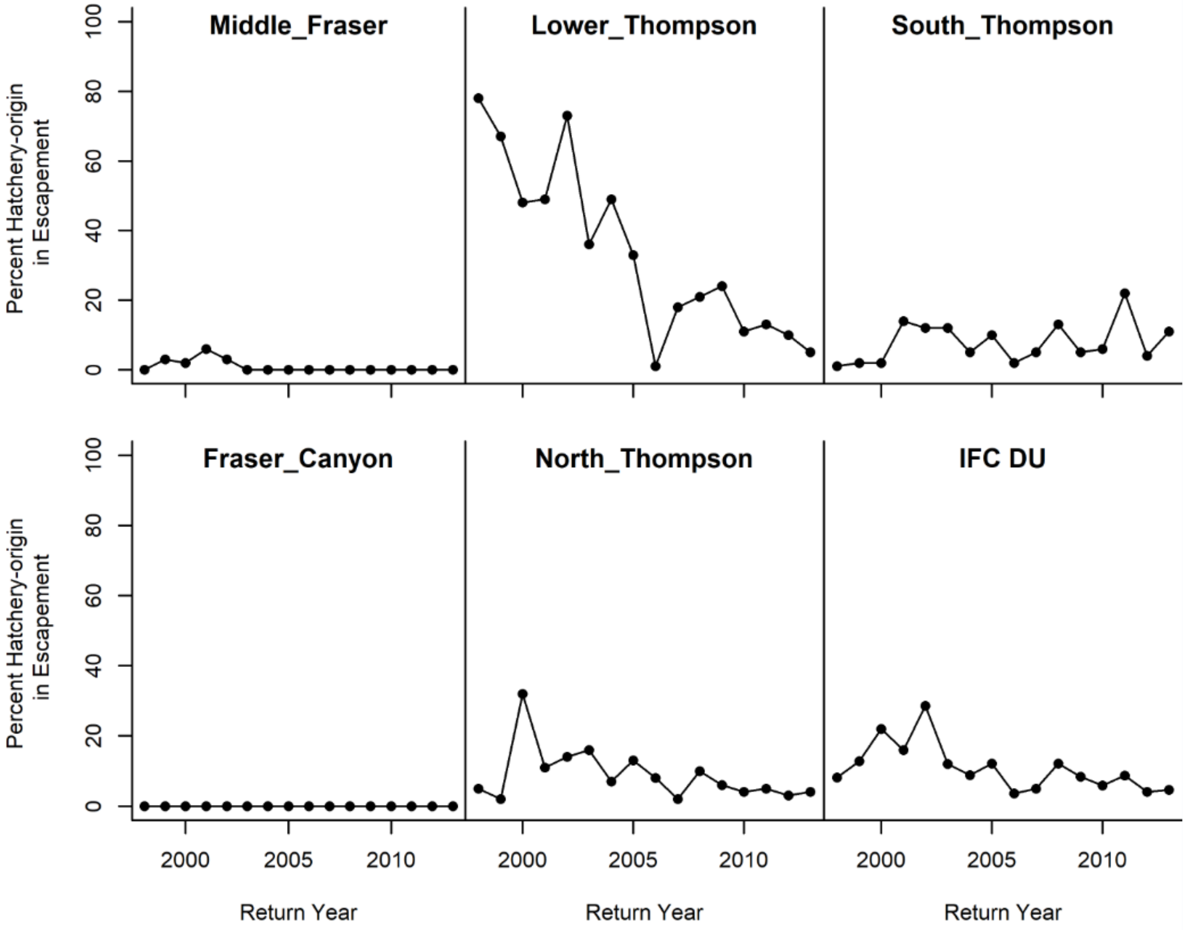

Figure 12. The percentage of IFC escapement from hatchery-origin across the CUs and DU from 1998-2013.

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 IFC.

Salmon farming has been connected to the introduction of new pathogens and diseases. Piscine Orthoreovirus (PRV) and Heart and Skeletal Muscle Inflammation (HSMI) were likely introduced to the Pacific ocean in the late 1970s and 2000s, respectively (DFO 2018a). The disease HSMI may occur after a fish contracts PRV and sometimes several other pathogens and leads to sublethal and occasionally lethal effects. In 2013, around 5% of a sample of 60 Coho Salmon from British Columbian waters had PRV (Marty et al. 2015); however, the percentage of IFC in those fish is unknown. Current evidence suggests that there are likely no population-level effects from PRV and HSMI on Fraser River sockeye but further research is still required (DFO 2018a, 2019).

The spread of PRV and native pathogens may be exacerbated by interactions between Coho Salmon and salmon farming mismanagement. Although the study was not specific to IFC, Connors et al. (2010) found that coastal Coho Salmon productivity was negatively impacted in populations that migrated past open-net salmon farms that had untreated sea lice (*Lepeophtheirus salmonis*) outbreaks. Proper treatment in the form of fallowing (i.e. emptying pens of salmon at targeted times) buffered against the negative impacts by reducing parasite transmission rates (Connors et al. 2010). New finfish aquaculture policy in British Columbia may also move many fish farms away from migratory salmon routes. Current knowledge suggests that IFC distribution in the Strait of Georgia does not have a large overlap with salmon farms.. Therefore, open-net pen salmon farming may increase transmission rates of PRV (and native pathogens) to IFC during migration past these areas, but effective management may mitigate many of the impacts.

4.1.8 Pollution/contaminants

Although the threat of contaminants is broken into several sources below, it is important to highlight that these threat categories are inherently linked and have cumulative impacts. Control and mitigation of point-source contaminants is highly beneficial, but many contaminants are persistent in the environment, may travel long distances, and have a propensity to accumulate in sediments and food chains from multiple sources. The extensive migrations, physiological transformations, and rapid rates of growth of anadromous salmon make them particularly susceptible to exposure and accumulation of contaminants from many sources (Ross et al. 2013). For example, bioaccumulation in IFC individuals may be greatest in the ocean where the majority of their growth occurs and many contaminants can bioaccumulate in their food web (Ross et al. 2013). Subsequently, as adult salmon migrate back to freshwater spawning grounds, lipid-normalized concentrations of lipophilic organohalogens (e.g. polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs)) are known to increase (Debruyn et al. 2004, Kelly et al. 2011). Contaminants are known to impair salmonid olfactory function, migratory behaviour, and immune systems, which may reduce individual survival (Casillas et al. 1997) but can also reduce reproductive success and a population's productivity (Kelly et al. 2011).

An overview on sources and levels of contamination in the Fraser River watershed was conducted between 1992-1998 under the management of the Fraser River Action Plan (Gray and Tuominen 1999). Major sources of effluents included pulp mills and municipal wastewater treatment plants (WWTP), combined sewer outfalls (CSOs), and non-point sources such as urban, industrial, and agricultural runoff. Relatively minor sources included five permitted metal-mine discharges, atmospheric deposition, and runoff from highways, railway right-of-ways, and hydro-electric corridors. Changes to manufacturing processes just prior to 1999 in the pulp and paper industry and changes to effluent treatment in municipal WWTPs resulted in significant reductions in the loading of contaminants of concern to the basin. As a result, the relative importance of non-point sources (e.g. agricultural and urban runoff, and atmospheric deposition) as contributors to contaminant loading increased.

The level of impact for agricultural and forestry impacts was ranked as medium because increased sedimentation in runoff is also included in this category, whereas the other two threat categories were ranked as low-medium because their effects are:

1. difficult to assign to certain sources and

2. IFC populations have not been regularly monitored for contaminant concentrations.

Therefore, the impact rankings reflect the amount of uncertainty associated with these threats. Ross et al. (2013) provides a detailed summary of why salmonid life-histories make it difficult to identify impacts from any one source of pollutants, why salmonids are inherently sensitive to contaminants, and they suggest several steps to improve risk evaluation and subsequent advice to management. Currently, a highly beneficial activity would be to sample IFC for current contaminant levels to decrease our gap in knowledge of the impact of these threats.

Household sewage & urban waste water

Sewage and urban waste water enters rivers through three main pathways and contains numerous chemicals. Urban effluents can either pass through WWTPs or directly into streams through the sewer system/CSOs. Additionally, chemicals may enter groundwater pathways, which provides more filtration than direct sewer transport (McIntyre et al. 2015) but may have a negative effect of a slower and chronic discharge of chemicals as opposed to an acute discharge. Contaminants include (but are not limited to) 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 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. PCBs).

Highly impermeable urban landscapes and household plumbing divert contaminants and effluent into sewer systems that either directly outfall into rivers or first pass through WWTPs. The amount of urban effluent a city produces is directly related to its population size. The human population in Metro Vancouver, located at the mouth of the Fraser River, is the largest in the watershed and is also a migratory bottleneck where all IFC migrate through twice and sometimes reside as juveniles. In Metro Vancouver, secondary treatment facilities (employing additional biological treatment, such as anaerobic and/or aerobic microorganisms) at the Annacis and Lulu Island WWTPs built in 1998 resulted in a 70% reduction in total suspended solids and an 85% reduction in biochemical oxygen demand (Gray and Tuominen 1999). Subsequent additions to WWTPs has increased their capacity as the human population increases; however, sewage enters CSOs that bypass WWTPs when sewage volume becomes too great. The media recently requested Environment Canada to produce information on the amount of untreated sewage in BC and Canada. In 2016, Metro Vancouver released over 30,000,000 cubic meters of untreated sewage and British Columbia has the highest volume of combined sewer outflow of all the provinces in Canada (Cruickshank 2018, Li and Cruickshank 2018). Additionally, some street-side sewer systems are never directed to WWTPs. Heavy metals, such as copper from vehicles, can accumulate on roads and then enter CSOs. Heavy metals can affect both adult fish by increasing pre-spawn mortality rates (Feist et al. 2011, Scholz et al. 2011) and can affect juvenile salmon through chemosensory deprivation at low concentrations and may lead to mortality at higher concentrations (Sandahl et al. 2007). The severity that any of these threats are impacting IFC is unknown but because the entire DU must migrate through the lower Fraser River, the threat extent is extensive.

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

Dust from roads and highly trafficked areas can also act as a vector of fine sediments and contaminants (e.g. polycyclic aromatic hydrocarbons (PAHs) and heavy metals) to aquatic systems (Gjessing et al. 1984). Although traffic may be highest in urban areas, highways along streams that are closer to spawning areas may have relatively larger impacts because embryos are a more sensitive life stage. Dust from roads is an example where the source of the pollutants cannot be placed easily into urban, industrial, or rural, and is likely a combination of all activities.

Industrial & military effluents

Many industrial effluent outflows connect to municipal sewage systems, WWTP, and CSOs, but some facilities may also have their own treatment systems on site. Many 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 B.C.). 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 aresenate, and ammoniacal cooper arsenate; many direct discharges were reduced by around 90% since the mid-1980s (Gray and Tuominen 1999). Unfortunately, historical seepage of creosote into soil at historic operations resulted in significant underground reservoirs of contaminants that are slowly infiltrating systems through groundwater. Some factories that use creosote still exist; for example, there is a wood preservation plant that uses creosote to treat railway ties near Ashcroft in the Lower Thompson CU. Some contaminant discharge from wood preservation is released as steam condensate and may still be entering river systems where IFC reside.

Though many of the above contaminants have been removed from discharge, some contaminants do not degrade and continue to persist in the environment. Polychlorinated biphenyls (PCBs), other organohalogens (e.g. dichlorodiphenyltrichloroethane (DDT) and dioxin), and PAHs from industrial (and agricultural) discharge from before the 1980s are still present in Fraser River sediments (higher concentrations in lower Fraser River) and were even found in Burbot (*Lota lota*) in Chilko, Nicola, and Kamloops lakes (Garette 1980, Gray and Tuominen 1999). PCB concentrations may be highest in estuaries due to sediment deposition by rivers, but persistent organic pollutants (POPs) have also been found in the headwaters of the Fraser River (Gray and Tuominen 1999). The likely source of these POPs at higher elevations, is long range atmospheric transport and deposition coupled with the release of historic deposits of contaminants from melting glaciers and permanent snowfields. These contaminants are also not only from local sources; transport time of atmospheric contaminants from Asia to North America is estimated to be as little as 5-10 days (Ross et al. 2013). In a warming global climate, the release of contaminants from glacial deposits into headwaters may increase and expose younger more vulnerable stages of IFC to POPs. Additionally, PCBs and other POPs are still present in consumer products, and even though they are produced at much lower rates, their persistent nature allows them to accumulate in environments.

The impacts of POPs on IFC are uncertain due to a lack of monitoring. In other systems such as Puget Sound, Chinook Salmon have shown reduced smolt-adult survival in chemically contaminated river estuaries (primarily from historically discharged PCBs) whereas Coho

Salmon showed no substantial differences (Meador 2014). PCBs, DDTs, and PAHs were also typically higher in concentration in Chinook than Coho Salmon in estuaries (Johnson et al. 2007), possibly in relation to the shorter estuary residence times of Coho relative to Chinook Salmon or differences in diet (Chinook Salmon can be more piscivorous than Coho Salmon; Arbeider 2018).

Accidental spills from mine tailings and transportation of resources may have large impacts on Coho Salmon populations in the interior Fraser River. The recent Mt. Polley mine embankment breach may have had several negative impacts on the demes that use Quesnel Lake, its tributaries, or migrate through it. The breach released approximately 24 million cubic meters of copper/gold mine tailings effluent into Polley Lake, Hazeltine Creek and Quesnel Lake (Petticrew et al. 2015). The acute changes in turbidity and other suspended pollutants can cause physiological trauma (such as gill abrasions), increased incidence of disease, and behavioural changes (Bisson and Bilby 1982, Nikl et al. 2016). If copper sediments remain suspended or become suspended, there may also be impacts to juvenile salmonids chemosensory systems that may have lasting and detrimental behavioural effects (Sandahl et al. 2007). Short-term effects were likely limited to the few demes that rear in the immediate system in the year of the breach; however, long-term effects are unknown.

The short-term impacts of a diluted bitumen (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 embryotoxicities (Alsaadi et al. 2018). The large number of variable increases the uncertainty of the impacts of a dilbit spill. Two studies that examined the toxicity of dilbit on salmon were done on 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). In the interior Fraser River, the Trans Mountain pipeline runs the length of the North Thompson and along the Coldwater where IFC spawn and rear and it continues along the lower Fraser River where some IFC rear. Spills over land may also pose an unknown threat if dilbit or its constituents seep into groundwater and are transported into streams in low concentrations but over a long period of time. Dilbit is also transported by rail, where trains pose a derailing risk along several routes that run along the middle Fraser, North Thompson, South Thompson, lower Thompson, and lower Fraser River.

Other chemicals are also transported by rail, such as creosote and caustic substances that have the potential to kill hundreds of thousands of fish (Ross et al. 2013). Spills from industrial activities directly into streams would likely create acute but catastrophic impacts where they occurred, but chronic long-term effects are also a possibility if contaminants enter groundwater or accumulate in sediments.

There is one notable military training area in the interior Fraser River watershed, Chilcotin Military Training Area, but the pollution from it or other military areas were not assessed as a separate point source.

Agricultural & forestry effluents

Agricultural and forestry effluents include sediment, large woody debris (LWD), nutrients, and various toxic chemicals. In the interior, forest fires may exacerbate impacts of effluents and forest fire management can also result in the introduction of additional toxic chemicals; these threats will also be included in the threat level of this category because it does not fit well into any of the other Pollution/contaminants categories.

The frequency and magnitude of sedimentation that can occur from the removal of vegetation as the result forestry is based on 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 1992). 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. Sediments and their effects can be broadly separated into fine and coarse sediments. Fine sediments have more direct impacts than coarse, primarily by reducing egg survival through decreasing oxygen circulation, intrusion of fine sediments and preventing fry from emerging from redds (Chapman 1988, Meehan 1992). Other effects from fine sediments are changes to primary and secondary productivity, hyporheic exchange, and flocculation rates, which all interact in complex ways and their impacts are often variable across systems (Meehan 1992, 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 1992), however, the largest impacts from changes in course sediment stability in soils are more linked to increased landslide risk. The threat of landslides is considered in Element 10, but logging is an anthropogenic activity that highly exacerbates this otherwise natural process.

One complicated aspect of forestry effluents is LWD. The chronic impact of logging is that there is usually less LWD in effluent, which decreases habitat complexity (Meehan 1992). However, when stumps and LWD are left in piles at harvest locations, landslides may move large amounts of LWD into streams and modify habitats, create sediment traps, or impact connectivity (e.g. Tschaplinski and Pike 2017).

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. Above natural nutrient levels can cause eutrophication and create hypoxic zones in stagnated water that likely prevent juvenile salmon from using those habitats (Gordon et al. 2015). There is little evidence that this is occurring in the Interior Fraser (though data exists for analysis through Environment and Climate Change Canada); however, tributaries of the lower Fraser are known to become eutrophic (Gordon et al. 2015). Nutrients may also affect primary and secondary productivity in beneficial ways. Nutrient additions have been used to enhance stocks in lakes and streams before, but there are sometimes unintended consequences of increased predation rates that mask benefits (Hyatt et al. 2004, Collins et al. 2016). There are currently no nutrient enhancements in the interior Fraser River watershed.

The use of fire retardants that can be accidentally dropped into stream systems or enter with run-off water (Meehan 1992) will increase with increased frequency and intensity of fires. Yearling Chinook Salmon (*O. tshawytscha*) have reduced survival during seawater entry after exposure to fire retardant at sub-lethal concentrations (Dietrich et al. 2014); however, lethal doses were also estimated to exist if retardant was directly dropped on streams. Effects on yearling IFC are likely similar but the frequency and extent is uncertain for the interior of BC but likely to increase with increased forest fire frequency.

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

4.1.9 Other threats that exacerbate limiting factors

Climate Change

The abundance and productivity of salmon populations is related to changes in climate (Francis et al. 1998), which varies naturally, but anthropogenic emissions of carbon-equivalent gases are exacerbating many of the effects of climate. Various studies document the role of climate change in altering the marine ecosystem, primarily from bottom-up regulation, and relate them to shifts in smolt-adult survival for Coho and other Pacific salmon (Coronado and Hilborn 1998, Beamish and Mahnken 2001, Irvine and Fukuwaka 2011). Within the North Pacific Ocean, climate driven changes in current patterns have profound effects on coastal productivity by creating conditions favorable or unfavorable for upwelling, thus influencing the availability of nutrients on the continental shelf (Francis et al. 1998). The ability to predict climate impacts on salmon ecosystems is difficult and requires reliable regional-level projections and an understanding of the adaptive capacity of all the organisms in the system (Schindler et al. 2008).

There are several projections that estimate future climate-change impacts within the freshwater habitat of IFC. Morrison et al. (2002) observed that historic peak flows are occurring earlier and summer water temperatures are increasing in the Fraser River's mainstem. They projected that by 2070-2099, there would be an overall increase in flow volume (+5%) but a decrease in peak flow (-18%) that would occur an average of 24 days earlier than the average in 2002. For the same projection period, summer water temperatures were predicted to increase an average of 1.9 °C, which is enough to increase adult mortality in freshwater and pre-spawn mortality on the spawning grounds. Morrison et al. (2002) specifically noted that salmon migrating up the Thompson River (i.e. Lower Thompson, South Thompson, and North Thompson CUs) would encounter temperatures above their thermal tolerance in the future under the assumption that they do not have the adaptive capacity to handle consistently higher temperatures, which is likely. Porter and Nelitz (2009) projected the effects of various climate change scenarios on stream temperatures and hydrology in watersheds in the Cariboo-Chilcotin region (i.e. Middle Fraser CU). They found that under worst-case scenarios, increased air and water temperatures were likely to result in significant contractions in the current range of suitable habitat for Coho

Salmon during the next 80 years in most watersheds (but possible expansions in others). Both of these Fraser River watershed studies are analogous with projections of Washington State's north Cascades basins that predict a shift from snowmelt dominated systems to transient runoff dominated ones, with severe summer low flows, higher temperatures, and the additional risk of increased winter flooding frequencies (Mantua et al. 2010). These habitat changes can have a direct impact on both adult and particularly juvenile Coho Salmon survival.

There are no known IFC region-specific ocean climate change projections, but there is evidence that areas where IFC rear in the ocean may be affected or even buffered from some climate change impacts. Smolts typically rear in the Strait of Georgia and Juan de Fuca Strait and then either remain there or move to the Vancouver Island Continental Shelf before returning to the Strait to migrate upstream through the Fraser River estuary (Beamish et al. 1999, 2010, Weitkamp and Neely 2002). The coastal waters of British Columbia are projected to increase in sea surface temperature, chlorophyll *a,* and have neutral to decreasing sea surface heights associated with increased upwelling (Ban et al. 2016). The Strait of Georgia may have the least amount of change across each aspect, and the Vancouver Island Continental Shelf was also identified as a possible climate change refugia (Ban et al. 2016). These projections did not include the data from the years associated with the warm water anomaly event around 2015, colloquially referred to as "The Blob." The Blob began to form during the winter of 2013-2014 and reached its area coverage peak in 2015, creating unprecedented shifts in 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). It is difficult to tease apart how much global climate change affected the creation of The Blob, but its effects have been used as a rough approximation of what ocean conditions may be like in the future (Cavole et al. 2016). It is difficult to quantify the impacts of a short-term event like The Blob on IFC. But anecdotally, the two brood years that had the most smolts and post-smolts in the ocean between 2014/15 & 2015/16 (brood years 2012 & 2013) both had recruitment rates that were less than replacement after they were organized by age class. The frequency of extreme weather events, that create anomalies like The Blob or other events (considered "extreme El Niños") are projected to increase with global climate change (Cai et al. 2014).

There is currently much debate as to how Pacific salmon will respond to future climate change, but for Coho Salmon, the weight of scientific evidence suggests that the overall effect will be strongly negative within the 21st century (Beamish et al. 1997, 1999, Bradford 1998, Hartman et al. 2000, Irvine and Fukuwaka 2011). Healey (2011) reviewed the potential negative effects of climate change at each stage in the life cycle of Fraser River Sockeye Salmon, and his summary is highly applicable to IFC. The threat of future climate change to IFC is imminent and it represents a severe threat in the long-term because:

1. smolt-adult survival of salmon is correlated with climate-induced regime shifts and inter-annual variability in sea surface temperatures and ocean currents,
2. warmer temperatures have the potential to substantially reduce usable habitat, carrying capacity and productivity in both the freshwater and marine environments, and
3. anthropogenic climate change will not be reversible in a reasonable time frame.

The threat that climate change will alter the suitability of the marine and freshwater habitats for Coho Salmon is genuine; however, future conditions can neither be predicted with high accuracy nor controlled (Schindler et al. 2008).

Climate change will exacerbate the impacts or frequency of other threats. This will be discussed in Cumulative Impacts.

Hatchery Salmonids

The effects of hatchery practices and enhancement on genetics of wild populations has already been discussed; however, hatchery Coho Salmon are also a threat because they exacerbate natural processes such as competition, predation, and disease transmission, and contribute to mixed stock fisheries issues (Gardner et al. 2004).

Negative interactions between wild and hatchery Coho Salmon can occur in coastal and pelagic marine environments. Concern that hatchery Chinook and Coho Salmon were replacing wild fish in waters of Southern British Columbia was expressed by Noakes et al. (2000), with the negative impacts from the low productivity regime exacerbated by hatchery fish. This sentiment has been echoed since, with concern that hatchery fish are adding to competitive processes (Sweeting et al. 2003) because of the high diet and appetite overlap of hatchery and wild fish observed in the Strait of Georgia (Sweeting and Beamish 2009), and the role that fish growth has in early marine survival (Beamish et al. 2010). Large enhancement programs for Coho Salmon in the lower Fraser River and Burrard Inlet, Puget Sound, and the East Coast of Vancouver Island may pose a greater risk to IFC than enhancement directly within the interior Fraser River watershed. Beamish et al. (2008) estimated that the percentage of hatchery-reared Coho Salmon in the Strait of Georgia increased from near 0% in the early 1970s to a peak of nearly 75% in the late 1990s, and then declined to about 25% by 2006. Total production of hatchery Coho Salmon (mostly smolts) was ~8 million for British Columbia alone, and ~70-80 million for British Columbia, Washington and Oregon combined during the late 1990s, and declined to ~5 million and ~50 million in BC and the region as a whole, respectively, by 2010 (PSC 2013b). In addition to competition for resources, hatchery Coho Salmon may increase transfer of diseases and parasites, and increase predation and fishing mortality for wild fish that co-migrate with the large numbers of hatchery fish in the ocean (Gardner et al. 2004).

Hatchery IFC are only present in fresh water during spawning and outmigration because hatchery fry are no longer released; only smolts are released. Before hatcheries started producing only smolts, there were some concerns that fry were competing for freshwater habitat in the Eagle River (Gardner et al. 2004). Since the removal of hatchery fry, there may not be high levels of competition for freshwater rearing habitat because it is not currently considered limiting, however there is likely competition with hatchery fish in the smolt life stage when fish use habitats in the Fraser River estuary and Salish Sea.

4.1.10 Cumulative Impacts

Cumulative impacts are the combined impact of past and present human activities and natural process interacting. Unlike impacts from specific development activities, cumulative impacts occur over an extended period of time and as a result of a combination of a variety of activities. The COSEWIC threats calculator (COSEWIC 2012) assessment done of IFC by this working group, captured the additive cumulative impact of all threats assessed. The calculator ranked the overall threat impact as High-Very High, which suggests that the IFC DU may decline between 10-100% in the next 10 years due to the cumulative severity of the threats identified if additional mitigation is not implemented.

A major concern surrounding cumulative impacts is the ability of agencies or proponents to conduct development project reviews. Regulatory requirements of the *Canadian Environmental Assessment Act* (CEAA) ensure that the assessing biologist review, amongst other things, the cumulative impacts on the habitat that would occur as a result of the project. However, this mandatory consideration is only a requirement for projects subject to CEAA and does not apply to the majority of development activities reviewed by fisheries agencies. In order for a project review to properly assess cumulative impacts, analysis of the current condition of the watershed is required. This information is not provided for most development activities; therefore, assessors may have to rely on a combination of personal knowledge of the state of the watershed, existing literature, and advice of other professionals. Much of this information is qualitative in nature.

Climate change, forestry, and other activities that destabilize sediment may have additive or multiplicative impacts across the entire watershed. For example, the cascading effects of increases in pine beetle infestation of forests due to climate change may affect IFC by altering riparian and instream habitats, increasing risk of forest fires, and increase rates of forestry. In addition to the cascade of effects that may happen over a short timeframe, each will also interact and cumulatively destabilize sediments over multiple years and areas of continued activity through either removing vegetation and root structures or creating hydrophobic soils that increase surface runoff rates. Destabilization of bank sediments from these effects can increase the risks of landslides that can block spawning habitat or downstream migration of smolts. For example, cumulative years of bank destabilization from forestry and fire (Elephant Hill fire) and natural erosion combined with high flows resulted in the failure of the Bonaparte River fishway in 2018, which impeded IFC and other migrating salmonids from reaching spawning habitat. Subsequent local flood events and higher-than-average flows then continued to prevent repairs to the fishway.

Warmer temperatures and habitat alterations will also compound the threat to IFC from predators, competitors, pathogens, and contaminants. Warmer temperatures interact with habitat loss by increasing the demand to forage or find refugia but reducing its supply. An additional interaction is that alien fishes have higher temperature preferences and thermal tolerances than IFC in their freshwater environment (Bradford et al. 2008a, 2008b, Tovey et al. 2008); further adding competitive demand on refugia between IFC. Shifts in ocean communities may result in less nutritious prey (Cavole et al. 2016) and unknown shifts in predator communities. All of these stresses may hinder salmon immune systems and heighten impacts from pathogens (Miller et al. 2014). Warmer temperatures may also increase the toxicity of contaminants (Laetz et al. 2013, Sappal et al. 2014), whose sublethal effects will then interact with effects from predators, competitors, and pathogens.

The IFC streams with the highest amount of likely cumulative impact are where the most human development exists: the lower Thompson, Nicola, and Shuswap subpopulation areas. Further development continues in these areas, increasing the risk of cumulative impacts. The primary land uses that have contributed to habitat loss and deterioration are forestry, agriculture, urban and rural development, linear development and water extraction. With continued population growth, the cumulative impact of human activities will put increasing pressure on watershed catchments, sediment stability, and water resources, and will continue to affect the viability of IFC.

The lower Fraser River and Strait of Georgia are also affected by multiple threats that contribute to cumulative impacts. Destruction of fish habitat may be minimal at a specific development site; however, when combined with other spatially limited impacts, the result can be significant. For example, a single dyke along a stream reach wouldn't significantly alter the stream hydrology; however, continuous dyking could reduce overall stream length leading to significant hydrological changes that can detrimentally affect the fish habitat and behaviour. Over 700 km of cumulative stream habitat have been relegated to storm sewer status, impacted by culverts, or paved over in the Fraser Valley (FRAP 1998). Loss or degradation of this stream habitat and riparian vegetation has reduced the capacity of the lower Fraser River and its tributaries to support rearing IFC. Point and non-point source pollutants affect water quality throughout the range of freshwater and marine habitats of IFC. All suspended sediments from the watershed may also settle in the lower Fraser River and its estuary. More than 300 outfalls discharge into the Georgia Basin, carrying municipal sewage, urban storm-water runoff, and various chemicals from industrial operations. Both wild and hatchery Coho Salmon and other salmonids also all compete within the Strait of Georgia for resources that have been impacted by a regime shift in the ocean and may be impacted further in the future through long-term climate change an ocean warming.

Table 9. DFO threats assessment calculator for Interior Fraser Coho Salmon. Note that categories are a slight modification of the COSEWIC Categories, see Appendix 7. Refer to the text for extensive comments on each threat and to Appendix 7 and DFO (2014b) for detailed description of each factor level in the table. The bracketed number following the Threat Risk ranking represents the Causal Certainty rank. Examples are not inclusive of all threat aspects.

Threat	**Likelihood of Occurrence**	**Level of Impact**	**Causal Certainty**	**Threat Risk**	**Threat Occurrence**	**Threat Frequency**	**Threat Extent**	**Examples**	**COSEWIC Category**
Modifications to Catchment Surfaces	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive	removal of forest and vegetation, and creation of impervious surfaces resulting in modified hydrological regimes	7.3
Linear Development	Known	Medium	High	Medium (2)	Historical/ Current/ Anticipatory	Continuous	Extensive	reducing habitat complexity through channelization, riprapping	7.3
Agricultural & forestry effluents	Known	Medium	High	Medium (2)	Historical/ Current/ Anticipatory	Continuous	Extensive	additional sedimentation resulting from removal of vegetation	9.3
Food, Social, & Ceremonial, Recreational, and Commercial Fishing	Known	Low-Medium	Very High	Low-Medium (1)	Historical/ Current/ Anticipatory	Recurrent	Extensive	adult mortality resulting from direct and indirect fishing mortality	5.4
Dams & water management/ use	Known	Low-Medium	High	Low-Medium (2)	Historical/ Current/ Anticipatory	Continuous	Extensive	groundwater extraction for agricultural use. Large and small hydroelectric dams	7.2

Threat	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent	Examples	COSEWIC Category
Introduced genetic material	Known	Low-Medium	High	Low-Medium (2)	Historical/ Current/ Anticipatory	Recurrent	Narrow	influence of hatchery-origin fish interbreeding with natural-origin fish	8.3
Household sewage & urban waste water	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive	pollution from combined sewer outfalls, e.g. microplastic, heavy metals, hormones, etc.	9.1
Industrial & military effluents	Known	Low-Medium	Medium	Low-Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive	pollution from operational effluent, stored waste, and accidental spills	9.2
Science Activities	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Recurrent	Narrow	stock assessment (test fishery, mark-recapture) and academic research	6.3
Mining & quarrying	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Recurrent	Restricted	primarily placer mining that occurs in-river	3.2
Fire & fire suppression	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Recurrent	Restricted	direct heating from fires; ditch digging and water scooping	7.1
Invasive Plants Modifying Habitat	Known	Low	Medium	Low (3)	Historical/ Current/ Anticipatory	Continuous	Narrow	Cheatgrass growing in floodplains	7.3

Threat	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent	Examples	COSEWIC Category
Livestock farming & ranching	Likely	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted	cattle directly crushing redds	2.3
Roads & railroads	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Narrow	maintenance, widening, and construction of brides directly in river	4.1
Utility & service lines	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Narrow	maintenance, widening, and construction of utility (e.g. pipelines) directly in river	4.2
Shipping lanes	Known	Low	Low	Low (4)	Historical/ Current/ Anticipatory	Recurrent	Extensive	dredging, primarily in the lower Fraser River	4.3
Invasive non-native/alien species	Known	Unknown	Medium	Unknown (3)	Historical/ Current/ Anticipatory	Continuous	Extensive	primarily invasive fishes that are predators of juvenile IFC	8.1
Introduced Pathogens and Viruses	Unknown	Unknown	Medium	Unknown (3)	Historical / Anticipatory	Continuous	Narrow	Piscine Orthoreovirus and Heart and Skeletal Muscle Inflammation	8.5
Recreational Activities	Likely	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Recurrent	Restricted	ATVs, other off-road vehicles, horses directly crushing redds	6.1

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

The majority of Threats in Element 8 may impact habitat properties from Elements 4-5. Specifically (in order of Threat Risk): modifications to catchment surfaces, linear development, agricultural and forestry effluents, dams and water management/use, household sewage and urban waste water, industrial and military effluents, mining and quarrying, fire & fire suppression, invasive plants modifying habitat, roads and railroads, utility and service lines, shipping lanes, and recreational activities. The pathways have been described in Element 8 but are primarily associated with impacts to water quality (e.g. temperature and pollutants), stream hydromorphology (e.g. seasonal changes in timing and magnitude of flow), turbidity and sedimentation, simplification of habitat features, reduced connectivity, and impacts to groundwater and hyporheic flows.

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

Natural limiting factors are defined as “non-anthropogenic factors that, within a range of natural variation, limit the abundance and distribution of a wildlife species or a population” (DFO 2014a). 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 (Table 10) **unless** there are other factors (anthropogenic threats) that are exacerbating natural levels of variation or impacts to a population. As almost all of the natural limiting factors are affected by anthropogenic induced climate change or landscape-level development, they are intertwined with existing threats and impacts.

4.3.1 Biological and physiological limits

Salmon typically have life-history characteristics that promote rapid population growth given adequate habitat and survival; however, several natural factors potentially limit their adaptability that may limit their recovery potential under current or future circumstances. Coho Salmon eggs and alevins in particular (larval stage with yolk sac that is more environmentally sensitive than eggs) need water and sufficient oxygen. Natural fluctuation in flow can cause dewatering, freezing, and hypoxia, which may limit egg and alevin survival. Coho Salmon redds and alevins require substrate smaller than ~20 cm that is well aerated (Sandercock 1991), thus they are limited in where they can spawn; though there is little evidence that substrate is currently a limiting factor for IFC nor has been found as limiting in coastal populations (Bradford et al. 2000). The specific habitat requirements of IFC, which have developed through long-term evolutionary processes, may impact them if other threats change habitat properties over time at a faster rate than they can adapt. Female size and fecundity varies from year to year as a result of ocean conditions. If female size and fecundity decline, and thus productivity, this could become a limiting factor for recovery. The high mortality rate from egg to spawning adult in salmonids may be a limiting factor at certain thresholds and is difficult to estimate because it is the product of many processes and survival among many life stages. The cumulative mortality from egg to adult is linked to most of the threats identified in Element 8 in addition to predation, and there is uncertainty associated with natural or historical survival parameters. Finally, Coho Salmon are semelparous and have a fairly fixed age distribution, limiting them to reproducing on only once and potentially limiting genetic mixing across broods. However, the generally high fecundity, productivity, and straying rates of Coho Salmon buffer many of the potentially limiting effects of semelparity and low age-at-maturity diversity. The effects of genetic loss that may impact biological and physiological limits has been assessed separately in section *4.1.7 Invasive & other problematic species & genes*, which is why this natural limiting factors threat level was scored as low.

4.3.2 Varying ocean and freshwater conditions

Altered freshwater conditions due to climatic variation may affect both juvenile and adult Coho Salmon. Since most juvenile IFC spend a full year in freshwater, they are particularly susceptible to freshwater habitat conditions. Furthermore, mature Coho Salmon may spend weeks or months in freshwater undertaking energetically rigorous behaviours such as migrating upstream and spawning, making them also vulnerable to freshwater conditions. Variations in temperature, flow, turbidity, and productivity may alter metabolism and behaviour in ways that increase mortality through stress, starvation, and predation. IFC may be highly susceptible to these variations across each CU because they currently have low productivity, which increases their risk of extirpation due to random variation (Holt and Bradford 2011). Anthropogenic changes in climate will exacerbate variability in freshwater conditions as well as the magnitude and frequency of extreme weather events. Projections on changes to freshwater conditions from climate change have been discussed in Element 8. The combination of IFC's currently low productivity and possible carrying capacity along with climate change impacts are the primary reasons that this category received an uncertain but potentially high level of impact score.

Altered ocean and estuary conditions due to climatic variation are also known to impact salmon (Francis et al. 1998). For IFC, the shift from historic to current productivity regimes suggests that these populations are susceptible to effects from major climate shifts. Within the Gulf of Georgia, where IFC smolts first enter the ocean, prey availability is driven by the availability of nutrients on the continental shelf and by complex currents delivering water from the continental shelf into the Georgia Basin. The shift in current circulation in the Gulf of Georgia in 1989 was linked to a shift in global climate (Beamish et al. 1999), and is hypothetically connected to the subsequent productivity regime shift in IFC. Although there are no projections on when another regime shift may occur, there is little evidence to suggest a major shift in ocean climate regimes since 1989 (Irvine and Fukuwaka 2011). Overall, ocean trends in Salmon abundance in the North Pacific suggest that recent climate conditions have benefited Pink and Chum Salmon, while negatively impacting Coho and Chinook Salmon (Irvine and Fukuwaka 2011). Anthropogenic climate change is exacerbating effects of naturally varying ocean conditions that IFC have shown a high sensitivity to, which is why this this category received an uncertain but potentially high level of impact score.

4.3.3 Parasites and pathogens, predation, and competition

Disease, predation, and competition are an interrelated and complex suite of factors. For example, diseases caused by parasites and pathogens often change the behaviour of salmon such that they become more susceptible to predation or are left at a competitive disadvantage (Miller et al. 2014). High competition can result in exposure to higher predation and the threat of predators may incur vigilance costs that causes schooling behaviour and increases local competition. Although these interrelations are difficult to quantify, there are several anthropogenic factors that hypothetically or empirically have been shown to affect certain aspects of each.

There are several naturally occurring parasites and pathogens that can affect Pacific salmon. Sea lice (*Lepeophtheirus salmonis* and *various Caligus sp.*) are the most frequent external parasites of Pacific salmon, which naturally occur in the ocean and are transmitted between salmon species and several non-salmonid fishes. Currently, the sensitivity of IFC to variability in pathogen rates caused by sea lice has not been quantified. Open-pen-net salmon farms are one anthropogenic activity that could exacerbate sea lice and disease transmission rates; however the potential effects may become diminished if open-pen-net salmon farms are moved from the Broughton Archipelago and other migration routes as planned in BC. No naturally occurring pathogens or viruses were identified as limiting factors beyond natural variation; however, there is also a lack a testing for disease rates and infected fish may be predated before capture in fisheries or returning to the spawning ground. Thus, the effects from parasites and pathogens was ranked as unknown.

Predation is a source of mortality for Coho Salmon across all life stages. However, there is uncertainty in the rates of predation by specific predators on each life stage. The threat of predation begins as an egg and carries onto the entire juvenile freshwater life stage. Freshwater predators of juveniles include many opportunistic fishes, small mammals, and birds (Sandercock 1991). Juvenile Coho Salmon are also known to cannibalize smaller individuals and eggs (Taylor and McPhail 1985a). In the estuary and early ocean period, the list of predators increases to include any piscivorous marine fishes, marine birds, and marine mammals. When adults return to spawn in freshwater, larger mammals and birds become their predators. Table 11 provides a more detailed list of possible predators.

The effects of predation may also vary with the overall abundance of IFC and co-occurring prey. In some systems that have constant levels of predators because they are sustained by other prey items, a low abundance of Coho Salmon may suffer proportionally larger impacts from predation (depensatory effects). Whereas if Coho Salmon are the sustaining prey, low abundances of Coho Salmon may attract fewer predators or have less competition for areas that provide predator refuge. However, these scenarios are hypothetical and there is a large amount of uncertainty around what may actually happen. Coho Salmon may suffer higher predation rates if high abundances of co-occurring prey draw higher abundances of predators. Hatchery Coho Salmon are known to exacerbate predation rates on wild Coho Salmon in other systems by attracting larger than natural aggregates of predators (Nickelson 2003). The continued production of Hatchery Coho Salmon and other salmonids that are released into the Strait of Georgia are primarily why this limiting factor was scored as having a Medium level of impact.

Competition within Coho Salmon can occur over spawning area, predator refuges, and prey resources. Competition for spawning area and displacement of redds made by conspecifics can be a major source of compensatory dynamics in Salmon. For IFC at current population abundances, competition for spawning areas is likely lower than historic levels in most streams but still present and possibly exacerbated by returning hatchery-origin individuals. Competition for predator refuges in freshwater may also not be a limiting factor because juvenile IFC display less territorial behaviour than coastal Coho (Chapman 1962, Warren 2010), unless habitat destruction minimizes the quantity of refuges. Competition for prey resources is likely the most limiting type of competition for IFC, but it is difficult to measure and observe; however, as noted in *4.1.9-Hatchery Salmonids*, hatchery Coho Salmon may increase competition in ocean environments because of their diet overlap (Sweeting and Beamish 2009). There is uncertainty in how natural competition may be affecting IFC but cumulative impacts from other threats may exacerbate competition in ocean or freshwater environments, hence the ranking of a Medium level of impact.

4.3.4 Landslides

Landslides can block migration of both adult and juvenile fish, destroy habitat, and alter habitat conditions by introducing unnaturally high concentrations of sediment. The historical slide at Hells gate (1914) was caused by anthropogenic construction, but represents a worst case scenario of a slide that could happen naturally or from cumulative impacts (as described in

Element 8). The slide at Hells gate affected all CUs because they all must migrate through the Fraser Canyon. Current landslide risks are more CU specific and are predicted to occur in the Bonaparte, Nicola, and Westroad river watersheds due to the cumulative effects of forestry, fire, pine beetles, and changing climate. In June 2019, a landslide was discovered on the mainstem of the Fraser River (near Big Bar north of Lillooet) that will impact the Upper Middle Fraser subpopulation of the Middle Fraser CU until fish passage can be provided. 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 access to or burying spawning gravel.

Table 10. Natural limiting factors assessed in the DFO threats assessment and calculator framework for Interior Fraser Coho Salmon. The Threat Risk of a natural limiting factor is assumed to be Low unless there are external anthropogenic factors that are exacerbating the effects of a natural limiting factor. Refer to the text for extensive comments on each threat and to DFO (2014b) for detailed description of each factor level in the table. The bracketed number following the Threat Risk ranking represents the Causal Certainty rank.

Limiting Factor	Likelihood of Occurrence	Level of Impact	Causal Certainty	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent	Notes
Varying Ocean Conditions	Known	Medium-High	Very High	Medium-High (1)	Historical/ Current/ Anticipatory	Continuous	Extensive	exacerbated by climate change; historic evidence of possible impacts
Varying Freshwater Conditions	Known	Medium-High	High	Medium-High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive	exacerbated by climate change that shifts temperature and flow
Competition	Known	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive	exacerbated by hatchery-origin Coho Salmon
Predation	Known	Medium	Medium	Medium (3)	Historical/ Current/ Anticipatory	Continuous	Extensive	exacerbated by hatchery-origin Coho Salmon
Avalanches/ landslides	Likely	Low-Medium	High	Low-Medium (2)	Historical/ Current/ Anticipatory	Recurrent	Narrow	exacerbated by forestry and climate change
Biological & Physiological Limits	Known	Low	Very High	Low (1)	Historical/ Current/ Anticipatory	Continuous	Extensive	semelparous, fecundity and thermal constraints, etc.
Native Parasites & Pathogens	Known	Unknown	Low	Unknown (4)	Historical/ Current/ Anticipatory	Continuous	Extensive	data deficient on disease transmission rates; may be exacerbated by farm and hatchery fish

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

Co-occurring species typically take on the forms of predators, competitors, or prey (Table 11), all of which will have a different relationship with regards to the threats that may impact Coho Salmon abundance or behaviour. Predators will typically be negatively impacted by threats if the abundance of Coho Salmon decreases; however, some threats may benefit predators by changing IFC 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 Coho Salmon or certain levels of sediment suspension may reduce a Coho Salmon's ability to see but not affect some predators, thus increasing the likelihood a predator will succeed. Competitors will generally benefit from lower abundances of Coho Salmon, but if a competitor has similar habitat requirements or prey requirements that are being impacted by different threats then they will also be impacted negatively. Competitors in the marine environment may be most at risk of similar threats to ocean productivity as Coho Salmon are. Impacts to ocean productivity is also a direct impact to marine prey species of Coho Salmon, who would normally benefit from reductions in Coho Salmon abundance.

Most of the threats that would impact habitat features would also impact many of the co-occurring species. For example, any terrestrial predator would be impacted by changes to the watershed catchment such as decreases in forests or increased urbanization. Trees and riparian vegetation are also directly impacted as they are the habitat features that are often destroyed. Changes to freshwater flow through modifications to catchment surfaces, linearization, and water use (e.g. irrigation) will affect all aquatic species, most in a negative way. Some introduced and invasive species may benefit from increased temperature regimes in freshwater because they have physiological tolerance to high temperatures and can outcompete native species. The Ministry of Environment currently surveys introduced aquatic species and management action to eradicate them in several systems has occurred.

The only primary research currently being done on IFC is that by commercial fisheries and stock assessment with DFO. Commercial fishing is one source of data on co-occurring salmonids and other bycatch. The Ministry of Environment surveys many of the other trout and freshwater species. Research on Southern Resident Killer Whales is increasing at several universities and within DFO in association with their reliance on salmon. There are no known projects that are directly investigating interactions between many of the birds and mammals (Table 11) with IFC.

Table 11. List of co-occurring species, general habitat they overlap in, and what their relationship is to Coho Salmon. ~ indicates that this interaction is likely relatively weak. This table is general and not inclusive of all possible co-occurring species nor interactions.

Species	Habitat	Interaction
Rainbow Trout	Fresh water	Predator, Competitor
Cutthroat Trout	Fresh water	Predator, Competitor
Bull Trout	Fresh water	Predator, Competitor
Yellow Perch	Fresh water	Predator, Competitor

Species	Habitat	Interaction
Bass sp.	Fresh water	Predator
Northern Pikeminnow	Fresh water	Predator, Competitor
Chub sp.	Fresh water	~Competitor
Sculpin sp.	Fresh water	Predator
Mountain Whitefish	Fresh water	~Competitor
Black Crappie, Pumpkin Seed, Panfish et al.	Fresh water	Predator
Aquatic Invertebrates	Fresh water	Prey, ~Predator
Freshwater zooplankton	Fresh water	Prey
Juvenile Salmon sp.	Fresh water to Marine	Competitor, Prey
Adult Salmon sp.	Marine to Fresh water	Competitor
Nooksac Dace	Lower Fraser	~Competitor
Mink	Fresh water	Predator
Bear sp.	Fresh water	Predator
Wolf	Fresh water	Predator
Riparian Vegetation	Fresh water	Recycler
Salish Sucker	Lower Fraser Rearing	~Competitor
Spiny Dogfish	Marine	Predator
Harbour Seal	Estuary, Marine	Predator
Sea Lion sp.	Estuary, Marine	Predator
Killer Whale	Marine	Predator
Pacific Herring	Estuary, Marine	Prey, Predator, Competitor
Anchovy	Marine	Prey, Competitor
Surf Smelt	Estuary, Marine	Prey, Competitor
Sandlance	Marine	Prey, Competitor
Capelin	Marine	Prey, Competitor
Pacific Sardine	Marine	Prey, Competitor

Species	Habitat	Interaction
Squid sp.	Marine	Prey, Competitor, Predator
Rockfish sp.	Marine	Prey, Competitor
Flounder sp.	Estuary, Marine	Prey, Competitor
Sablefish	Marine	Predator, Competitor
Lanternfish sp.	Marine	Prey, Competitor
Pacific Hake	Marine	Predator, Competitor
Pacific Saury	Marine	Prey
Walleye Pollock	Marine	Prey, Competitor
Marine zooplankton	Marine	Prey
Great Blue Heron	Fresh water, estuary	Predator
Merganser sp.	Fresh water	Predator
Belted Kingfisher	Fresh water	Predator
Alcid sp.	Marine	Predator, Competitor
Cormorant sp.	Estuary, Marine	Predator, Competitor
Gull sp.	Estuary, Marine	Predator
Loon sp.	Marine	Predator

5 RECOVERY TARGETS

5.1 ELEMENT 12: PROPOSED CANDIDATE ABUNDANCE AND DISTRIBUTION TARGETS FOR RECOVERY

Recommended recovery targets for the IFC DU incorporate both abundance and distribution components that follow the SMART (Specific, Measurable, Achievable, Realistic, and Time-bound) framework (DFO 2011), the Precautionary Approach framework (DFO 2005b), and other RPA guiding documents (DFO 2005a, 2014b). The final recommended target was developed in the context of prior recovery objectives (IFCRT 2006) and analysis done on IFC for both DFO and the Pacific Salmon Commission (Decker et al. 2014, Korman et al. 2019). Only escapement data from 1998-2016 (currently available data) were used to calculate the target because this is after a major shift in assessment methodology (Appendix 5).

The IFCRT (2006) suggested recovery objectives based on ecological and conservation theory. The IFCRT targets aimed to maintain the viability and diversity of naturally spawning IFC. They included the aspect of delineated subpopulations within each CU (note that COSEWIC refers to the CUs as subpopulations, and here we refer to subpopulations as a higher resolution scale within the CUs, refer to Table 2). The delineations were based on the distance between spawning systems, the presence of large watersheds or lakes, the presence of partial barriers to migration, and some limited genetic evidence. Delineating areas within each CU fosters monitoring, protection, and enforces mitigation responses to prevent the loss of spawning systems within the large spatial aspects of each CU. The ecological theory behind the subpopulation delineations is based on straying behavior. Straying between spawning groups occurs at a decreasing rate with distance from natal streams (Quinn 1993) and the arrangement of suitable spawning habitat (e.g., inter-patch distance and connectivity) plays a central role in metapopulation dynamics (Schtickzelle and Quinn 2007). Therefore, the recolonization rate of spawning locations following local extirpation and the overall risk of extinction is related to how close or connected streams are.

Two of the IFCRT objectives included specific adult spawner abundance and distribution targets, which are subsequently referred to as the short-term and long-term targets (Table 12) in this Element. The short-term target was recommended when the IFC COSEWIC status was Endangered, and thus represents an immediate recovery target designed to prevent extinction or loss of genetic diversity. The short-term target may still be the minimum objective, but now that the IFC COSEWIC status has been assessed as Threatened (an improvement from Endangered (Irvine 2002)), a more precautious longer-term target may offer more desirable management outcomes through achievement of what is considered to be a recovered IFC DU in the current environmental conditions. The IFCRT long-term target is one example of an achievable and more precautious goal. The long-term target is that the 3-year geometric average of natural-origin escapement in all of the subpopulations within each of the five populations (CUs) is to exceed 1,000 Coho Salmon. The 3-year mean represents average abundance per generation (three consecutive years in IFC) and is used to smooth out annual variations and influences from both dominant and sub-dominant brood lines that may exist. Specifically, the geometric mean places less weight on the years of high abundance relative to an arithmetic mean, facilitating a more precautionary approach and ensuring that recovery status does not change on the basis of a single large return. The geometric mean is also not as conservative as a harmonic mean, which is greatly influenced by low return numbers and primarily used to average rates and not abundances.

*Table 12. Candidate abundance and distribution targets for the Interior Fraser Coho DU. The IFCRT long-term target is what is suggested in this report. *This is the recommended target.*

Target Name	Description
IFCRT short-term target	The 3-year geometric average, natural-origin escapement in at least half of the subpopulations within each of the five populations is to exceed 1,000 spawning Coho Salmon, excluding hatchery fish spawning in the wild.
IFCRT long-term target*	The 3-year geometric average, natural-origin escapement in all of the subpopulations within each of the five populations is to exceed 1,000 spawning Coho Salmon, excluding hatchery fish spawning in the wild.
Alternative Targets	The 3-year geometric average, natural-origin escapement in all of the populations (CUs) exceeds 80% of S_{MSY} or other reference point (see Appendix 8).

The abundance target is distributed at the subpopulation-level and, therefore, implies a distribution target that assumes fish are still occupying at least some tributaries at this level.

Although this distribution target is currently vague (in the sense that specific stream targets are not identified), existing monitoring and management are also at the level of subpopulation (Decker and Irvine 2013, Decker et al. 2014) and there are currently insufficient resources to monitor and assess at a finer distribution.

Since subpopulations likely have different productivities and capacities, the aggregate DU abundance that meets the subpopulation target is expected to be greater than 11,000 (the sum of 1,000 per the number of subpopulations) on average. The IFCRT originally suggested that the DU target be 40,000 based on a qualitative assessment of historic data. Here, we used a more quantitative analysis of historic data to determine what the DU-level target could be.

The DU-level abundance target was informed by the probability that each sub-DU target was met for a given DU abundance (Figure 13). Prior assessments of the IFCRT targets used logistic-type regressions to identify different probabilities that a sub-DU target was met across known DU abundances (Decker et al. 2014, Korman et al. 2019). A generalized linear model was used with a binomial family error distribution and logit link function because the model is fit to binary data, i.e. all CU targets were either met (success) or at least one was not (failure). This analysis was done in R (R Core Team 2018) using the package lme4 (Bates et al. 2015). The DU abundance target was approximated at the 95 percentile (i.e. y = 0.95) of sub-DU target success from the model output. The 95 percentile represents a buffer from the lowest observed sub-DU target failure and an achievable, historically observed mark near the 100 percent success asymptote (Figure 13).

The dataset included natural-origin escapements from 1998-2016. For the purpose of this analysis, natural-origin returns are defined as first generation Coho Salmon spawning in natural rivers. Estimation of natural-origin returns was conducted by removing the estimated enhanced contribution of adipose absent and adipose present hatchery returns from total returns. Adipose clip rates were determined during field programs and applied to total return to estimate adipose absent contribution; however, adipose present returns required further classification as natural or hatchery origin. The hatchery return of adipose present IFC was estimated from survival rates, for the life stages between release and adult, and ERs for adipose present fish. Survival rates were estimated using mark recovery data for CWT release stages and data from the Mark Recovery Program database. Enhanced contribution from adipose present hatchery IFC returns was then removed from the total adipose present returns to estimate natural returns. This method was described in section 2.1.4 of Parken et al.[1]. As per the target description, data were transformed into 3-year running geometric means:

$$(1)\ esc_t = \prod_{t=1999}^{2015}(esc_{t-1}, esc_t, esc_{t+1})^{1/3}$$

where *esc* is escapement at the subpopulation-level or the DU-level during return year *t*. The resulting DU target was estimated as a 3-year geometric mean abundance of **35,935** natural-origin spawners. Ideally, the DU would not drop below this 3-year average in subsequent years after meeting it for the initial time. Several alternative targets that were considered are discussed in Appendix 8; however, most are ± 2,000 spawners from the above recommendation (Table 36).

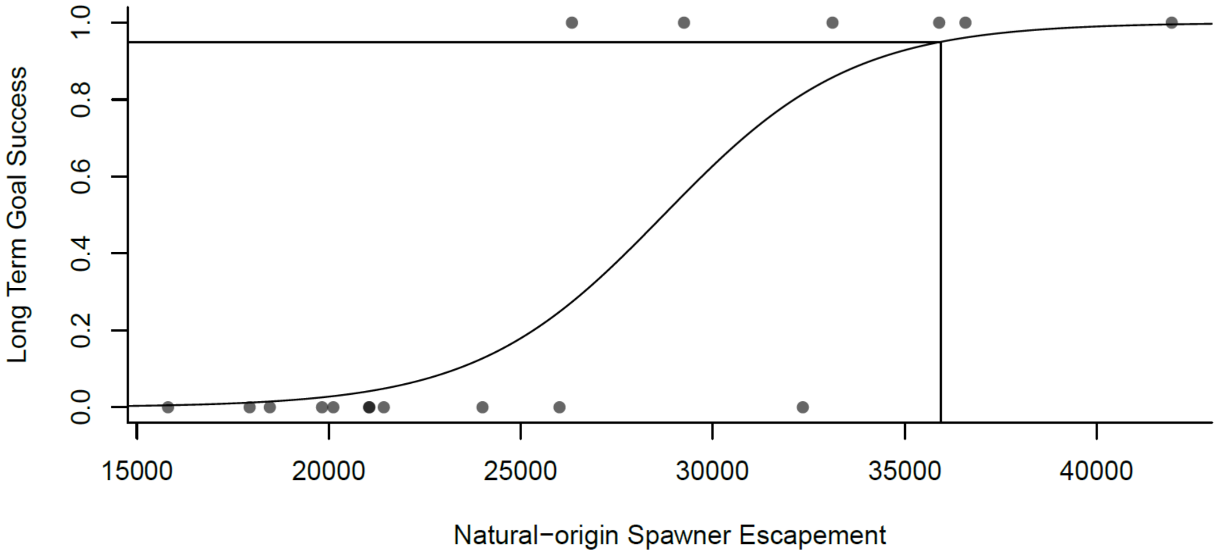

Figure 13. IFCRT long-term target assessed at the DU-level for natural-origin spawners from 1998-2016. Logit-link generalized linear model regression between 3-year geometric mean escapements of natural-origin spawners and whether or not there was a long-term target success i.e. 3-year geometric mean > 1000 in any subpopulation. Data is from return years 1998-2016. The perpendicular lines indicate the mean 95 percentile of success occurs at 35 935 spawners.

The IFCRT long-term target does not include a “time-bound” component (required by SMART), so the default minimum 10 years (which encompasses 3 generations) will be used in subsequent elements. Projecting further than 10 years is not recommended because there are only 16 years of stock-recruit data available to create parameter estimates and variance.

The choice of recovery target is not limited to the scenario presented here. For example, the Wild Salmon Policy assessment framework uses a comprehensive set of population dynamics, trend, abundance, distribution, and productivity information to determine a population’s status. All of these aspects are recommended for consideration in the definition of recovery and setting targets. Productivity and marine/smolt-to-adult survival in particular are important aspects to monitor for IFC. The change from historic (higher) to current (lower) productivity regimes is, to a large degree, preventing IFC from recovering to historical return levels. Specific productivity targets may be useful in determining the IFC DU’s status as well as its ability to survive and recover. Several alternative abundance targets that were considered relate to 80% S_{MSY} benchmarks resulting from stock-recruit analyses that operate at the CU-level (Appendix 8). However, stock-recruit relationships are only as robust as the data they are based upon and there are several possible issues or sources of uncertainty with the IFC data set. Any models and all targets should be reviewed as more data become available or environmental conditions that affect underlying population dynamics such as productivity or survival change.

5.2 ELEMENT 13: PROJECTED POPULATION TRAJECTORIES GIVEN CURRENT POPULATION DYNAMICS PARAMETERS

5.2.1 Caveats and conditions

There are some issues associated with the IFC dataset that need to be considered when extrapolating results from model fitting and forward simulation. The major issue is that models used to estimate ER follow several assumptions that are likely incorrect (PSCCWTW 2008, PSC 2013a), and the models do not calculate error in their estimates (see section *4.1.4* for more detail). Therefore, any back-calculation of recruitment from escapement is inherently uncertain and may be in error. Error and uncertainty in recruitment will subsequently be carried-over to estimates of α', the parameter that represents productivity at low stock size, which will also affect estimates of β and carrying capacity. Several other issues that are often found within salmon datasets are present, including uncertainty in escapement estimates and age distribution in recruits. Previous simulation modelling on data-limited CUs of Chum Salmon found that uncertainty in escapement and age-at-maturity within plausible ranges had relatively minor impacts on the precision and accuracy of stock-recruitment-based benchmarks compared with variability in underlying productivity and ERs, suggesting that parameter estimates may be relatively robust to uncertainty in these variables (Holt et al. 2018). However, it should be realized that any modelling done with the IFC dataset, in its current state, contains unaccounted uncertainty that may be either major (e.g. from ER) or minor (e.g. from escapement or age-at-maturity) in its properties.

An additional condition of extrapolating from these results is that the model assumes stationarity in parameters and covariates. Non-stationarity may arise, however, from trends in productivity driven by biological or environmental interactions. For example, future productivity, survival, and carrying capacity may differ from historic and recent time periods because ecosystems react in variable ways to climate change, continued human population growth, hatchery genetic influence, development, mitigation, and restoration. Analysis that could incorporate time-varying productivity or predictions in how climate and development may change survival and carrying capacity at a fine spatial and temporal scale would be beneficial if there were data to support them. The subsequent analysis in *5.4 Element 15*, presents different levels of average smolt-to-adult survival and fisheries mortality in the form of ER (which is primarily incidental fisheries mortality for IFC), but even this assessment's uncertainty may be underestimated due to future change as well as from the quality of the data.

Finally, there is also a complication from hatchery-origin fish reproducing in the wild. The subsequent analysis uses natural-origin recruitment, however, natural-origin recruits may have one or two hatchery-origin parents (i.e. parents that were raised in a hatchery and returned as hatchery-origin adults that then spawned in the wild). Hatchery-origin adults that spawn in the wild are included in the escapement that contributes to natural-origin recruitment because all fish produced in the wild are indistinguishable when they return (unless there is genetic analysis, but no such analysis has been done). In the forward projection, the seed years include both natural-origin and hatchery-origin spawners but afterwards it is assumed that hatchery production is stopped and that only the natural-origin recruits contribute to subsequent recruitment. Hatchery-origin fish have also been found to have a relatively lower fitness than natural-origin fish (Nickelson 2003, Grant 2012), however this condition was not represented in the population dynamics modelling.

Here, the DU abundance trajectory and probability IFC reach the recovery target is explored using stock-recruitment models and forward projection. Stock-recruitment models are widely used to assess salmon population dynamics and in forward projection (Holt and Bradford 2011). Two similar and iterative model approaches have been used to approximate the population dynamics for IFC (Korman et al. 2019 , Parken et al.[1]). The most recent assessment (done in 2018) also employed a forward simulation analysis to assess the probability that the DU made it to a recovery objective (Korman et al. 2019). The recent assessment presented results from three models that each represent a different hypothesis about alternative population dynamics scenarios (DFO 2018b). These scenarios were developed by a working group familiar with the data and system after the original model underwent a CSAS review (DFO 2018b). Thus, these scenarios are subsequently referred to as “expert opinion.” The original methods described by Korman et al. (2019) are reproduced below in addition to any alterations.

Parameter estimates for α, β and γ (smolt-to-adult survival covariate) were obtained using a hierarchical Bayesian model. Hierarchical modeling techniques have been shown to incorporate more information into parameter estimates than some non-hierarchical techniques in fisheries stock assessment (Askey et al. 2007; Forrest et al. 2010). This approach may help reduce the uncertainty in parameter values for stock-recruitment relationships when data sets are short, noisy and results are synthesized among multiple populations (Myers and Mertz 1998; Myers 2001; Michielsens and McAllister 2004). When species or populations share common demographic parameters, (e.g. intrinsic productivity or density independent survival in shared environments), hierarchical modeling enables information to be shared among populations which may lead to less uncertainty in stock-recruitment statistics (Liermann et al. 2010). The Bayesian framework also allows for informative priors to be set based on expert opinion to influence a model’s statistical properties. The use of informative priors may be helpful to provide insight on model behaviour and population dynamics of small stock-recruit datasets that may not have sufficient observations at high or low abundances to accurately estimate model parameters.

When the analysis for this report was conducted, the major landslide near Big Bar on the Fraser River was not known to DFO nor its impacts on migratory salmon investigated. The majority of IFC spawn in areas below the Big Bar slide site but one subpopulation (Upper Middle Fraser) spawns above the slide. The suggested recovery target was based on maintaining 1000 or more natural-origin spawners in all subpopulations. Therefore, the recovery target would likely not be met if the Big Bar slide acts as an ongoing impediment to IFC migration to the Upper Middle Fraser subpopulation.

5.2.2 Data and Model Preparation

The data are from DFO Fraser Stock Assessment and the treatments are the same as outlined in Appendix 5. The data are inclusive from brood years 1998-2013 (return years 2001-2017) because brood-year 2014 will also have recruits in return year 2018, for which the ER data are not verified yet.

Recruitment Reconstruction

The age distribution of adults is an important factor in determining the number of recruits that belong to a given brood year because the total number of recruits is required to estimate productivity and carrying capacity parameters. As highlighted in Element 3, most (average 88%) IFC return to spawn as 3_2 (1.1) fish, having spent one winter as an egg, one winter as a parr in freshwater, and one winter at sea. Yet, approximately 12% of IFC parr spend an additional winter in freshwater and return as 4_3 (2.1) fish. Some analyses ignore age structure, but there is enough age information on IFC to construct age distributed recruits through either using real data or applying some type of average.

Parken et al.[1] applied the average observed proportion of 3_2 and 4_3 fish across all CUs to each CU-return year and then arranged recruits into their associated brood years. This method was employed because there was not enough data to discern a pattern in the age distribution across the time-series within CUs. The underlying biological assumptions is that the age distribution of returning fish remains approximately constant. A possible issue of assuming a constant age structure by return year is that the production of age-3 recruits in small year classes could be overestimated because the abundance of age-4s from the preceding brood would be underestimated for those years when a small year is preceded by a larger one. The possible bias of over- or underestimating the number of recruits belonging to each brood year could then affect stock-recruitment parameter estimates, and lead to significant autocorrelation effects.

Korman et al. (2019) assumed that the age distribution of brood years was constant in their model, rather than return years. Korman et al. (2019) proposed that assuming a brood-year-based age distribution may be more justifiable because smolt age composition is likely driven by habitat conditions in freshwater. However, they acknowledged that the age composition of adult returns by brood may depend on the relative smolt survivals of the two age groups as they enter the ocean in different years. Thus, survival variation could generate variability in age structure by brood year, but there may not be enough data to accurately predict these interactions. Therefore, there may be undesired effects of under or over estimating recruits by assuming constant age distribution by brood; but because the dominant age class is 3_2, variance in the number of age 4_3 recruits due to different survival may be minimal because they occur at relatively lower abundances.

A third way to approach assigning adult returns to ages and brood years is to directly apply available estimates of the proportion of each age in returns and infilling when there is no estimate. This method does not assume a constant age distribution in neither broods nor returns. However, there are only three CUs (Lower Thompson, North Thompson, and South Thompson) that have some scale samples (which are used for aging) across the time-series and not every CU-year combination for those CUs has adequate samples. Additionally, scale samples were not always taken in a methodological manner across the tributaries within a CU, thus there is a risk of introducing bias, particularly in small samples. To avoid such bias, any sample (tributary-year) with 50 or fewer individuals was removed and a weighted mean was used to calculate the average proportion of 3_2 fish in each CU-year, year, and an average for the DU overall. For any CU-year without a sample, the year average (i.e. from all CUs with data) was applied. For any year without samples, the DU overall average was applied. The assumption that is made to infill data in this way is that the proportion of recruits that return to a given year will covary across CUs. Biologically, this covariance is possible if regional climate patterns that are shared across CUs determines the proportion of juveniles that remain to become 4_3 fish or determines the overall survival of 3_2s and 4_3s for a given brood year. When small sample sizes (50 or fewer individuals) were removed, the Pearson's correlation coefficients between each CU pair with data were 0.44, 0.52, and 0.78, which are considered moderate to high degrees of correlation. Each of the prior methods also rely on the scale age data but include an extra degree of separation from the data; for this reason and others outlined in Appendix 9, the third approach was used here to reconstruct recruitment.

Stock-Recruitment Parameter Estimates

The Ricker model was used to estimate several parameters of the stock-recruitment data, which will then be used in the subsequent forward projections. Prior analysis of IFC have compared the fit and behaviour of other stock-recruit functions (e.g. Beverton-Holt, breakpoint regression, Deriso, Power) and found that the Ricker function produced the most biologically conservative and reasonable parameter estimates (Korman et al. 2019), Parken et al.[1], Folkes et al. 2005, Decker et al. 2014). The following model and methods are primarily based on those developed and written by Korman et al. (2019), whose model included a hatchery-based smolt-to-adult survival rate index covariate and took the base form of:

$$(2)\ \hat{R}_{i,a,t} = p_{i,a,t-a} \cdot S_{i,t-a} \cdot e^{\alpha_i + \gamma \cdot Ln(M_{t-1}) - \beta_i \cdot S_{i,t-a}}$$

where *p* is the proportion of recruitment produced from the same spawning cohort returning at age *a* (*a*=3, 4) in CU *i* from brood year *t-a*, S is the total number of spawners in CU *i* in brood year *t-a*, $\hat{R}$ is the predicted number of natural-origin recruits returning in year *t* of age *a* produced from the escapement in brood year *t-a*, α is a term related to maximum survival and productivity when there are no density-dependent effects (S→0) and when the smolt-to-adult survival (M_t) is 1 (i.e. 100% smolt-to-adult survival) for each CU *i*, β is a density-dependent term describing the rate of decrease in log-survival with increasing spawner abundance for each CU *i*, and γ is the smolt-to-adult survival coefficient shared across CUs. The smolt-to-adult survival covariate is log-normally distributed (Figure 20b), which is why the natural-log is taken in the equation. The smolt-to-adult survival covariate was also not standardized so that the natural-log could be performed on the raw values and so that the effect of γ→0 when M→1. Note that the smolt-to-adult survival (M_t) used in the prediction is one year prior to recruitment (*t*-1), thus we assume all Coho spend one year at sea (which seems reasonable given the age data). Recruitment from a given brood will therefore depend on smolt-to-adult survival rates two and three years after spawning for age-3 and -4 year fish, respectively.

Total recruitment from a brood is calculated as the sum of age-3 and -4 year recruits in consecutive years according to,

$$(3)\ \hat{R}_{i,by} = \hat{R}_{i,a=3,by} + \hat{R}_{i,a=4,by}$$

where $\hat{R}_{i,by}$ denotes the total predicted recruitment returning to CU *i* from brood year *by*.

What could be interpreted as maximum productivity, which occurs when spawner abundance is low, changes each year with the smolt-to-adult survival according to,

$$(4)\ \alpha'_{i,t} = \exp(\alpha_i + \gamma \cdot Ln(M_t))$$

where $\alpha'_{i,t}$ is the year-specific maximum productivity estimate for CU *i*. This model assumes that smolt-to-adult survival affects productivity at low stock size most, having no direct interaction with the density-dependence parameter (β); however, affecting productivity will affect recruitment at all stock sizes as well as calculations of carrying capacity (~α'/β). This is consistent with the view that the majority of density dependence for salmon (including Steelhead) occurs during their freshwater rearing phase. Additionally, because smolt-to-adult survival is based on hatchery smolts that have not shared freshwater conditions as natural-origin eggs, fry, and parr, it may not be a strong covariate of environmental effects in freshwater for the egg deposition-to-smolt life stages. Processes that act in freshwater are also known to covary at much smaller spatial scales than those in the ocean (Myers et al. 1997). Therefore, by including a covariate for smolt-to-adult survival, the model structure allows approximation of productivity for a future period by replacing ln(M_t) in Equation 2 with $\overline{M}$, which can represent the mean smolt-adult survival for a future period.

Korman et al. (2019) also developed a Ricker model with depensatory mortality. Depensatory effects are possible if there are disproportionately large negative effects at small escapements, such as proportionally higher predation rates or reduced spawning success due to difficulty in finding mates. The depensatory model takes the additional step of:

$$(5)\ \hat{R}_{dep\ i,by} = \frac{S}{S+\delta} \cdot \hat{R}_{i,by}$$

where δ is the escapement where recruitment is reduced to 50% of the value it would have been in the absence of depensatory mortality. Prior research on salmon population viability have suggested that negative effects, such as those from loss of genetic diversity or from other forms of depensation, may occur when populations drop below 1000 spawners (Bradford and Wood 2004, IFCRT 2006). Thus, δ was not estimated but assumed and set at 1000 for this analysis.

For each model, parameter estimates for α, β and γ were obtained through Bayesian estimation and assumed that observations of ln(R/S) were normally-distributed random variables (~*Normal*) with means predicted by recruitment models described above,

(6) $Ln\left(\frac{R_{i,by}}{S_{i,by}}\right) \sim Normal(Ln\left(\frac{\hat{R}_{i,by}}{S_{i,by}}\right), \tau_i)$

where (τ_i) is the estimated precision (inverse of variance).

When populations share common demographic parameters, hierarchical Bayesian modeling (HBM) enables information to be shared among populations which may lead to less uncertainty in stock-recruitment parameters. In this hierarchical stock-recruitment model, stock-recruit data for all CUs in the IFC Management Unit (MU) are used simultaneously to estimate parameters for individual CUs as well as hyperparameters that define the hyperprior distribution from which CU-specific values of productivity arise. To do this, parameter estimates α_i for each CU were drawn from a normal hyperprior distribution,

(7) $\alpha_i \sim Normal(mu\_\alpha, tau\_\alpha)$

Where mu_α and tau_α represent the mean and precision of the normal hyperprior distribution describing the variation in natural-log-productivity among CUs. These hyperparameters are estimated during model fitting. Estimates of τ_i and β_i for each CU were assumed to be independent and γ was estimated as a single common parameter across CUs. Korman et al. (2019) also fit the base Ricker model (Equation 2) assuming the α_i's were independent to evaluate the effect of the HBM structure for comparative purposes and found that the hierarchical structure improved model fit and increased the amount of variation it explained.

The Bayesian estimation approach also allows for informative priors to be set to incorporate prior knowledge of biological systems or to explore population dynamics under assumed circumstances in the context of statistical inference. In the case of IFC, current spawning abundances are less than half of historic abundances, which showed much lower over-compensatory dynamics. The most recent research that went through the CSAS processes (Korman et al. 2019) and analyzed IFC proposed a hypothesis that IFC may not have as much over-compensation that the base Ricker functional form indicated. One component of this position was that the data were particularly sparse at higher spawner abundances, which makes it difficult to estimate carrying capacity accurately. Additionally, there is one brood line that has persisted at a relatively higher and more stable spawner abundance than the other two brood lines (Figure 14), which may be viewed as evidence for a higher capacity than the base Ricker model originally estimated (Korman et al. 2019). To account for this, Korman et al. (2019) estimated parameters using an informative prior on carrying capacity (α' / β_i) in both a Ricker and a Ricker with depensation models in addition to estimating parameters using a Ricker model with vague priors.

(8) $\beta_i = (\alpha_i + \gamma \cdot Ln(\bar{M})) \,/\, (cap_i \cdot 1000)$

The mean for the prior distribution on cap for CU i is calculated as an increase on the carrying capacity that was calculated from CU-specific linearized Ricker models calculated using maximum likelihood. The prior replaces the vague prior that was set on β in the base Ricker model. Korman et al. (2019) used an exploratory approach to determine the minimum adjustment to carrying capacity needed to buffer over-compensatory dynamics based on expert opinion (DFO 2018b) over the range of escapements that have been observed since 1998. However, the precision of this prior has been relaxed to 0.5 since the previous research's iteration (Korman et al. 2019), to decrease potential negative effects of an overly informative prior. The relaxation of this prior's precision resulted in the forward simulations from the two reports differing as well as changes to the median parameter estimates. However, the overall behaviour of the posterior is more true to the original intention of the prior, which was to reduce over-compensatory dynamics and not only constrain parameters to create a higher carrying capacity (compare figures in Appendix 10 to Figure 17, Figure 18, and Figure 19). The precision in this report was chosen based on minimizing the frequency of unrealistic parameter sets (e.g. those with $-\beta$ or those that caused biologically unrealistic over-compensatory dynamics; see Appendix 10) in the posterior while still dampening over-compensation.

The three model forms used in the most recent research (Korman et al. 2019) will be used here because they have been reviewed once already and because of the limited amount of time to explore alternative models or hypothesis. The models are subsequently defined as:

- **Ricker:** The Ricker model (Equation 2) with vague priors on mu_α, tau_α, γ, β, and τ (Table 13). This model does not include depensatory mortality. This relationship allows for over-compensation in recruitment at higher stock size and solely relies on the certainty of the data to estimate parameters. Therefore, this model assumes that the data are accurate and precise even though there is known uncertainty. The subsequent models incorporate the effects of hypothetical scenarios.
- **Ricker–PriorCap:** The **Ricker** model but with informative priors on carrying capacity (α' / β_i) that is used to back-calculate β_i. The mean of the prior on carrying capacity was set as 1.5-fold larger than the carrying capacities from CU-specific Ricker models
- **Ricker–Dep:** The **Ricker-PriorCap** model with informative priors on carrying capacity and an additional step (Equation 5) with the parameter δ which was fixed at 1000 per CU. The informative priors on carrying capacity required means that were 1.75-fold larger than the carrying capacities relative to estimates from the base Ricker models to buffer the additional effects from depensation.

Models were fit using WinBUGS (source code provided in Appendix 11, pseudo-code provided in Figure 15). Vague priors were used for model parameters (identical to those used by Parken et al.[1]) except for the β_i parameter in the Ricker–PriorCap and Ricker–Dep models, which is replaced by the prior cap_i and Equation 8 (Table 13).

To fit the models, a Markov Chain Monte Carlo (MCMC) was run for 45,000 iterations, the first 25,000 were discarded to remove any "burn-in" effects and every 10th iteration was stored to reduce autocorrelation. Three chains were initialized from different randomly determined starting points. Convergence of the chains were visually assessed by monitoring trace plots of Markov chains for each parameter, as well as by examining the Gelman-Rubin convergence diagnostics (all median $\hat{R}$ values were <1.01;Table 14).

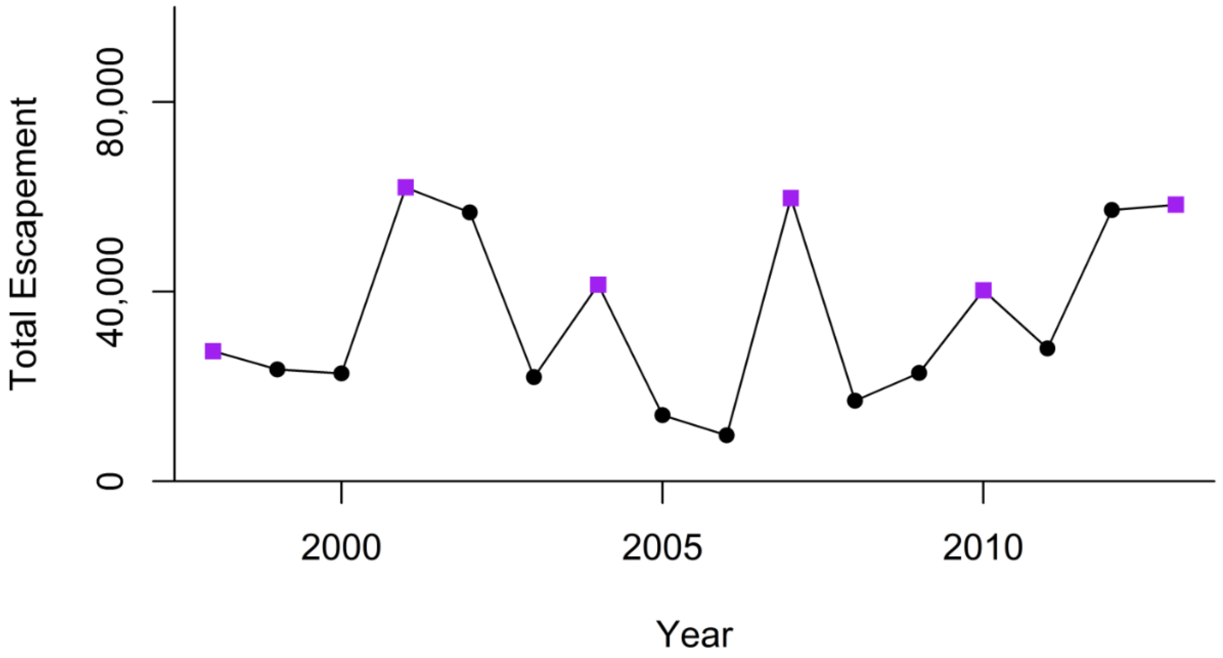

Figure 14.Total escapement of hatchery- and natural-origin IFC through time. One brood line (purple squares) has consistently exceeded the other two since 1998.

Table 13. Priors for Bayesian model parameters and symbol descriptions. Updated from those in Parken et al[1].

Parameter	Description	Prior
$\ln(R/S)$	Likelihood Function	$Normal{\sim}\left(\ln\left(\widehat{R/S}\right), \tau\right)$
τ	Precision in likelihood	$Gamma{\sim}(0.01, 0.01)$
α	Stock productivity before effects from smolt-to-adult survival	$Normal{\sim}(mu\_\alpha, tau\_\alpha)$
β	Rate of over-compensatory dynamics as a function of spawner abundance	$LogNormal{\sim}(1, 0.1)$
mu_α	Hyperparameter for mean α_i	$Normal{\sim}(1, 0.5)$
tau_α	Hyperparameter for precision in α_i	$Gamma{\sim}(0.1, 0.1)$
γ	Smolt-to-adult survival hyperparameter	$Normal{\sim}(0, 0.01)$
cap	Carrying Capacity	$Normal{\sim}(cap\_prior, 0.5)$
i	Indicates a CU-specific parameter	-
p	Proportion of age *a* fish	-

Parameter	Description	Prior
a	Spawner age, either 3 or 4 years	-
t	Return year	-
by	Brood year	-

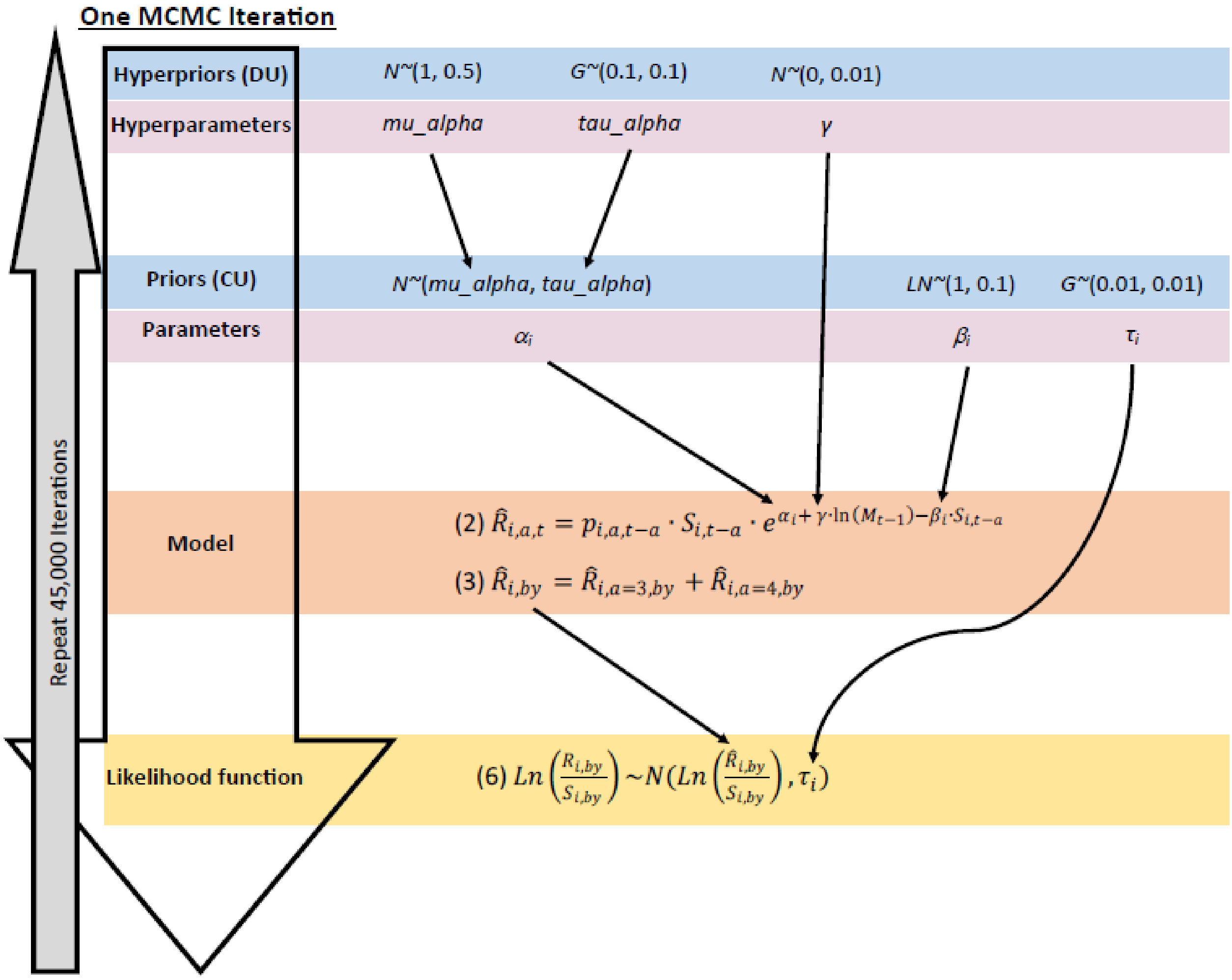

Figure 15. Pseudocode for Hierarchical Bayesian Ricker model with vague priors. Posterior produced through Markov chain Monte Carlo (MCMC). Symbol definitions can be found in Table 13. Hyperprior and prior distributions are in blue; hyperparameters (which inform prior distributions or are shared across CUs) and parameters (which are CU-specific) are in pink; the base model is in orange; and the likelihood function is in a yellow box. At the end of each iteration (i.e. the end of the downward facing arrow), posterior parameter estimates and residuals are produced (results) and the information is used by the next iteration (Markov Chain).

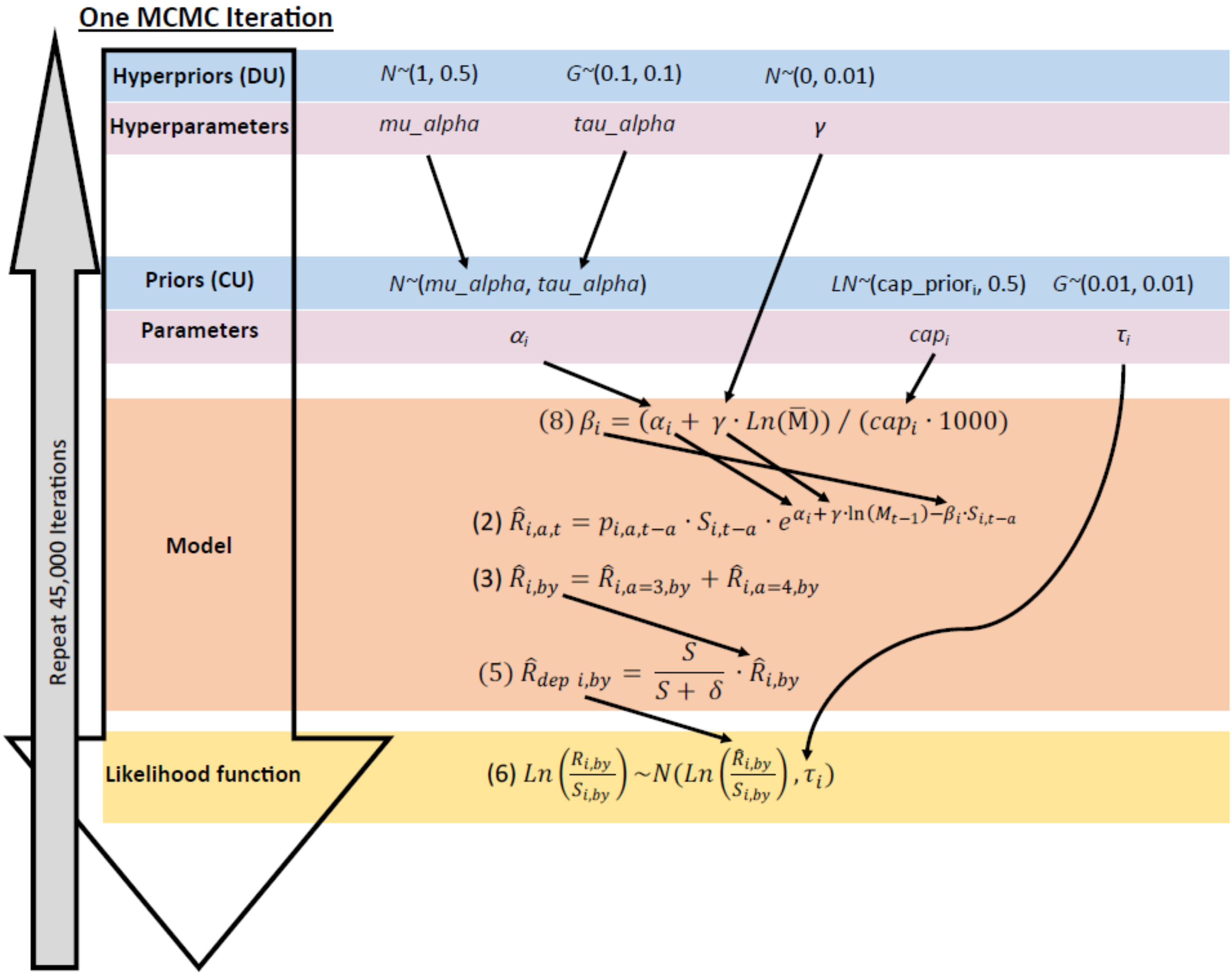

Figure 16. Pseudocode for Hierarchical Bayesian Ricker model with informative prior on carrying capacity (Ricker-PriorCap and –Dep models). Posterior produced through Markov chain Monte Carlo (MCMC). Symbol definitions can be found in Table 13 and Figure description in Figure 15. Note that δ equals 1000 for the Ricker-Dep but would be 0 in the Ricker-PriorCap.

Modelling Results and Suggestions

The median residuals over the time series and against fitted values were assessed to inform model fit and behaviour (Appendix 12). The addition of the γ parameter improved the homoscedacity in the models with informative priors on carrying capacity most. Trends and slight temporal autocorrelation over time, however, were observed in the residuals of some CUs. The residuals in the Lower Thompson and Fraser Canyon CUs deviated the most from the aggregate trend and in seemingly opposite directions, which could be driven by CU-specific biogeoclimatic events or CU-specific anthropogenic impacts to their freshwater environment. The Middle Fraser CU residuals also had a slightly increasing trend over time. Trends and autocorrelation in the residuals suggest that there may be time varying productivity or additional environmental covariation that has not been represented in the models. For example, the WSP assessment noted that the Lower Thompson CU had steadily increasing smolt production since 1995, which may need to be incorporated into subsequent stock-recruit analysis (DFO 2015a).

As expected, the two models with informative priors had a different behaviour than the Ricker with vague priors (Figure 17, Figure 18, and Figure 19). The Fraser Canyon CU was affected least by the informative priors in the Ricker-PriorCap and Ricker-Dep models, but this CU was the most likely to have habitat limitations due to the small number of systems where IFC are known to or presumed to spawn (Figure 5). The Ricker-PriorCap and Ricker-Dep models both had fewer effective parameters than the vague Ricker model (Table 14). The Ricker-PriorCap model had the smallest median mu_α and β parameter estimates. The Ricker-Dep model had the highest median mu_α, likely due to the model compensating for the assumed depensatory effects, which had few spawner values below 1000 for the effects to be fit to. The Ricker-Dep model's median β parameter estimates were in between the other two models, which when combined with its high alphas produced carrying capacities that were close to the Ricker-PriorCap's carrying capacities (as expected). The median carrying capacities of the Ricker-PriorCap and –Dep models were 1.57 and 1.47 times higher on average than the Ricker with vague priors' median carrying capacities.

The Ricker-PriorCap and Ricker-Dep models also overestimated recruits at high spawner abundances in the North Thompson CU compared to the base Ricker model. This was a probable model behaviour due to the informative priors that were designed to buffer over-compensatory dynamics. However, there may be more warrant in noting that this trend was not as apparent in the other CUs, which suggests that the models fit the data despite the informative priors designed to change their statistical behaviour.

The observed concerns in the non-uniform distribution of residuals and in the quality of the data may be improved with subsequent data collection and analysis. Several suggestions are:

1. Continue collecting spawner abundance, ER, and biological data to increase the length of the dataset because the DU is currently data-limited. Increased contrast, particularly at higher spawner abundances, would improve parameter estimation (e.g. around carrying capacity) and allow for additional covariates. Increased scale sampling effort across both the number of systems and in the number of samples would bolster confidence in age-based recruitment reconstruction.
2. Improve estimates of exploitation and the uncertainty around estimates. The current fishery monitoring programs have very low sampling rates to recover CWTs or any other type of stock identifier (e.g. passive integrated transponder tags, parentage-based tagging), and incompletely estimate the number of kept and released Coho Salmon in times and areas where fisheries occur. Improving the fishery monitoring programs is necessary to improve estimates of ERs and to reduce their uncertainty. Modifications to the current ER modelling techniques may also be necessary to improve their representation of Mark Selective Fisheries.
3. Include compounding uncertainty in the data (i.e. escapement and recruitment) so that more of the uncertainty can be represented in the models. An errors-in-variables modelling analysis would be beneficial because the catch and escapement estimates have error, which precludes accurately estimating stock productivity, carrying capacity, and effects of covariates.
4. Investigate the use of additional or alternative covariates to describe unexplained variability, temporal autocorrelation, and temporal trends in productivity. Alternative covariates could represent: hatchery contribution or proportion of natural influence, smolt production, and various freshwater environmental covariates. Some CUs (e.g. Fraser Canyon) could include time-varying productivity trends or models that incorporate differencing (non-stationary).
5. a) Explore alternative model types. Additional comparisons of the results obtained with non-Bayesian maximum likelihood models would also provide insight on the relative performance and influence of the often more complex Bayesian approach.

b) Incorporate finer metapopulation aspects into alternative models once additional data has been collected, e.g. apply stock-recruit dynamics at finer population / subpopulation levels or relax assumptions about similar productivity using partial or non-hierarchical models.

Table 14. Median model performance estimates from three Ricker stock-recruitment models with and without a smolt-to-adult survival covariate. Ricker has vague priors Ricker–PriorCap and -Dep have strong priors on β, and Ricker–Dep also includes depensation. $\hat{R}$ is the potential scale reduction factor, used here as a convergence diagnostic. pD is the number of effective parameters. DIC is the Deviance Information Criteria and may be used as a metric to identify model fit, with lower DIC equating a better statistical fit.

Model	$\hat{\mathbf{R}}$	**pD**	**DIC**
Ricker	1.002	14.7	159.1
Ricker-PriorCap	1.001	9.08	172.7
Ricker-Dep	1.003	9.21	181.9

Table 15. Median parameter estimates and their 0.1-0.9 credible intervals (in brackets) from three Ricker stock-recruitment models. Ricker has vague priors. Ricker–PriorCap and -Dep have strong priors on carrying capacity which affects the β estimation, and Ricker–Dep also includes an assumed depensation effect. There are CU-specific estimates for α and β while mu_α and γ are hyperparameters shared across the CUs in the Bayesian hierarchical model. Note that median parameter estimates are not necessarily a set from the posterior distribution and may not be used independently to do projections or subsequent analysis. Also note that $\alpha \neq \alpha'$, which is maximum productivity at the origin (see equation 4). Entire posterior distribution is available upon request.

Model	**Parameter**	**Middle Fraser**	**Fraser Canyon**	**Lower Thompson**	**North Thompson**	**South Thompson**
Ricker	α	2.39 (1.7-3.08)	2.6 (1.85-3.37)	2.47 (1.78-3.18)	2.55 (1.88-3.26)	2.41 (1.69-3.13)
	β	0.00012 (0.00007-0.00017)	0.00032 (0.00022-0.00043)	0.00012 (0.00008-0.00017)	0.00008 (0.00006-0.0001)	0.00009 (0.00005-0.00013)
	γ	-	-	0.36 (0.21-0.51)	-	-
	mu_α	-	-	2.46 (1.76-3.16)	-	-
Ricker-PriorCap	α	2.26 (1.47-2.98)	2.56 (1.69-3.37)	2.43 (1.63-3.15)	2.46 (1.65-3.18)	2.29 (1.49-3.04)
	β	0.00007 (0.00004-0.00011)	0.00028 (0.00015-0.0004)	0.00008 (0.00005-0.00013)	0.00004 (0.00003-0.00007)	0.00005 (0.00003-0.00008)
	γ	-	-	0.37 (0.19-0.52)	-	-
	mu_α	-	-	2.36 (1.57-3.09)	-	-
Ricker-Dep	α	2.5 (1.69-3.31)	2.78 (1.89-3.7)	2.59 (1.77-3.41)	2.45 (1.64-3.25)	2.44 (1.61-3.25)
	β	0.00009 (0.00006-0.00012)	0.0003 (0.00016-0.00043)	0.00009 (0.00006-0.00014)	0.00004 (0.00003-0.00006)	0.00006 (0.00004-0.00009)
	γ	-	-	0.34 (0.17-0.52)	-	-
	mu_α	-	-	2.52 (1.72-3.31)	-	-

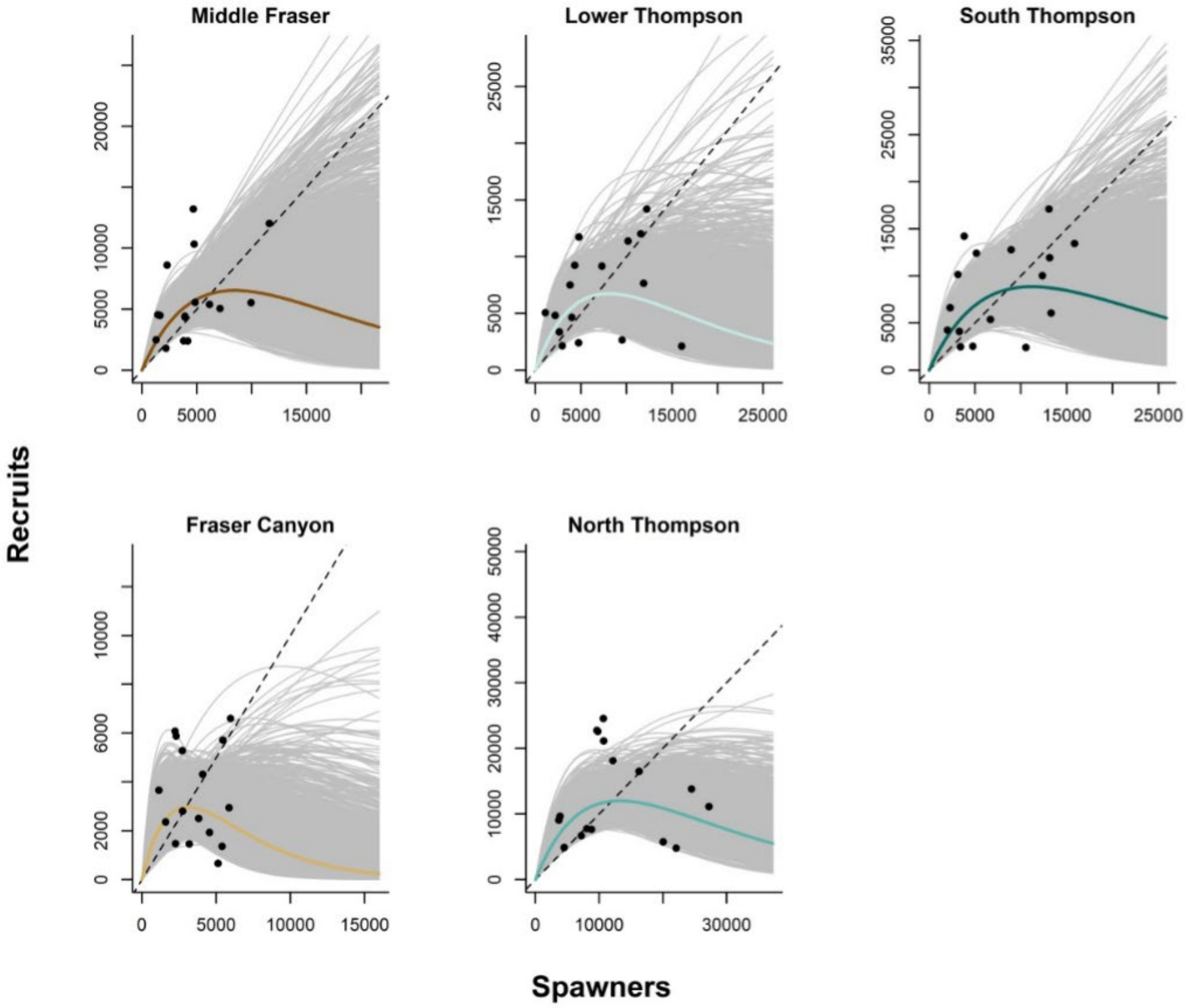

Figure 17. Ricker model behaviour with vague priors at the average smolt-to-adult survival (0.010). Thick coloured lines are the result of a combination of median parameter values. Thin grey lines are each posterior parameter set and represent the uncertainty in parameter estimates and model behaviour. Solid black points are the observed data, which are not necessarily a result of average smolt-to-adult values. Black dashed line is the 1:1 S:R replacement line.

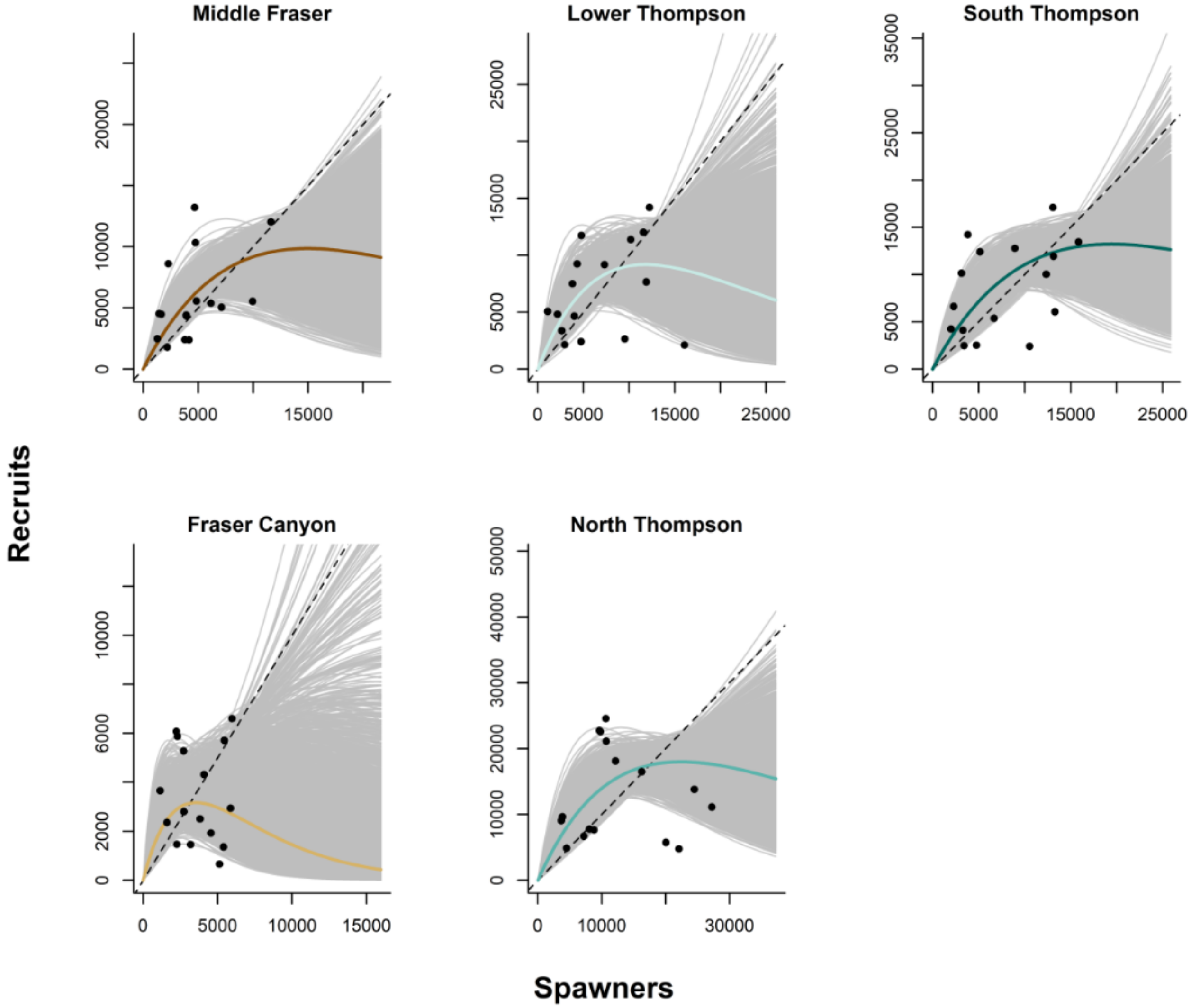

Figure 18. Ricker-PriorCap model behaviour with informative prior on carrying capacity at the average smolt-to-adult survival 0.010.See Figure 17 for caption details.

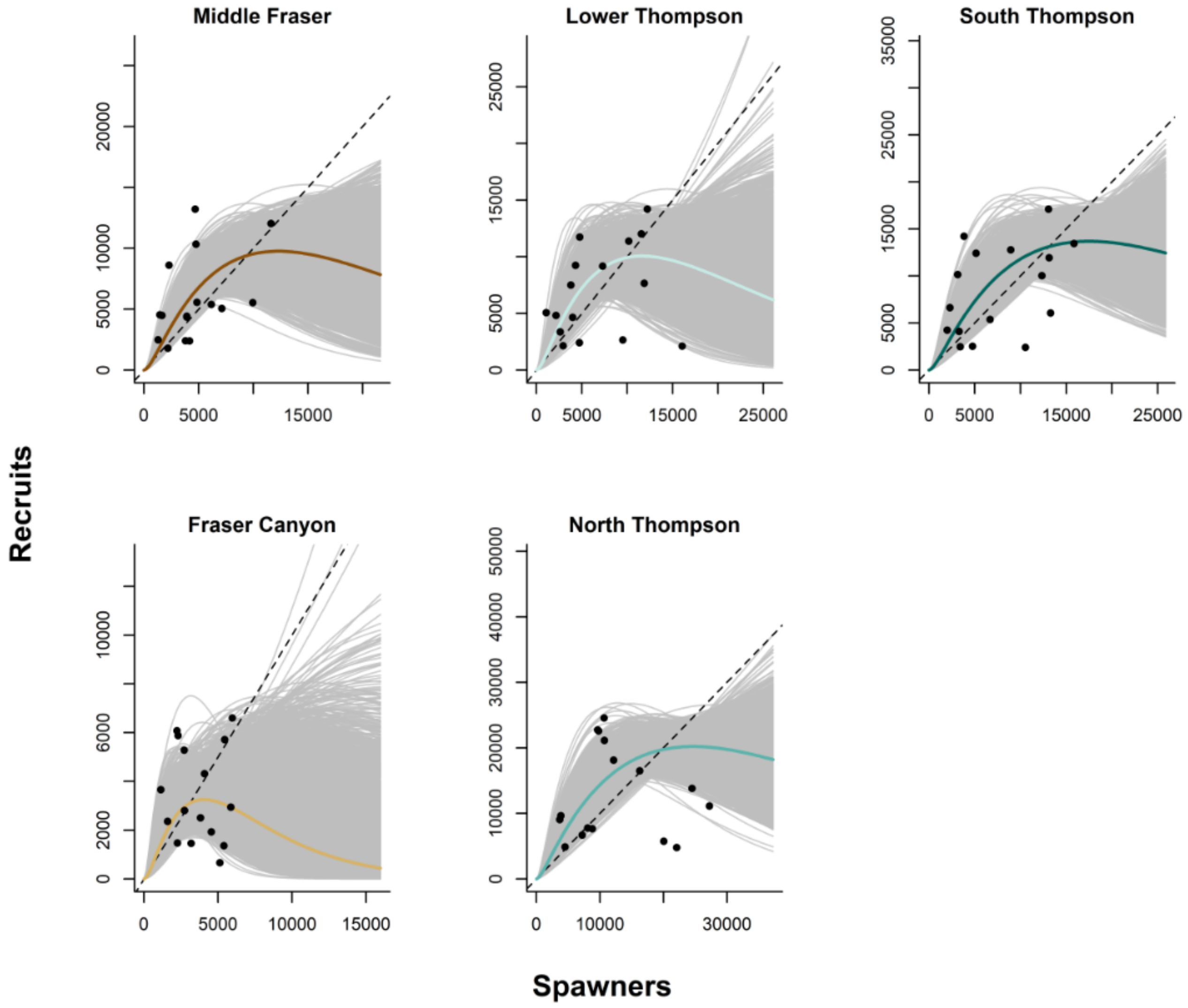

Figure 19. Ricker-Dep model behaviour with informative prior on carrying capacity and assumed depensatory dynamics at smolt-to-adult survival) held at the average (0.010).See Figure 17 for caption details.

5.2.3 Forward Projection & Assessment of Recovery Probability

The abundance trajectory and probability that the IFC DU reaches the recovery target was assessed using forward projections of escapement from the output of the three models described above. Since only 16 years of data were used to estimate parameters and determine the variability in the posterior, only 10 additional years were projected. The models were run for 500 Monte Carlo trials. Five hundred trials was deemed sufficient to capture stable expectations and uncertainties in performance metrics (i.e. the standard error in metrics across simulations run for 500 trials was ≤3%). Each trial was seeded with the latest 4 years of escapement data (2014-2017) because the first simulated year would include 4_3 fish from 2014 and 3_2 fish from 2015. Therefore, the projected returns occur between 2018-2027. The proportion of age *a* fish from CU *i* in year *t* in Equation 2, $p_{i,a,t-a}$, was replaced with $\bar{p}_{i,a}$, where $\bar{p}$ is the average proportion of age *a* (*a*=3, 4) in CU *i*. As M_t (smolt-to-adult survival from Equation 2) is not the same for age 3 and 4 fish, using a constant $\bar{p}$ will result in a variable age distribution in recruits based on the differential smolt-to-adult survival of age 3 and 4 fish.

For each of the 500 Monte Carlo trials in each simulation, parameters and covariates were sampled from the joint posterior and then varied annually to imitate the trends and variability observed in the models. Parameter sets of α, β, and γ values with CU for each trial were drawn at random from the joint posterior of the specified model. Simulated deviates were then applied to each year of a trial to reflect the magnitude of inter-annual deviations for each CU from the DU mean, as well as the extent of covariation in deviates for each CU with the common trend among CUs.

A smolt-to-adult survival value for each trial year was drawn from a log-normal distribution (*Log Normal*~(-4.58, 0.447)) based on the natural-log mean (-4.58, i.e. smolt-to-adult = 0.010) and natural-log standard deviation (0.447) in the data after brood year 1999 (i.e. brood years 2000-2013), which is after the last peak in survival and represents the lower variability (i.e. stable state) that has been observed in survival in recent years. This was decided because the recent past is likely most representative than the immediate future. Autocorrelation was not detected in the data, thus none was added for randomly selecting smolt-to-adult survival through time (each trial year). Randomly sampled smolt-to-adult values were also bound by 0.0027 and 0.0671, which are 10% below and above historically (1984-2013) observed limits (0.003-0.061), respectively.

Escapement was calculated from age 3 and 4 fish after an ER was applied. An ER value for each return year was drawn from a beta distribution (*Beta*~(4.08, 28.58)) based on the mean (0.125) and standard deviation (0.057) of the data after return year 1998, which is after major regulation changes in fisheries and represents the most recent and stable period (with the exception of return year 2014). Values sampled from a beta distribution are naturally bound between 0 and 1.

The randomly sampled smolt-to-adult survival and ER values used to predict the recruitment and escapement of age 4 fish from brood year *t* was applied to predict the recruitment and escapement of age 3 fish from brood year *t+1* because ocean conditions and harvest pressures are shared with the younger age class of the subsequent brood year, respectively. Therefore, only a new smolt-to-adult and ER value for age 4 fish was drawn during each year of a trial and the age 3 fish received the previously sampled values. There was no autocorrelation detected in the smolt-to-adult survival or ER datasets, thus no autocorrelation was applied in the forward simulation

A quasi-extirpation threshold (QET) was also employed in each of the model simulations. Large impacts at very low abundances can result from both genetic impacts (i.e., inbreeding) and population dynamics, including depensatory demographic effects that include random variations in sex ratio, the ability to find mates in space and time, and proportionally higher predation rates at low abundance relative to high abundance. These processes can effectively extirpate populations. The potential for uncertain and detrimental impacts at very low abundances may be dealt with by including a QET in forward simulation. In the case of salmon, the QET is usually defined as having 100 or fewer spawners in all consecutive cycle lines of a complete generation (Bradford and Wood 2004, Holt and Bradford 2011), which is 3 years in IFC. Therefore, if 3 consecutive years of escapement (i.e. after ER is applied) within a CU of 100 or less spawners occurs in a trial, then that CU is considered extirpated (escapement of 0) for the rest of that trial.

The source code for the forward simulation analysis is provided in Appendix 11.

Model-averaged population performance metrics

Multi-model inference is increasing in use because it reduces the risk of picking the “wrong” model and it can incorporate the uncertainty derived from multiple hypothesis on model behaviour (Ianelli et al. 2016, Anderson et al. 2017). Here, the Monte Carlo simulation results from each model are combined and given equal weight because consensus between the authors of this report was not reached on the relative likelihoods of each model and information criterion approaches to weighting were not appropriate because the informative priors were set so that the statistical fit was likely to decrease. The decision to give equal weight was also made because the prior report (DFO 2018c) did not present favor across the proposed hypothesis, which may be considered expert opinion.

After the escapement for each model’s trials were combined, three population performance metrics were calculated.

1. **Final success**: the final 3-year geometric mean escapement at the DU was calculated for each trial, which was assigned a value of 1 for successfully meeting or exceeding the target of 35,935 and assigned a 0 for failing. Final success is reported as the percentage of simulation trials that were successful (scored a 1).
2. **Percentage of positive trajectories**: The percent change in abundance was calculated over 10 years for each trial in the same fashion as in 2.2.3 Long term and recent population trajectories. If a population’s percent change was positive, it was assigned a value of 1. The percentage of positive trajectories was then reported.
3. **Percent change**: From the calculation above, the median percent change over 10 years was reported as well as the 10th and 90th quantiles, which represent the 80% uncertainty interval. The percent change provides context of the possible magnitude of the trajectory and captures additional uncertainty better than the simple proportion of trials metrics.

The Intergovernmental Panel on Climate Change (IPCC) has adopted certainty categories[6] (Mastrandrea et al. 2010) that were used to communicate the results in more descriptive and understandable language.

Results

The results from the equally-weighted model average forward simulations are presented, but it is important to remember the caveats around uncertainty. Although the model framework will represent the uncertainty inherent in such a short and variable stock-recruit dataset, there were

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[6] The International Panel of Climate Change adopted several risk/certainty categories that are now widely used to categorically describe probabilities of scenarios occurring. Very likely ≥ 90 %, Likely ≥ 66%, About as likely as not 33-66%, Unlikely ≤ 33 %, Very Unlikely ≤ 10 %.

other sources of uncertainty that were not necessarily captured. Therefore, uncertainty in these estimates may be underrepresented.

At the current average ER (0.125) and smolt-to-adult survival (0.010), the percentage of final success in trials was 41%. The percentage of positive trajectories was 50%, likely a result of the assumption around stationarity in the parameters and covariate. The median percent change in 10 years was 0% and the 80% uncertainty interval spanned -29% & to 29%. Note that this percent change over 10 years is less than the DU average estimated from the recent trend in Section *2.2.3 Long term and recent population trajectories.* Therefore, reaching the recovery target in 10 years and having positive population growth under current conditions is "about as likely as not[6]" (i.e. equally likely as negative population growth). There is potential for the population to remain stable (neither decrease nor increase) but there is high uncertainty in the trajectory.

Detailed figures and tables are presented in the *Results* section of *5.4 Element 15*.

Separated model results (figures) are presented in Appendix 12. The model-averaged results resemble the Ricker-PriorCap and Ricker-Dep models more because they had more similar results than the Ricker with vague priors

5.3 ELEMENT 14: ADVICE ON THE DEGREE TO WHICH SUPPLY OF SUITABLE HABITAT MEETS THE DEMAND OF THE SPECIES BOTH AT PRESENT AND WHEN THE SPECIES REACHES THE POTENTIAL RECOVERY TARGETS

As discussed in *3 HABITAT AND RESIDENCE REQUIREMENT*, the Interior Fraser watershed is particularly large and difficult to assess in the context of habitat requirements and supply. The impacts from several threats, particularly climate change, may also change the suitability of a habitat annually and seasonally. Additionally, the behaviour of IFC is different than coastal populations that have more detailed information and associated estimates of how much area is required at different densities of rearing juveniles and, therefore, is not directly transferable knowledge.

This Element represents a notable gap in knowledge in the context of IFC. The existing data on accessible stream habitat (Appendix 6) was produced using unknown methods and may be dated. There is also a lack of data to inform the translation of accessible distance data into carrying capacity. For this element to be properly addressed, research on CU-level fry dispersal, behaviour, densities, and survival is required in combination with an assessment of the state of knowledge on habitat throughout the interior Fraser River watershed. Some information exists for some systems in the Community Mapping Network database, but it will take experienced analysts to utilize the information and identify more specifically where knowledge gaps exist in regards to habitat quality and quantity.

Future assessment of the supply of suitable habitat would benefit from collaboration between DFO Science, DFO Fish and Fish Habitat Protection Program, and BC Ministry of Environment, as well as many individuals who have compiled information in the Community Mapping Network database who may not be associated with an organization.

Future assessments may also benefit from attempting to assess changes in the marine environment that have likely impacted the carrying capacity of smolts.

5.4 ELEMENT 15: THE PROBABILITY THAT THE POTENTIAL RECOVERY TARGET CAN BE ACHIEVED UNDER CURRENT RATES OF POPULATION DYNAMICS, AND HOW THAT PROBABILITY WOULD VARY WITH DIFFERENT MORTALITY AND PRODUCTIVITY PARAMETERS

Please refer to *5.2.1 Caveats and conditions* to understand associated caveats and conditions before reading this section.

5.4.1 Analysis Summary

Methods

Following the same simulation methods in *5.2 Element 13*, the average smolt-to-adult survival and ER values were varied to approximate different future productivity and mortality. Smolt-to-adult survival values were explored in 0.001 increments from 0.003 to 0.04 for every ER between 0 and 0.30 in increments of 0.01. Note that these increments represent the average in a distribution in the forward simulations, which randomly sample from the distributions for each year in the trials. Several smolt-to-adult survival and ER values derived from properties of their recent, observed distributions (Figure 20 are also discussed in the results.

The following smolt-to-adult survival values were derived from their observed distributions: the minimum (0.003) and maximum (0.021) observed values from the recent time period (brood years 2000-2013) to represent probable extremes; the maximum observed value since the productivity regime shift (0.041 in brood year 1998), which was an atypically high peak of smolt-to-adult survival in the current regime; and 1 standard deviation (in natural-log space) above (0.016) and below (0.007) the 2000-2013 brood years' mean.

The following ER values were derived from their observed distribution or for insight into additional management scenarios: 0 for a best-case survival scenario; one standard deviation below (0.068) and above (0.183) the post-1997 ER average; an additional lower value (0.03) between 0 and 0.06; and three higher values, 0.20, 0.25, and 0.30, the last of which is near the highest observed single-year ER. When the ER was set to 0, no variation around it was used to represent an absolute 0 adult-mortality scenario and because the beta distribution does not function well with a mean equal to 0.

Each combination of smolt-to-adult survival and ER were simulated for 500 trials, each projecting 10 additional years into the future. The simulations were ran using the posteriors from the three model outputs from *5.2 Element 13*: The Ricker, Ricker-PriorCap, and Ricker-Dep models. The Monte Carlo simulation results from each model were combined and an equally weighted model average result is reported for the performance metrics: final success, percentage of positive trajectories, and percent change.

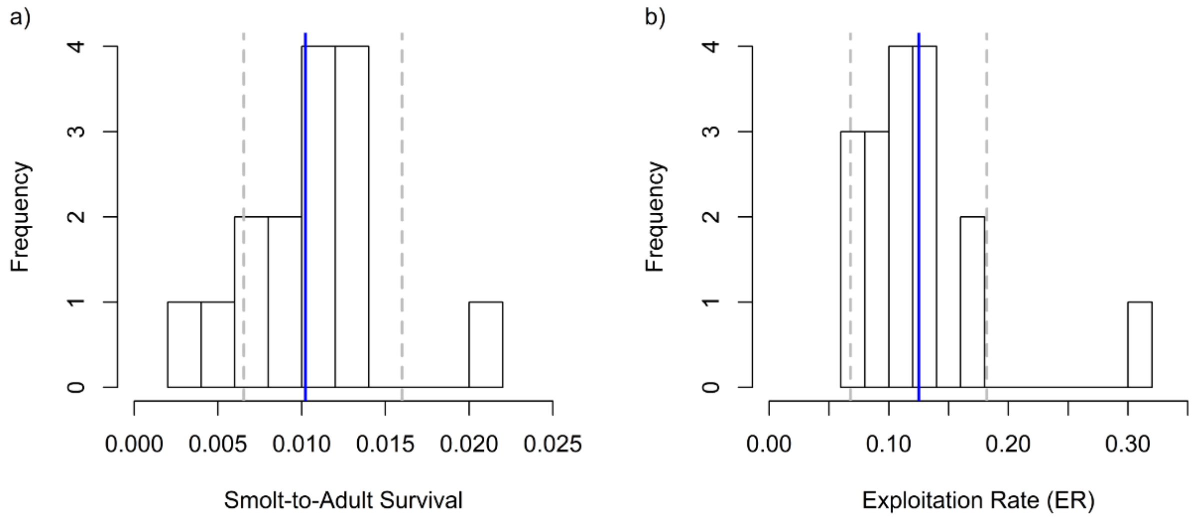


Figure 20. Histogram of observed (estimated) a) smolt-to-adult survival and b) exploitation rate values since brood years 1999 and 1997, respectively. The two time periods represent the most recent and stable periods for each variable. The vertical blue line in a) is the mean smolt-to-adult assuming a natural-log normal distribution. The blue line in b) is the mean ER assuming a normal distribution. The grey dashed lines in both figures are one standard deviation above and below the blue line averages of their respective distributions. Note that the blue lines and grey dashed lines are used in subsequent figures to denote the same areas for reference to this figure.

Results

These results are bound by hypothetical and static changes in average survival and mortality (i.e. under equilibrium conditions), and thus represent ocean regime shifts that benefit juvenile salmon survival, a stable and constant reduction in ERs (or other sources of mortality), or an increase in productivity. The relationship between α, smolt-to-adult survival, and productivity α' are found in Equation 4 in *5.2.2 Data and Model Preparation*, which is why changes in smolt-to-adult survival may be extrapolated to changes in productivity (increased smolt-to-adult survival = increased productivity). The results only consider the abundance portion of the recovery target, but a reminder that the DU target was designed with reaching a subpopulation-level abundance-distribution goal in mind and that the distribution of IFC is an equally important aspect of recovery.

There is a strong pattern that higher smolt-to-adult survival and lowered ER increase the percentage of simulations meeting the suggested recovery target and that the IFC DU abundance increases. The final success and percentage of positive trajectories were almost 100% correlated (Figure 21, Figure 22).

There was higher sensitivity to changes across observed variability (range between standard deviation) in smolt-to-adult survival than in ER (Figure 23). Smolt-to-adult survival changed the percentage of positive trajectories 1.8 times the absolute rate that ER did when smolt-to-adult survival and ER were scaled between the range of their observed standard deviations and a linear regression was performed against the change in the percentage of positive trajectories (slope of scaled smolt-to-adult survival regression = 25.8%, slope of scaled ER regression = -14.2%). Changing smolt-to-adult survival in 0.001 increments (biologically relevant unit of change) away from the current average smolt-to-adult survival, while keeping ER constant, resulted in increasing the percentage of positive trajectories by an average of 9% in the range of one standard deviation from the mean (Figure 23). Changing ER in 0.01 increments (relevant unit of change for management) away from the current average ER, while keeping smolt-to-adult survival constant, resulted in increasing the percentage of positive trajectories by an average of 4% in the range of one standard deviation from the mean (Figure 23).It is important to note that **recovery of natural-origin, anadromous IFC is unlikely (< 33%) under decreased smolt-to-adult survival** at most ERs given the parameters in these models. Focus should be placed on the results in the smolt-to-adult survival values of 0.007-0.016 (Table 16, Table 17, and Table 18), as they are representative of the immediate past, and are assumed to be reasonable for the immediate future when considering potential impacts of climate change or continued anthropogenic development.

Separated model results (figures) are presented in Appendix 12. The model-averaged results resemble the Ricker-PriorCap and Ricker-Dep models most because they had more similar results than the Ricker with vague priors.

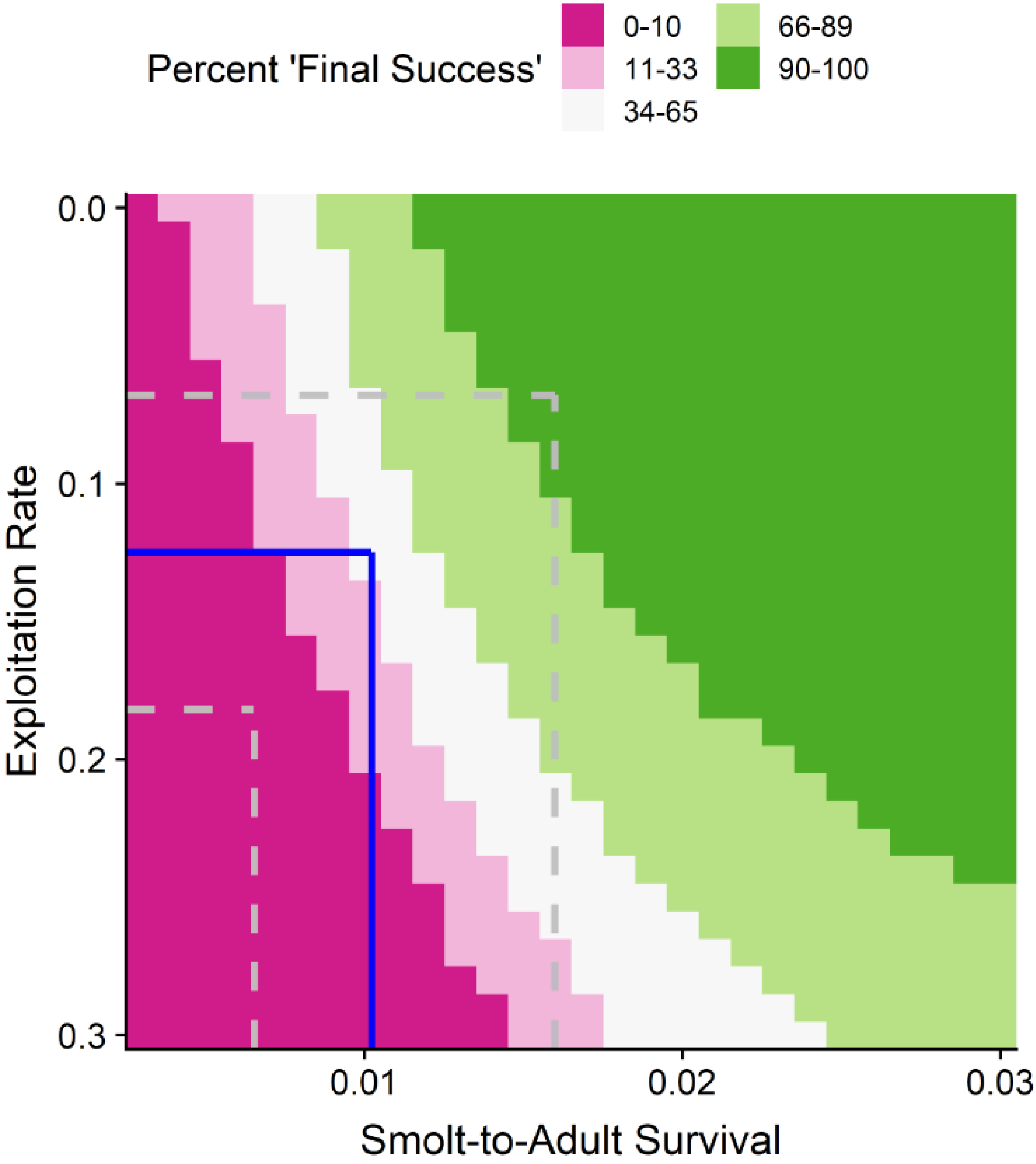


Figure 21. Percentage of model-averaged Monte Carlo simulation results where the final 3-year geometric mean was ≥ 35,935 ('Final Success'). The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average.

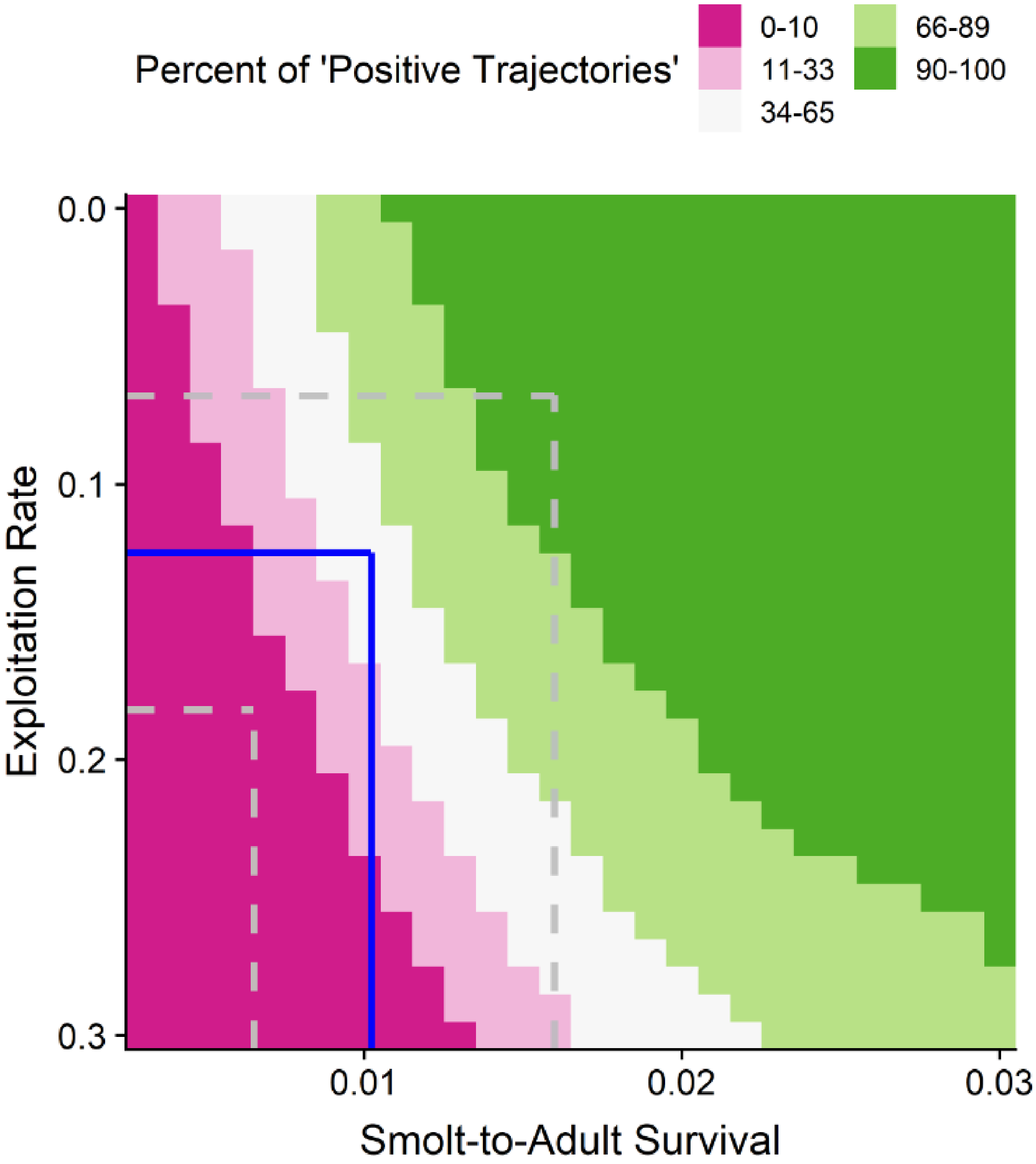
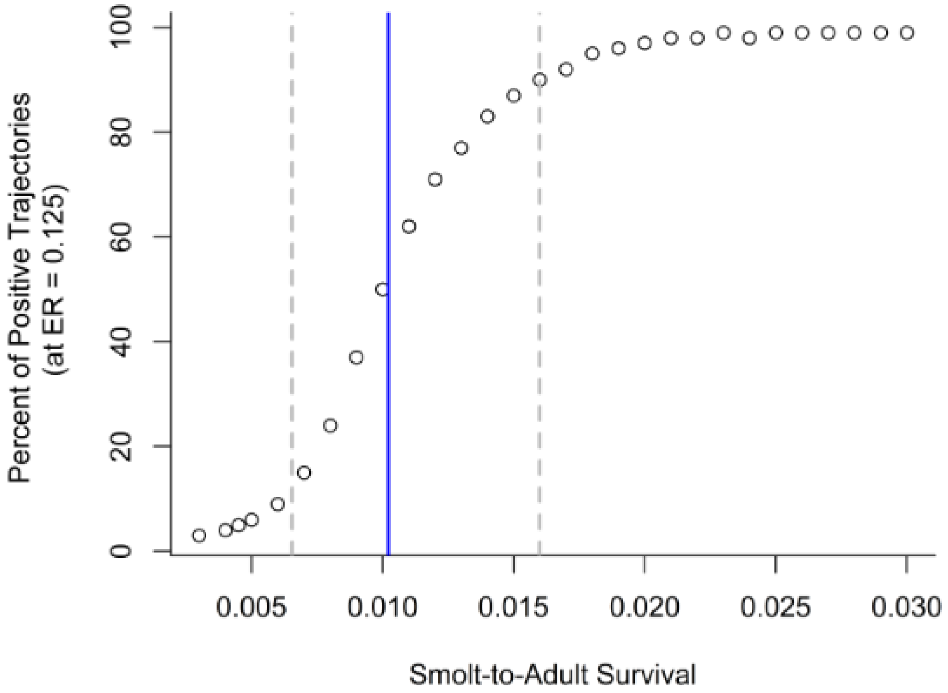


Figure 22. Percentage of model-averaged Monte Carlo simulation results where the population trajectory was positive ('Positive Trajectory'). The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average



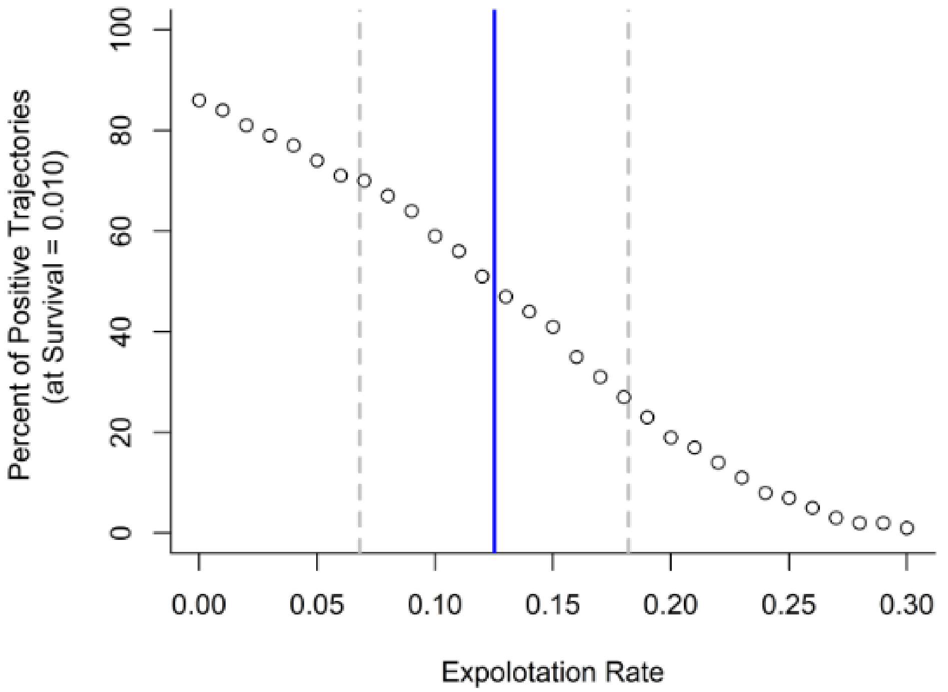


Figure 23. Incremental change in percentage of positive trajectories in simulations across smolt-to-adult survival (top) and exploitation rates (bottom) when the other metric is held at the current average. Blue line indicates the current average of each metric and the gray dashed lines are one standard deviation away.

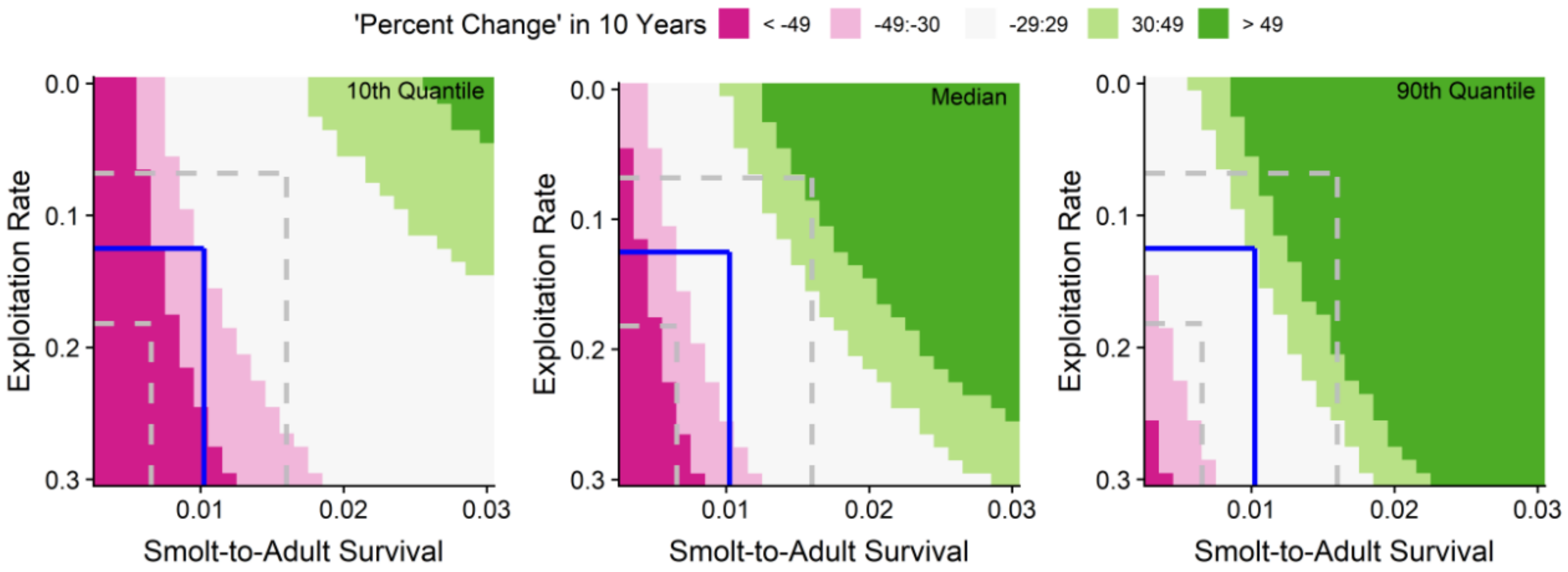


Figure 24. Median (middle panel), 10th (left panel) and 90th (right panel) quantiles of percent change in 10 years from simulation trials. Blue line indicates the current average of either smolt-to-adult survival or exploitation rate and the gray dashed lines are one standard deviation away from each mean. Colour scale is bound by -100 and 100, so values that were smaller or larger than these are represented by the saturated colour.

Table 16. Summary of the percentage of trials that met the recovery target in the final 3-year geometric mean (Final Success) across several simulated exploitation rates (ER) and smolt-to-adult survivals.More ER and smolt-to-survival increments may be requested from the first author.

ER	Smolt-to-Adult Survival													
	0.003	0.005	0.007	0.009	0.01	0.011	0.013	0.015	0.017	0.019	0.021	0.023	0.025	0.03
0	8%	18%	45%	72%	81%	87%	95%	98%	99%	100%	100%	100%	100%	100%
0.01	7%	17%	41%	68%	79%	85%	94%	97%	99%	99%	100%	100%	100%	100%
0.02	7%	16%	38%	65%	76%	82%	92%	97%	99%	99%	100%	100%	100%	100%
0.03	6%	14%	35%	63%	73%	82%	90%	97%	99%	99%	100%	100%	100%	100%
0.04	5%	13%	32%	60%	72%	79%	90%	95%	98%	99%	99%	100%	100%	100%
0.05	5%	11%	28%	57%	68%	76%	88%	94%	97%	99%	99%	100%	100%	100%
0.06	5%	10%	26%	54%	66%	74%	86%	94%	97%	98%	99%	99%	100%	100%
0.07	4%	9%	21%	51%	63%	72%	85%	92%	96%	98%	99%	99%	99%	100%
0.08	3%	8%	19%	47%	60%	70%	83%	91%	95%	98%	99%	99%	99%	100%
0.09	3%	6%	17%	42%	56%	66%	81%	89%	94%	97%	98%	99%	99%	100%
0.1	2%	6%	15%	39%	52%	64%	78%	88%	93%	96%	98%	99%	99%	100%
0.11	2%	5%	12%	33%	47%	61%	76%	84%	92%	95%	98%	99%	99%	99%
0.12	2%	4%	11%	29%	43%	57%	73%	83%	91%	94%	96%	98%	99%	99%
0.13	1%	4%	9%	26%	40%	52%	70%	82%	88%	93%	96%	97%	98%	99%
0.15	1%	2%	7%	19%	31%	43%	64%	77%	85%	91%	94%	95%	97%	99%
0.2	0%	1%	2%	7%	11%	20%	42%	60%	72%	79%	86%	89%	92%	96%
0.3	0%	0%	0%	0%	1%	1%	4%	14%	27%	41%	52%	62%	68%	80%

Table 17. Summary of the percentage of trials that had positive population trajectories (Percentage of Positive Trajectories) across several simulated exploitation rates (ER) and smolt-to-adult survivals. More ER and smolt-to-survival increments may be requested from the first author

ER	Smolt-to-Adult Survival													
	0.003	0.005	0.007	0.009	0.01	0.011	0.013	0.015	0.017	0.019	0.021	0.023	0.025	0.03
0	10%	24%	52%	78%	86%	90%	97%	99%	100%	100%	100%	100%	100%	100%
0.01	9%	21%	50%	74%	84%	89%	96%	99%	99%	100%	100%	100%	100%	100%
0.02	9%	21%	47%	72%	81%	88%	95%	99%	99%	100%	100%	100%	100%	100%
0.03	8%	19%	43%	70%	79%	86%	93%	98%	99%	99%	100%	100%	100%	100%
0.04	7%	16%	40%	66%	77%	85%	93%	97%	99%	100%	100%	100%	100%	100%
0.05	6%	15%	36%	64%	74%	81%	92%	96%	98%	99%	100%	100%	100%	100%
0.06	6%	14%	34%	62%	71%	80%	90%	96%	98%	99%	100%	100%	100%	100%
0.07	5%	12%	30%	58%	70%	77%	89%	95%	98%	99%	99%	100%	100%	100%
0.08	5%	11%	27%	55%	67%	74%	87%	94%	97%	98%	99%	99%	100%	100%
0.09	4%	9%	24%	51%	64%	73%	85%	93%	96%	99%	99%	99%	99%	100%
0.1	4%	8%	21%	48%	59%	69%	83%	91%	96%	98%	99%	99%	100%	100%
0.11	3%	7%	19%	44%	56%	67%	82%	90%	95%	97%	98%	99%	99%	100%
0.12	3%	6%	16%	39%	51%	64%	80%	88%	94%	96%	98%	99%	99%	100%
0.13	2%	6%	14%	36%	47%	61%	77%	87%	93%	95%	98%	98%	99%	99%
0.15	2%	4%	11%	27%	41%	52%	71%	81%	89%	93%	96%	98%	98%	99%
0.2	1%	2%	4%	13%	19%	29%	51%	68%	78%	85%	90%	93%	95%	97%
0.3	0%	0%	0%	1%	1%	3%	9%	22%	36%	50%	60%	69%	74%	85%

Table 18. Summary of the median percent change over 10 years and the 10th and 90th percentiles across several simulated exploitation rates (ER) and smolt-to-adult survivals. More ER and smolt-to-survival increments may be requested from the first author

ER	**Smolt-to-Adult Survival**								
	0.003	0.007	0.009	0.01	0.011	0.013	0.015	0.021	0.03
0	-43 (-69, 0)	2 (-31, 38)	23 (-14, 56)	33 (-6, 65)	42 (1, 78)	56 (12, 92)	70 (23, 112)	99 (40, 158)	124 (56, 208)
0.01	-45 (-70, -2)	0 (-33, 36)	19 (-17, 54)	28 (-6, 62)	36 (-1, 70)	53 (10, 88)	67 (19, 107)	95 (39, 151)	122 (53, 203)
0.02	-46 (-71, -3)	-2 (-35, 34)	18 (-19, 50)	26 (-10, 60)	34 (-3, 68)	52 (9, 86)	63 (17, 103)	92 (36, 149)	121 (53, 204)
0.03	-47 (-72, -7)	-5 (-36, 32)	16 (-18, 49)	24 (-12, 56)	32 (-5, 65)	48 (6, 79)	61 (16, 100)	90 (35, 147)	118 (51, 206)
0.04	-49 (-73, -8)	-7 (-36, 28)	12 (-21, 44)	21 (-13, 55)	30 (-7, 64)	46 (5, 79)	56 (14, 96)	86 (34, 142)	114 (50, 193)
0.05	-50 (-73, -10)	-9 (-39, 26)	10 (-23, 42)	20 (-17, 51)	28 (-9, 60)	42 (3, 76)	54 (11, 93)	83 (32, 140)	113 (48, 194)
0.06	-51 (-74, -12)	-12 (-40, 24)	8 (-25, 40)	16 (-17, 48)	24 (-12, 57)	39 (0, 72)	51 (10, 89)	82 (29, 137)	109 (46, 191)
0.07	-53 (-75, -15)	-13 (-41, 20)	6 (-26, 39)	14 (-18, 45)	22 (-12, 53)	37 (-1, 70)	49 (7, 87)	78 (26, 132)	107 (44, 186)
0.08	-54 (-76, -16)	-15 (-44, 17)	3 (-28, 35)	11 (-21, 43)	20 (-14, 50)	32 (-4, 64)	45 (5, 82)	74 (26, 126)	103 (43, 183)
0.09	-55 (-76, -18)	-17 (-44, 16)	0 (-29, 32)	9 (-22, 40)	17 (-17, 48)	31 (-6, 65)	44 (4, 79)	72 (24, 122)	101 (42, 176)
0.1	-56 (-77, -21)	-20 (-46, 13)	-1 (-32, 28)	7 (-25, 37)	15 (-18, 44)	28 (-9, 61)	41 (2, 76)	69 (20, 122)	98 (38, 176)
0.11	-58 (-77, -23)	-21 (-47, 11)	-4 (-32, 28)	4 (-26, 34)	12 (-20, 41)	24 (-9, 57)	37 (0, 72)	66 (19, 115)	96 (37, 168)
0.12	-58 (-78, -24)	-23 (-49, 8)	-6 (-35, 24)	1 (-28, 32)	10 (-23, 37)	22 (-12, 54)	33 (-2, 71)	62 (17, 112)	92 (35, 168)
0.13	-60 (-79, -26)	-26 (-50, 5)	-8 (-37, 22)	-1 (-30, 28)	7 (-25, 35)	21 (-13, 52)	32 (-4, 66)	60 (16, 107)	91 (34, 161)
0.15	-62 (-80, -30)	-29 (-53, 1)	-14 (-39, 15)	-5 (-34, 22)	2 (-27, 31)	14 (-19, 46)	26 (-10, 60)	54 (10, 103)	84 (29, 154)
0.2	-67 (-83, -39)	-39 (-58, -11)	-24 (-47, 3)	-17 (-43, 7)	-12 (-37, 17)	0 (-28, 30)	11 (-19, 44)	39 (0, 83)	67 (16, 132)
0.3	-77 (-88, -56)	-55 (-71, -34)	-45 (-61, -22)	-40 (-57, -18)	-34 (-53, -12)	-25 (-46, -1)	-17 (-41, 11)	7 (-24, 45)	35 (-8, 90)

6 SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

6.1 ELEMENT 16: INVENTORY OF FEASIBLE MITIGATION MEASURES AND REASONABLE ALTERNATIVES TO THE ACTIVITIES THAT ARE THREATS TO THE SPECIES AND ITS HABITAT

This section discusses both specific and broad mitigation strategies including threats to IFC from; development, fishing, alien invasive species (AIS) introductions, hatcheries, dams and water management as well as threats from global warming.

As has been described in *4 THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF INTERIOR FRASER COHO SALMON*, threats to salmon are numerous and varied, as well as cumulative and increasingly synergistic. Many of these individual threats associated with human activity affect IFC at the CU and subpopulation-level and management and mitigation of their impacts will need to be implemented at finer levels than the DU. Cumulatively however, individual threats can be similarly consequential at the DU-level when compared to activities such as fishing or those contributing to or exacerbated by global warming and there should be some level of co-ordination of mitigation measures at the DU-level as well as at finer spatial scales. Additionally, the mitigation measures discussed below are widely applicable to other COSEWIC-assessed salmonids that use the same watersheds as IFC.

6.1.1 Development

The behaviour of IFC is diverse in that they occupy a range of habitats and are present in many of the small and medium sized tributaries and off-channel habitats throughout their extensive distribution. Because their distribution is wide and their life cycle depends on various freshwater habitats for at least two years, IFC are present and directly or indirectly threatened by a wide array of human activities. Threats to IFC from activities related to human works or activities can be addressed through specific mitigation 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 result in fish mortality, there can be insufficient understanding and planning around the implications to fish productivity. Planning for catchment area modification activities such as forestry, agricultural and range, mining as well as urban development needs to consider the cumulative hydrological effects of deforestation and riparian disruption. Currently, in forestry and other industries, there is little if any consideration of the existing state of a watershed’s hydrological health when planning future extraction activities, yet the hydrological regimes of watersheds are inextricably linked to salmon health (Hartman and Brown 1988, Tschaplinski and Pike 2017). This is also the case for the ecological functions of off-channel habitats and non-fish bearing streams in regard to IFC population health (Sharma and Hilborn 2011). The contribution that these lesser understood water bodies make to salmon prey availability, and flow and temperature refugia needs to be better understood and protected.

There are several legislated Acts and their associated guidance policies and documents that describe the regulations and best practices for works or activities that impact fish. These products include but are not exclusive to; the *Provincial Riparian Area Regulations* (RAR) under the *Riparian Areas Protection Act*, the *Forest and Range Practices Act* (FRPA), the *Mines Act*, the *Water Sustainability Act* as well as the *Federal Fisheries Act* and the *Fisheries Protection Policy Statement*. These acts recognize the link between activities and habitat threats and provide the regulatory framework for reducing those threats; however, cooperation within multijurisdictional regulation frameworks, policy interpretation, planning, monitoring and enforcement are all areas that require 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 and so may work against the interests of those undertaking development. As such, those undertaking works that can potentially threaten salmon productivity must be compelled to work in ways to mitigate for harm to IFC and other COSEWIC-assessed or SARA-listed salmon. Significant gaps have been identified in models that use professional reliance or self-declared development plans with habitat impacts to ensure compliance with regulations (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 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) that can cause bankruptcies that prevent companies and governments from affording the required mitigation activities would be beneficial.

A legal and policy framework that is consistent and consistently applied at the municipal, regional district, provincial, federal, and First Nations levels is required to compel the public to develop within the guidelines of regulations intended to protect salmon. As well, recognition of science-based advice to inform a continuity of legislation and policy between political spectrums and philosophies is required so that protection of IFC and co-occurring COSEWIC-assessed salmonids' habitat is stable through time.

6.1.2 Commercial; Food, Social, and Ceremonial; and Recreational Fishing

The nature of fisheries impacting Southern BC Coho has changed significantly over the past 40 years (IFCRT 2006, DFO 2015a). During the 1980s, large commercial fisheries resulted in millions of Coho Salmon removals from marine areas and retention of wild Coho Salmon in recreational and First Nations fisheries was the accepted practice in both marine and freshwater fisheries (Irvine 2002). After the dramatic decline in Southern BC Coho Salmon productivity in the early to mid-nineties, all fisheries targeting IFC directly, and impacting IFC through by-catch, were ended or significantly restricted by 1998 (IFCRT 2006).

Since 1998, there has been a meaningful reduction in retention of wild Coho Salmon in Canada and most Canadian fisheries impacts are due to unlawful harvest or fishery-related incidental mortality (FRIM) on IFC through by-catch in fisheries targeting other species such as Sockeye, Pink and Chum salmon (PSC 2013a, DFO 2015a).

Understanding of the true impact of the reduction in targeted fisheries on the overall IFC ER has been confounded by several factors including unlawful fishing, changes to the nature of fisheries (e.g. less commercial fisheries, recreational fishery limited to retention of hatchery marked fish), and inadequate understanding of fisheries impacts on released fish (PSC 2013a). One factor that is integral in estimating stock-specific fisheries impacts is the number of released CWTs as well as indicator stocks. The hatcheries in the interior Fraser River watershed are currently at or near capacity; therefore, increasing the number of indicator stocks and CWT fish is limited by current resources.

Several aspects of the recreational fishery have created both potential for risks and a greater ability to mitigate direct impacts on IFC. In the current period from 1998 to the present, recreational fisheries have seen an increase in their power to detect and catch fish due to the introduction of electronic downriggers and more accurate fish finders, which can increase their efficiency in catching fish but also allow them to target the sections of the water column where Coho Salmon are less likely to swim in. Better communication between fishers through internet media can alert them to areas with good fishing but also be a conduit to inform on current fishing regulations. Finally, there is potentially better or similar access to IFC because the amount of fish removed by commercial fisheries in downstream areas has greatly decreased, which may result in more catch-and-release incidences by subsequent recreational fisheries. Both genetic samples and increased voluntary reporting of catch-and-release Coho Salmon would be required to better gauge impacts from recreational fisheries and inform subsequent management.

Recreational fisheries mitigation may include but is not limited to: use of gear that decreases impacts to released fish such as barbless hooks, fish handling and fish identification instruction for those seeking to catch and retain (or release) salmon, diminished fishing opportunities when compliance with regulations and voluntary CWT head recoveries fail to reach target levels, and increased enforcement of regulations.

First Nations (FN) fisheries (FSC and FN commercial) have changed since 1998 with an increase in fishing restrictions (timing, length of openings, licence conditions regarding the way gear is fished and mark selective retention) based on stocks of concern across most salmon species. There have also been changes in the ways these fisheries access fish due to the expansion of drift gill nets in the Mission to Hope area, increased access for sales fisheries using selective fishing gear (beach seine, shallow seines and fish wheels) and through initiatives to move commercial access to FN fisheries in terminal areas. These fishing efforts seldom target IFC, and gear restrictions around the IFC migration window are in place to reduce impacts to the IFC population.

Fisheries planning is currently conducted based on fisheries effort, catch per unit effort and IFC distribution information that may no longer be relevant. A better understanding of how decisions, and changes to fisheries management actions, impact recent IFC ER is required to better manage IFC within the current fisheries framework. Current data deficiencies include: catch from licensed but unmonitored fisheries, and uncertainty in FRIM rates such as on-board mortality, drop-off and post-release mortality and sub-lethal effects of gear encounters (Patterson et al. 2017). In the recreational sector, angler reported releases of non-target fish are uniformly below third-party release observations of the same fishery (Babcock et al. 2003; Bijsterveld et al. 2002; DFO consultation document 2014; Diewart et al. 2005; Vélez-Espino et al. 2010). Similarly, unlawful fishing remains unquantified as the watershed in the province of BC is vast and regulations are not fully enforced in some areas and times. There are limited resources for enforcement to patrol and monitor every river, every fish population, and every reach of valuable fish habitat (pers. comm. Barry Zunti 2019). Improvements to the understanding of sources of fisheries mortality would help to improve the accuracy of fisheries planning and maintain fisheries impacts within an allowable overall ER. For example, more comprehensive fishery catch estimation initiatives such as iREC and greater enforcement to curtail unlawful fishing activity are both activities that can improve mitigation effectiveness.

Other mitigation strategies may be achieved through licencing, including closure of fisheries when and where IFC are known to be present. The current understanding of IFC marine distribution in the Coho FRAM relies on CWT data from 30 to 40 years ago (PSC 2013a). If distribution has changed, a better understanding of current IFC marine distribution and timing would potentially open fisheries where they are currently closed and close fisheries where they are newly impacting IFC. Alternatively, mitigation for overexploitation of IFC may involve moving fisheries to more terminal IFC areas, where surplus to spawning goals could be identified and managed with more certainty.

Impacts from net fisheries openings during co-migration of IFC can be further mitigated by stipulating shorter opening durations, shorter gillnet set times, shorter nets, larger gill net mesh size or tangle tooth net 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.

Research and stock assessment activities must use the least invasive techniques when possible. Impacts to fish must be monitored and feedback to programs must occur to improve fish handling techniques.

6.1.3 Alien invasive species introduction

Introduction of AIS is difficult to mitigate as it takes only a few individuals, sometimes introduced unintentionally, to irrevocably alter a watershed. A multipronged approach of public education, monitoring of areas likely to be points of introduction, and enforcement through strong disincentives are required. Where AIS are detected, all efforts to eradicate those species should be undertaken as quickly as is possible and monitoring programs should be implemented and sustained to ensure eradication is complete.

6.1.4 Hatcheries

Current SEP policies include; the SEP Production Planning Framework (DFO 2018d), Biological Risk Management Framework for Enhancing Salmon in the Pacific (DFO 2013a), and the Operational planning guidelines (DFO 2016). In addition, a SEP Biological Assessment Framework and SEP Genetic Management Implementation Guidelines are near completion. Every DFO facility has a comprehensive Pacific Aquaculture Regulation license that is site-specific and outlines policies and procedures for site management and community facilities also have a set of best management practices (DFO 2013b). These documents form the basis for sound practice but adherence to them by those planning production and operating facilities should be reviewed periodically. Hatchery activity may be improved both at the planning stages and at hatchery sites during daily operations. Measures to more comprehensively prioritize hatchery activity, as well as monitor returning populations for percent natural influence, hatchery stock timing and size influences on natural populations would improve the ability to mitigate threats associated with hatchery activity.

Some mitigation measures around hatcheries from the documents cited in this section include:

1. proportional marking of hatchery fish and effective monitoring of all systems where hatchery fish return directly or stray
2. alternate release strategies could be employed to minimize straying
3. when capturing broodstock, every effort to only collect naturally-produced fish in a manner representative of the size and timing distribution of the naturally-produced return
4. understanding carrying capacities and effects on fish growth in both the freshwater and marine environments to mitigate the effects of competition by hatchery fish

Although the focus here has been on mitigating the effects of hatcheries on natural populations, hatcheries are also an important tool for other aspects in fisheries management as noted in *6.1.2 Commercial; Food, Social, and Ceremonial; and Recreational Fishing* (e.g. CWT indicator stocks).

6.1.5 Dams and water management/use

Water management through flood mitigation structures, impoundment, and water extraction represent threats to the various life history stages of IFC (Sherwood et al. 1990, Irvine 2002, Beechie et al. 2004, COSEWIC 2016).

Large dam structures (e.g. hydroelectric dams) must allow for upstream adult IFC passage as well as for safe downstream IFC fry and smolt passage. Additionally, water release strategies must adhere to methods informed by system-specific ecological flow requirements, which may be important for both adults and juveniles. Ecological flow requirements must include spring freshets to incorporate allochthonous material, clear sediments from spawning gravel, and introduce woody debris and inundate off channel habitat (Biggs et al. 2005). Water release must also be mindful of summer temperature and flow management requirements for IFC. Temperature may be better controlled by designing dams that can release from lower stages of the water column as well as spilling from the surface of impoundments.

In addition to large dams, there are many smaller water impoundment structures on lake headed systems in IFC watersheds as well as in the lower Fraser River. Water management with regard to extraction of overland flows and aquifers may be in direct conflict with the water needs of IFC and other stream dwelling animals. These structures are mostly in place for irrigation and flood mitigation purposes; the majority of which are not managed in a manner that addresses passage or flow requirements for fish. Recognition and protection of off-channel habitat for IFC rearing is critical to maintaining IFC productivity into the future. Flood mitigation structures impede the seasonal dispersal of juvenile Coho Salmon into favoured off channel areas during spring freshet.

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. 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, strictly voluntary. Though modern water licences are granted with metering requirements and within associated allocations, many water licences exist that are unmetered and water extraction in some river systems is recognized to be over-allocated. Proper allocation, metering, monitoring and enforcement within a water use planning framework needs to be achieved to sustain salmon habitat.

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 per-existing groundwater use. Though *The Water Sustainability Act*’s move to licence 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-water requirements.

6.1.6 Global warming and climate change

Mitigating for the effects of climate change begins by mitigating for climate change itself. Steps need to be taken by every level of government to reduce green house gas emissions. However, this is unlikely within the time frame that will satisfactorily address the threat of climate change, and current development practices will likely exacerbated the additive threats of global warming (Healey 2011). What were once regarded as one in one hundred year events are now increasing in frequency (Hamlet 2011).

Global warming and climate change is likely to exacerbate many threats, creating cumulative impacts that may impede progress on many of the previously recommended mitigation measures. For example, more extreme precipitation events caused from climate change will compound with the increased run-off rates that result from logging and forest fires. Impediments to mitigation activities for those threats may occur through public demand for impoundment structures for urban or agriculture protection. Increased failures of tailings ponds and water treatment facilities as well as higher rates of scouring, riverbank failure, and avulsion events will also act as conflicting issues to mitigation measures for salmon. As well, failures of infrastructure due to extreme events, and insufficient monitoring and maintenance, may lead to a greater number of instream works, which in turn may contribute to threats as discussed under the Development section above.

The current regulatory frameworks and best practices may all need to be revised and coordinated such that management decisions can adapt to the more regular arrival of higher flood flows and altered snowpack melt regimes while considering unintended consequences to salmon. For example, frameworks for 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 will all need to be revisited due to climate change. In particular, the current practice of unregulated groundwater extraction, unmonitored surface water extraction activity, slow reaction times to drought conditions, and the lack of coordinated planning around watershed-level hydrological function will all need innovative solutions or improvement to be more responsive to climate change.

Active management of flow regimes is one possible solution to climate driven changes in hydrology and will be discussed more thoroughly in section *6.2 Element 17: Inventory of activities that could increase the productivity or survival parameters*.

6.1.7 Conclusions around mitigations

Salmon survival over their historical range clearly requires trade offs that society appears willing to make but in practice, often fall far short of achieving. The issue of salmon conservation as discussed by Lackey (2005, 2006), as with all resource conflicts, is characterized by complexity, polarization, winners and losers, delayed consequence, national versus regional conflict, and an ambiguous role for science, amongst other challenges.

Similar to the threats that are occurring, mitigation of those threats needs to be applied both to individual works and activities, as well as to broader activities affecting salmon at the landscape level, which can be organized roughly by biogeoclimatic zones. The current practices of urban development, mining, forestry, and agriculture, as well as fisheries management, will need to be revisited with an understanding of how climate change will alter and likely exacerbate the effects of these activities on salmon habitat and therefore salmon productivity in both the freshwater and marine environments.

Due to the complexity of the IFC life history, several key factors contributing to healthy IFC productivity are managed in a multijurisdictional framework. IFC's productivity and survival depend on cool, clean, connected waterways, as well as intact riparian and off-channel habitats spanning thousands of kilometers of stream length and flowing through a myriad of land titles and activities. The effective mitigation of risk requires recognition of the impact of activities on salmon habitat and survival, development of clear and effective legislation and regulations, as well as policy and best practice documents to address those threats, and equally important, funded monitoring and enforcement of mandated measures. As well, strategic planning is required to identify bottlenecks to IFC survival so that allocation of funding opportunities can make meaningful improvements to IFC and salmon productivity.

The vast connected area that is intertwined with salmon habitat requirements dictates that protection and management has to be undertaken and coordinated between many levels of government including: First Nations, Federal, Provincial, and Municipal governments, which hold separately the jurisdictions of land use and planning, water use and allocation, resource extraction management, and fisheries planning and enforcement. Past and current practices have often operated independently where the interpretation and application of policy and regulation for the protection of salmon was inadequate or not considered at all. Relatively recent modifications to sections of the *Fisheries Act* around habitat protection also enabled different levels of government to act more independently or not consider all aspects of salmon habitat in relation to development and potential impacts (Olszynski 2015). A more integrated and landscape-level approach is needed to make planning and employment of mitigation measures effective.

6.2 ELEMENT 17: INVENTORY OF ACTIVITIES THAT COULD INCREASE THE PRODUCTIVITY OR SURVIVAL PARAMETERS

As noted in *4.3 Element 10: Natural factors that will limit survival and recovery*, almost all of the natural limiting factors are affected by anthropogenic climate change or landscape-level development and are intertwined with existing threats and impacts. Therefore, most of the mitigation activities and processes suggested in *6.1 Element 16: Inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat* would also benefit productivity and survival.

Hatchery production is different than most threats because it can be both a threat to genetic diversity but also a mitigation measure to increase abundance of a natural population. Conservation enhancement, used in systems deemed to be below apparent carrying capacity or highly at risk of extirpation, is already present in the interior Fraser River and includes enhancement in the Deadman River in the Lower Thompson CU and on the Salmon River in the South Thompson CU. However, the performance of these programs has not been monitored and reported against any quantifiable objectives. It is integral to identify biological goals for hatchery-influenced populations (e.g. a target proportionate natural influence *PNI* level), consistently monitor populations, and be adaptive in management responses to mitigate genetic risks (Flagg 2015). New guidelines have been proposed around conservation-based hatchery programs that detail some of the complexities associated with different phases of recovery or restoration of a population (Withler et al. 2018). An important aspect of these phases is that their primary objectives and the management scenarios adapt to the status of the DU. Conservation phases range from preservation, recolonization, and local-adaptation, to fully restored. Limiting hatchery enhancement by scaling it with natural production and DU status, and sourcing brood-stock representatively from natural stocks are integral for maintaining genetic diversity while bolstering abundance (Withler et al. 2018).

Water management is also different because it can be both a threat and mitigation measure. In *6.1.5 Dams and water management/use*, water management was discussed in the context of mitigating the impacts of water removal for urban, agricultural, or commercial use; however, reservoir management and regulated flows may also be a tool for mitigating impacts from climate change. As the frequency of droughts or extreme precipitation events increases, so will the frequency of unsuitable flows and thermal regimes that may reduce survival of IFC in some systems. Previous research on Bull Trout has shown that reservoir management has the potential to mitigate impacts from projected climate change (Benjankar et al. 2018). Currently, there is research to examine the feasibility and effectiveness of reservoir management in the Coldwater River by the Scw’exmx Tribal Council, but this tool may be beneficial in multiple systems.

There are also activities (e.g. predator or competitor management) that could be done as mitigation measures to increase survival in the estuary and marine environment; however, these were not investigated thoroughly enough to be included in this report as suggestions. Further research on activities in the ocean environment that could be used as mitigation measures is required to fulfill this element.

6.3 ELEMENT 18: IF CURRENT HABITAT SUPPLY WAS INSUFFICIENT TO ACHIEVE RECOVERY TARGETS (SEE ELEMENT 14), ADVICE ON THE FEASIBILITY OF RESTORING THE HABITAT TO HIGHER VALUES

Element 14 was not addressed due to data and time limitations; however, the mitigation activities outlined in *6.1.1 Development* and *6.1.5 Dams and water management/use* are likely to result in restoring habitat properties to higher qualities. To reiterate, Coker et al. (2010) has previously identified general activities and how they mitigate threats in aquatic environments that would result in increased habitat quality, and this document should be consulted when identifying activities that may restore habitat.

The IFCRT (2006) identified several research projects that would assist in fulfilling this element in future assessments and recovery strategies (Table 8) as well as identified several general strategies to mitigate impacts of habitat change (IFCRT 2006, Section 3 Table 9).

6.4 ELEMENT 19: ESTIMATED REDUCTION IN MORTALITY RATE EXPECTED BY EACH OF THE MITIGATION MEASURES OR ALTERNATIVES IN ELEMENT 16 AND INCREASED IN PRODUCTIVITY OR SURVIVAL ASSOCIATED WITH EACH MEASURE IN ELEMENT 17

The interaction between changes in habitat quality and quantity to changes in life-history parameters represents a major gap in knowledge for IFC. Interactions are likely system specific and will require substantial resources and time to assess. Only changes in ER to mitigate the impact of fisheries was assessed, as it is the only threat assessed in this paper with enough data for a detailed evaluation. Sections *5.4* and *7.1.1* present and discuss simulated changes in population trajectory to changes in ER. Changes to smolt-to-adult survival were also explored in section *5.4*, but it is impossible at this time to relate the magnitude of change in smolt-to-adult survival to specific mitigation actions.

6.5 ELEMENT 20: PROJECTED 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

No mortality rates nor productivities were identified in Element 19. Changes in ER are discussed in *7 ALLOWABLE HARM ASSESSMENT* because there were data to support the modelling of changes in this activity. Data to inform on changes from other mitigation measures was not available to model directly.

As a coarse proxy, changes in the smolt-to-adult survival rate from the analysis done in *5.4 Element 15* can be approximated to changes in productivity due to the relation of maximum productivity at the origin (α'), α, and the smolt-to-adult survival covariate (γ), as described in Equation 4. To reiterate however, it is not possible at this time to connect the magnitude of these changes to specific mitigation activities.

Despite a lack of quantifiable rates, mitigation or restoration that increased productivity would increase the probability of a positive population trajectory and reaching the recovery target. Subsequent simulations and research may provide insight on how changes in productivity (or the α parameter) would affect reaching the recovery target given different hypothetical scenarios; however, this exploration assumes that effective mitigation activities occur or a regime change in the marine environment would result in higher productivity.

6.6 ELEMENT 21: RECOMMENDED PARAMETER VALUES FOR POPULATION PRODUCTIVITY AND STARTING MORTALITY RATES, AND SPECIALIZED FEATURES OF THE POPULATION MODEL

It is highly recommended to contact the lead author of this document before any exploratory analysis is done for economic, social, and cultural impacts that is based off of the model described in *5.2 Element 13* and *5.4 Element 15*. There is a considerable *Caveats and conditions* section attached with the population model and several sources of uncertainty (that have been outlined briefly) in the parameters listed in *2.3 Element 3* and the discussion in *4.1.4 Food, Social, and Ceremonial; Recreational; and Commercial* .

7 ALLOWABLE HARM ASSESSMENT

7.1 ELEMENT 22: EVALUATION OF MAXIMUM HUMAN-INDUCED MORTALITY AND HABITAT DESTRUCTION THAT THE SPECIES MAY SUSTAIN WITHOUT JEOPARDIZING ITS SURVIVAL OR RECOVERY

The broad definition of **allowable harm** is: “Harm to the wildlife species that will not jeopardize its recovery or survival” (DFO 2014b). 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 2014b). Therefore, recovery is higher on the spectrum of population persistence than survival.

To conclude that activities may be permitted under Section 73 of *SARA* as allowable harm, several criteria need to be fulfilled (DFO 2004a). To assist in answering these criteria, four basic questions were outlined in the “Moncton Protocol” (DFO 2004b):

1. What is the present/recent species trajectory?
2. What is the present/recent species status?
3. What is the expected order of magnitude / target for recovery?
4. What is the expected general time frame for recovery to the target?

With an overarching question, “Can the species recover if human-induced mortality is greater than zero?”

Many of the elements of the Moncton Protocol are now captured in the elements of RPAs.

It was also observed that the survival and recovery of species that use freshwater often depended on habitat features. The Moncton Protocol was revised to incorporate habitat management in allowable harm assessments (DFO 2006); however, this is often difficult to fulfill when impacts on populations from altered habitat are not quantified.

7.1.1 Assessment

Considering that the average IFC DU recruits per spawner exceeds replacement (Table 6), recovery is likely possible if human-induced mortality is minimal given current environmental conditions and variability, *and* assuming impacts from the identified threats are also mitigated. The forward simulations from *5.2 Element 13: Projected population trajectories given current population dynamics parameters* provide some plausible ranges of DU responses to adult mortality in the form of ER (Table 16, Table 17, Table 18), which may be used to inform allowable harm under current environmental conditions. The required data to inform on allowable harm around habitat represents a major gap in knowledge for IFC.

By considering the model-averaged forward simulation results in the context of the IPCC's certainty categories (Mastrandrea et al. 2010), population responses to ER under the current smolt-to-adult survival (average = 0.010) may be discussed in terms of the plausibility of occurring.

The proportion of simulations that met the suggested recovery target in the final 3-year geometric average of the projection (final success) entered the likely range (≥ 0.66) at an ER of 0.06 and lower at current smolt-to-adult survival; however, no proportion of simulations reached the very likely range (≥ 0.9) at the current smolt-to-adult survival. At an ER of 0.06 and current average smolt-to-adult survival, it is likely that the population trajectory may be positive (percentage of positive trajectories = 0.71); however, the median percent change in 10 years was 16% and the 80% uncertainty interval was -17 to 48% (i.e. crossed 0%).

The uncertainty interval of the percent change metric always crossed 0% at current smolt-to-adult survival across all ERs even when ER was set at 0 with no variability around it, which indicates uncertainty in whether the DU population trajectory will be positive or negative at any ER under recent conditions. At an ER of 0, the 80% interval around percent change was -6 to 65% with a median of 33%. The "percentage of positive trajectories" at 0 ER at the average smolt-to-adult survival was in the likely range (0.86) and it had the highest proportion of final success (0.81). Therefore, positive population growth and meeting the recovery target in 10 years may be likely at ER of 0.06 or less but there is unaccounted for uncertainty in the modelling that produced this result and a there is a possibility of a negative DU population trajectory. The plausibility of positive population trajectories increases towards ER of 0.

The additional uncertainty that was not captured in the forward simulation results (see *5.2.1 Caveats and conditions*) makes it difficult to confidently identify at which point the DU is at risk from failing to meet the recovery target with high certainty solely based on changing ER. The forward simulation was particularly sensitive to changes in average smolt-to-adult survival in both the positive and negative directions, thus recommendations of allowable harm should be revised regularly as environmental conditions vary. If listed, the recommended period to report on recovery strategies is five years but annual updates to the modelling associated with estimating impacts from ER is recommended as more data accumulate. The effect of changing ER to achieve successful recovery to the recommended abundance target is an immediate management action that DFO may use but other activities that were identified as threats also need to be considered.

Many anthropogenic activities may act additively or cumulatively, which may be considered in the context of total-adult-equivalent-mortality or changes to productivity. In the context of the modelling work done here, changes to ER and smolt-to-adult survival may be viewed as rough proxies for changes in total-adult-equivalent-mortality or productivity, respectively. There is an assumption that the current impacts from threats remains constant to current conditions in the forward projection; however, hypothetical changes to total-adult-equivalent-mortality or productivity may change in the future due to increasing (or decreasing) impacts from other threats. For example, the model result associated with an ER of 0.12 may not be truly representative if future activities result in additional adult-equivalent mortality above the current background rate. Additionally, results associated with a smolt-to-adult survival value of 0.009 may represent a scenario where baseline impacts to the productivity in the freshwater increase. Therefore, harm from other activities will need to be considered in addition to the harm associated with ER when considering the probability of reaching the recovery target.

The existing and growing harm associated with several threats to IFC habitat may have larger impacts to population trajectory than ER, despite the lack of quantitative relationships to survival and productivity across CUs. As previously noted, population growth is sensitive to egg-to-smolt survival, which is impacted by activities in watersheds. Many threats from the *Element 8* threats assessment are associated with impacts to watersheds and freshwater habitat. The highest ranked threats include modifications to catchment surfaces, linear development, and agricultural and forestry effluents, respectively. The activities associated with modifications to catchment surfaces primarily include forestry, followed by agriculture and then urban development (impervious surfaces). The rate and expansion of forestry, agriculture, and urban development is variable across CUs. Linear development, which often results in decreased amount and complexity of habitat, is primarily from flood and tidal protection measures in the lower Fraser River but also associated with agricultural and urban development along rivers in the interior. Agricultural and forestry effluents are directly related to the style of activity (e.g. clear-cut vs. selective) but also bank gradient and natural levels of precipitation and soil composition, which differs across the CUs along with the levels of those activities. In addition to the various sources of ER, the following activities were also identified as having low to medium (i.e. uncertain relative to the three previous threats listed), threat risks to IFC: Dams and water management/use, introduced genetic material (hatchery influences), and effluents from both urban as well as industrial and military activities. All of the aforementioned activities warrant the attention of subsequent considerations of Allowable Harm by recovery teams if IFC are listed.

There are several DFO-mandated policies and frameworks to guide activities that may cause harm as well as how and when to reduce excessive harm from direct exploitation, bycatch, and habitat impacts. These policies and frameworks include the salmon-specific *Canada’s Policy for Conservation of Wild Pacific Salmon (the Wild Salmon Policy, WSP)* and the broader DFO policy, the *Sustainable Fisheries Framework.* The WSP places conservation of salmon and their habitats as the first priority for resource management, which includes safeguarding genetic diversity of wild salmon, and maintaining habitat and ecosystem integrity. The *Sustainable Fisheries Framework* includes guidance on decision-making that incorporates the precautionary approach, ecosystem-based fisheries management, and policies on managing bycatch. A particularly applicable guideline from the Precautionary Approach in the context of data-limited IFC is “about being cautious when scientific information is uncertain, unreliable or inadequate, and not using the absence of adequate scientific information as a reason to postpone or fail to take action to avoid serious harm to [a] resource.” The Precautionary Approach may also be beneficial to use in the context of harm from threats to habitat as well as in fisheries management. These policies and guidelines should be considered if subsequent recovery strategies are initiated.

Although the allowable harm recommendation in the following paragraph is based on the existing simulation results and application of the precautionary principle, there are several aspects to consider when allowable harm is considered in the future. The recommendation may be considered in a high-level context and that CU-year-specific allowable harm assessments may be done in the future as additional data are collected; however, the ability to manage ER and habitat impacts at the CU-level precludes CU-year-specific caps. Also, the US is not required to reduce its impact on IFC below a 10% ER at the current Pacific Salmon Treaty

(PST) status of IFC; however, there is language in the PST that allows Canada to request a reduction in ER (PSC 2019). Lastly, it is recommended to address the research identified by the IFCRT (2006) that may fill the knowledge gaps associated with habitat impacts such that a more quantitative approach may be taken in subsequent assessments.

Due to the uncertainty around the levels of harm associated with multiple activities and the current modelled probabilities of having positive trajectories under the current scenario, the following recommendation around allowable harm is made: **only activities in support of the survival and recovery of IFC,** which may result in possible mortalities (e.g. stock assessment, research, or mitigation/habitat restoration activities), **be permitted to ensure positive population growth** until the IFC DU returns to the suggested target population level and threats have been mitigated such that IFC are not considered Threatened.

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9 REFERENCES CITED

Alderman, S. L., L. A. Dindia, C. J. Kennedy, A. P. Farrell, and T. E. Gillis. 2017a. Proteomic analysis of sockeye salmon serum as a tool for biomarker discovery and new insight into the sublethal toxicity of diluted bitumen. Comparative Biochemistry and Physiology - Part D: Genomics and Proteomics 22:157–166.

Alderman, S. L., F. Lin, A. P. Farrell, C. J. Kennedy, and T. E. Gillis. 2017b. Effects of diluted bitumen exposure on juvenile sockeye salmon: From cells to performance. Environmental Toxicology and Chemistry 36:354–360.

Alsaadi, F., P. V. Hodson, and V. S. Langlois. 2018. An Embryonic Field of Study: The Aquatic Fate and Toxicity of Diluted Bitumen. Bulletin of Environmental Contamination and Toxicology 100:8–13.

Anderson, D., H. Moggridge, P. Warren, and J. Shucksmith. 2014. The impacts of ‘run-of-river’ hydropower on the physical and ecological condition of rivers. Water and Environment Journal 29:268–276.

Anderson, S. C., A. B. Cooper, O. P. Jensen, C. Minto, J. T. Thorson, J. C. Walsh, J. Afflerbach, M. Dickey-Collas, K. M. Kleisner, C. Longo, G. C. Osio, D. Ovando, I. Mosqueira, A. A. Rosenberg, and E. R. Selig. 2017. Improving estimates of population status and trend with superensemble models. Fish and Fisheries 18:732–741.

Angilletta, M. J., E. A. Steel, K. K. Bartz, J. G. Kingsolver, M. D. Scheuerell, B. R. Beckman, and L. G. Crozier. 2008. Big dams and salmon evolution: changes in thermal regimes and their potential evolutionary consequences. Evolutionary Applications 1:286–299.

Araujo, H. A., C. Holt, J. M. R. Curtis, R. I. Perry, J. R. Irvine, and C. G. J. Michielsens. 2013. Building an ecosystem model using mismatched and fragmented data: A probabilistic network of early marine survival for coho salmon *Oncorhynchus kisutch* in the strait of georgia. Progress in Oceanography 115:41–52.

Arbeider, M. 2018. Juvenile salmon use of estuaries: investigating food web ecology, growth, and residency (M.Sc. Thesis). Simon Fraser University, Burnaby, British Columbia.

Askey, P.J., Post, J.R., Parkinson, E.A., Rivot, E., Paul, A.J., and Biro, P.A. 2007. Estimation of gillnet efficiency and selectivity across multiple sampling units: a hierarchical Bayesian analysis using mark-recapture data. Fisheries Research 83:162–174.

Atagi, D. Y. 1994. Estuary use by juvenile coho salmon (*Oncorhynchus kisutch*): is it a viable life history strategy? University of British Columbia.

Babcock, E. A., E. K. Pikitch, and C. G. Hudson. 2003. How much observer coverage is enough to adequately estimate bycatch? University of Miami, Miami, FL.

Ban, S. S., H. M. Alidina, T. A. Okey, R. M. Gregg, and N. C. Ban. 2016. Identifying potential marine climate change refugia: A case study in Canada's Pacific marine ecosystems. Global Ecology and Conservation 8:41–54.

Barnes, W. J. 1999. The Rapid Growth of a Population of Reed Canarygrass (*Phalaris arundinacea L.*) and Its Impact on Some Riverbottom Herbs. The Journal of the Torrey Botanical Society 126:133–138.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software 67:1–48.

Beacham, T. D., M. Wetklo, L. Deng, and C. Macconnachie. 2011. Coho salmon population structure in North America determined from microsatellites. Transactions of the American Fisheries Society 140:253–270.

Beakes, M. P., J. W. Moore, S. A. Hayes, and S. M. Sogard. 2014. Wildfire and the effects of shifting stream temperature on salmonids. Ecosphere 5:1–14.

Beamish, R. J., and D. R. Bouillon. 1993. Pacific Salmon Production Trends in Relation to Climate. Canadian Journal of Fisheries and Aquatic Science 50:1002–1016.

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49:423–437.

Beamish, R. J., C. Mahnken, and C. M. Neville. 1997. Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment. ICES Journal of Marine Science 54:1200–1215.

Beamish, R. J., C. Mahnken, and C. M. Neville. 2004. Evidence That Reduced Early Marine Growth is Associated with Lower Marine Survival of Coho Salmon. Transactions of the American Fisheries Society 133:26–33.

Beamish, R. J., G. A. McFarlane, and R. E. Thomson. 1999. Recent declines in the recreational catch of coho salmon (*Oncorhynchus kisutch*) in the Strait of Georgia are related to climate. Canadian Journal of Fisheries and Aquatic Sciences 56:506–515.

Beamish, R. J., R. M. Sweeting, K. L. Lange, and C. M. Neville. 2008. Changes in the Population Ecology of Hatchery and Wild Coho Salmon in the Strait of Georgia. Transactions of the American Fisheries Society 137:503–520.

Beamish, R. J., R. M. Sweeting, K. L. Lange, D. J. Noakes, D. Preikshot, and C. M. Neville. 2010. Early Marine Survival of Coho Salmon in the Strait of Georgia Declines to Very Low Levels. Marine and Coastal Fisheries 2:424–439.

Beechie, T., E. Beamer, and L. Wasserman. 2004. Estimating Coho Salmon Rearing Habitat and Smolt Production Losses in a Large River Basin, and Implications for Habitat Restoration. North American Journal of Fisheries Management 14:797–811.

Benjankar, R., D. Tonina, J. A. McKean, M. M. Sohrabi, Q. Chen, and D. Vidergar. 2018. Dam operations may improve aquatic habitat and offset negative effects of climate change. Journal of Environmental Management 213:126–134.

Berejikian, B., and M. Ford. 2003. Review of relative fitness of hatchery and natural salmon. Seattle, WA: Northwest Fisheries Science Center; U.S. Dept. Commer., NOAA Tech. Memo NMFS-NWFSC-61.

Biggs, B. J. F., V. I. Nikora, and T. H. Snelder. 2005. Linking scales of flow variability to lotic ecosystem structure and function. River Research and Applications 21:283–298.

Bijsterveld, L., S. Di Novo, A. Fedorenko, and L. Hop Wo. 2002. Comparison of catch reporting systems for commercial salmon fisheries in British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2626. 44p.

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

Bisson, P. A., and R. E. Bilby. 1982. Avoidance of Suspended Sediment by Juvenile Coho Salmon. North American Journal of Fisheries Management 4:371–374.

Bjornn, T.C. and Reiser, D.W., 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication, 19:138.

Booth, D. B., D. Hartley, and R. Jackson. 2002. Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts1. Journal of the American Water Resources Association 38:835–845.

Boulton, A. J., S. Findlay, P. Marmonier, E. H. Stanley, and H. M. Valett. 2002. The functional significance of the hyporheic zone in streams and rivers. Annual Review of Ecology and Systematics 29:59–81.

Bradford, M. 1998. A risk assessment for Thompson River coho salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 1998. 23p. (Accessed Jan 21, 2019)

Bradford, M. J. 1995. Comparative review of Pacific salmon survival rates. Canadian Journal of Fisheries and Aquatic Sciences 52:1327–1338.

Bradford, M. J., and J. R. Irvine. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 57:13–16.

Bradford, M. J., R. A. Myers, and J. R. Irvine. 2000. Reference points for coho salmon (*Oncorhynchus kisutch*) harvest rates and escapement goals based on freshwater production. Canadian Journal of Fisheries and Aquatic Sciences 57:677–686.

Bradford, M. J., C. P. Tovey, and L.-M. Herborg. 2008a. Biological Risk Assessment for Yellow Perch (Perch flavescens) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc 2008/073. vi + 27 p. (Accessed Feb 15, 2019)

Bradford, M. J., C. P. Tovey, and L.-M. Herborg. 2008b. Biological Risk Assessment for Northern Pike (*Esox lucius*), Pumpkinseed (*Lepomis gibbosus*), and Walleye (*Sander vitreus*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc 2008/074. viii + 46 p. (Accessed Feb 15, 2019)

Bradford, M., and C. Wood. 2004. A review of biological principles and methods involved in setting minimum population sizes and recovery objectives for the September 2004 drafts of the Cultus and Sakinaw Lake sockeye salmon and Interior Fraser coho salmon recovery plans. DFO Can. Sci. Advis. Sec. Res. Doc 2004/128. iv + 48.

Bratty, J. 1999. The winter ecology of juvenile Coho Salmon (*Oncorhynchus kisutch*) in interior British Columbia streams (M.Sc. Thesis). University of British Columbia, Vancouver, B.C.

Brown, G. W., and J. T. Krygier. 1970. Effects of Clear-Cutting on Stream Temperature. Water Resources Research 6:1133–1139.

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

Brown, T. G., and P. Winchell. 2004. Fish Community of Shuswap Lake's Foreshore. Can. Tech. Rep. Fish. Aquat. Sci. 2568. viii + 39 p.

Cai, W., S. Borlace, M. Lengaigne, P. Van Rensch, M. Collins, G. Vecchi, A. Timmermann, A. Santoso, M. J. Mcphaden, L. Wu, M. H. England, G. Wang, E. Guilyardi, and F.-F. Jin. 2014. Increasing frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change 4:111–116.

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

Carter, K. S. 2014. Striking a Balance: the Challenges of Using a Professional Reliance Model in Environmental Protection-British Columbia's Riparian Areas Regulation. BC Office of the Ombudsperson, Public Report No. 50. Victoria, BC.

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

Cavalli-Sforza, L. L., and A. W. F. Edwards. 1967. Phylogenetic analysis: models and estimation procedures. Evolution 32:550-570.

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

Chapman, D. W. 1962. Aggressive behaviour in juvenile Coho Salmon as a cause of emigration. Fisheries Research Board of Canada 19:1047–180.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117:1–21.

Chapman, D. W., and E. Knudsen. 1980. Channelization and Livestock Impacts on Salmonid Habitat and Biomass in Western Washington. Transactions of the American Fisheries Society 109:357–363.

Chittenden, C. M., R. J. Beamish, C. M. Neville, R. M. Sweeting, and R. S. McKinley. 2009. The Use of Acoustic Tags to Determine the Timing and Location of the Juvenile Coho Salmon Migration out of the Strait of Georgia, Canada. Transactions of the American Fisheries Society 138:1220–1225.

Chittenden, C. M., M. C. Melnychuk, D. W. Welch, and R. S. McKinley. 2010. An investigation into the poor survival of an endangered coho salmon population. PLoS ONE 5:3–12.

Coker, G. A., D. L. Ming, and N. E. Mandrak. 2010. Mitigation Guide for the Protection of Fishes and Fish Habitat to Accompany the Species at Risk Recovery Potential Assessments Conducted by Fisheries and Oceans Canada (DFO) in Central and Arctic Region. Version 1.0. Can. Manuscr. Rep. Fish. Aquat. Sci. 2904: vi + 40 p. (Accessed Dec 10, 2018)

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

Connors, B. M., M. Krkošek, J. Ford, and L. M. Dill. 2010. Coho salmon productivity in relation to salmon lice from infected prey and salmon farms. Journal of Applied Ecology 47:1372–1377.

Coronado, C., and R. Hilborn. 1998. Spatial and temporal factors affecting survival in coho salmon (*Oncorhynchus kisutch*) in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 55:2067–2077.

COSEWIC. 2012. Guidance for completing the Threats Classification and Assessment Calculator and Determining the number of ‘Locations’. 2012.

COSEWIC. 2016. COSEWIC assessment and status report on the coho salmon *Oncorhynchus kisutch* Interior Fraser population, in Canada. Committee on the Status of Endangered Wildlife in Canada. xi + 50 p.

Cruickshank, A. 2018. Untreated sewage pollutes water across the country.

D’Eon-Eggertson, F., N. K. Dulvy, and R. M. Peterman. 2015. Reliable Identification of Declining Populations in an Uncertain World. Conservation Letters 8:86–96.

Debruyn, A. M. H., M. G. Ikonomou, and F. A. P. C. Gobas. 2004. Magnification and toxicity of PCBs, PCDDs, and PCDFs in upriver-migrating pacific salmon. Environmental Science and Technology 38:6217–6224.

Decker, A. S., M. A. Hawkshaw, B. A. Patten, J. Sawada, and A. L. Jantz. 2014. Assessment of the Interior Fraser Coho Salmon (*Oncorhynchus kisutch*) Management Unit Relative to the 2006 Conservation Strategy Recovery Objectives. DFO Can. Sci. Advis. Sec. Res. Doc 2014/086. xi + 64 p.

Decker, A. S., and J. R. Irvine. 2013. Pre-COSEWIC Assessment of Interior Fraser Coho Salmon (*Oncorhynchus kisutch*). DFO Can. Sci. Advis. Sec. Res. Doc 121. x + 57 p.

Dextrase, A. J., and N. E. Mandrak. 2006. Impacts of alien invasive species on freshwater fauna at risk in Canada. Biological Invasions 8:13–24.

DFO. 1998a. Salmon watershed planning profiles for the Thompson Nicola habitat management area. Vancouver, BC.

DFO. 1998b. Salmon watershed planning profiels for the South Thompson - Shuswap habitat managment area. Vancouver, BC.

DFO. 2004a. Revised Framework for Evaluation of Scope for Harm under Section 73 of the Species at Risk Act. DFO Can. Sci. Advis. Sec. Stock Status Report 2004/048.

DFO. 2004b. A Framework for the Department of Fisheries and Oceans to address Permitting Conditions under Section 73 of SARA. Appendix 4 in: National Science Advisory Meeting on Section 73 Permits under the Species at Risk Act. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2004/005.

DFO. 2005a. A Framework for Developing Science Advice on Recovery Targets for Aquatic Species in the Context of the Species at Risk Act. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/054.

DFO. 2005b. Proceedings of the Meeting of the Science Working Group on the Precautionary Approach; October 20 and 21, 2005. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2005/027.

DFO. 2006. National Science: Habitat management workshop on allowable harm assessment for aquatic species with habitat related threats. DFO Can. Sci. Advis. Sec. Sci. Advis. Sec. Proceed. Ser. 2006/034.

DFO. 2011. A Complement to the 2005 Framework for Developing Science Advice on Recovery Targets in the context of the *Species at Risk Act*. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/061.

DFO. 2013a. A Biological Risk Management Framework for Enhancing Salmon in the Pacific Region. Fisheries and Oceans Canada, Pacific Region. Fs144-38/2013E-PDF

DFO. 2013b. Community Involvement Program Best Management Practices Guide. Fisheries and Oceans Canada, Pacific Region. Fs144-43/2013E-PDF

DFO. 2014a. Guidance on assessing threats, ecological risk and ecological impacts for species at risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013. (Erratum: Juin 2016

DFO. 2014b. Guidance for the Completion of Recovery Potential Assessments (RPA) for Aquatic Species at Risk. DFO Can.

DFO. 2015a. Wild Salmon Policy status assessment for conservation units of Interior Fraser River coho (*Oncorhynchus kisutch*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/022.

DFO. 2015b. Guidelines for the Identification of Residence and Preparation of a Residence Statement for Aquatic Species at Risk 33.

DFO. 2016. A Compilation of Operational and Planning Guidelines for the Salmonid Enhancement Program. Fisheries and Oceans Canada, Pacific Region.

DFO. 2018a. Piscine Orthoreovirus (PRV) and Heart and Skeletal Muscle Inflammation (HSMI).

DFO. 2018b. Framework for determination of Pacific Salmon Commission reference points for status determination and associated allowable exploitation rates for select Canadian Southern Coho Salmon management units. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/016.

DFO. 2018c. PST Southern Coho Reference Points and Exploitation Rate Caps. Engagement Process Discussion Paper.

DFO. 2018d. SEP Production Planning: A Framework.

DFO. 2019. Peer Review concludes Piscine Orthoreovirus transfer from Atlantic salmon farms poses minimal risk to wild Fraser River sockeye.

Dietrich, J. P., A. L. Van Gaest, S. A. Strickland, G. P. Hutchinson, A. B. Krupkin, and M. R. Arkoosh. 2014. Toxicity of PHOS-CHEK LC-95A and 259F fire retardants to ocean- and stream-type Chinook salmon and their potential to recover before seawater entry. Science of the Total Environment 490:610–621.

Diewert, R. E., D. A. Nagtegaal, and K. Hein. 2005. A comparison of the results of the 1998 Georgia Strait creel survey with an independent observer program. Can. Manuscr. Rep. Fish. Aquat. Sci. 2716. vii + 39 p.

Dill, L. M., and A. H. G. Fraser. 1984. Risk of Predation and the Feeding Behavior of Juvenile Coho Salmon (*Oncorhynchus kisutch*). Behavioral Ecology and Sociobiology 16:65–71.

English, K. K., R. E. Bailey, and D. Robichaud. 2007. Assessment of Chinook returns to the Fraser River watershed using run reconstruction techniques 1982-4. DFO Can. Sci. Advis. Sec. Res. Doc 2007/020. vi + 76 p.

Evans, G. T., and J. B. Dempson. 1986. Calculating the sensitivity of a salmonid population model. Canadian Journal of Fisheries and Aquatic Sciences 43:863–868.

Feist, B. E., E. R. Buhle, P. Arnold, J. W. Davis, and N. L. Scholz. 2011. Landscape ecotoxicology of coho salmon spawner mortality in urban streams. PLoS ONE 6.

Flagg, T. A. 2015. Balancing Conservation and Harvest Objectives: a Review of Considerations for the Management of Salmon Hatcheries in the U.S. Pacific Northwest. North American Journal of Aquaculture 77:367–376.

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

FLNRORD. 2016. Invasive yellow perch means no fishing on Windy Lake.

Foerster, R. E. 1955. The Pacific salmon (genus *Oncorhynchus*) of the Canadian Pacific Coast with particular reference to their occurrence in or near fresh water. International North Pacific Fisheries Commission Bulletin 1:1–56.

Folkes, M., B. Ionson, and J. R. Irvine. 2005. Scientific advice for input to the Allowable Harm Assessment for Interior Fraser Coho Salmon. Canadian Science Advisory Secretariat 2005/083. 51 p.

Foote, C. J., and G. S. Brown. 2011. Ecological relationship between freshwater sculpins (genus *Cottus*) and beach-spawning sockeye salmon (*Oncorhynchus nerka*) in Iliamna Lake, Alaska. Can. J. Fish. Aquat. Sci. 55:1524–1533.

Forrest, R.E., McAllister, M.K., Dorn, M.W., Martell, S.J.D., and Stanley, R.D. 2010. Hierarchical Bayesian estimation of recruitment parameters and reference points for Pacific rockfishes (Sebastes spp.) under alternative assumptions about the stock-recruit function. Can. J. Fish. Aquat. Sci. 67:1611–1634.

Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of Interdecadal Climate Variability on the Oceanic Ecosystems of the NE Pacific. Fisheries Oceanography 7:1–21.

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

Fulton, R. J. 1969. Glacial lake history, southern interior Plateau, British Columbia. Geological Survey of Canada, Department of Energy, Mines and Resources Paper 69.

FWCP. 2017. Bridge-Seton watershed action plan. The Fish & Wildlife Compensation Program Version 9.

Gallardo, B., M. Clavero, M. I. Sánchez, and M. Vilà. 2016. Global ecological impacts of invasive species in aquatic ecosystems. Global Change Biology 22:151–163.

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

Garette, C. L. 1980. Fraser River Estuary Study Water Quality: Toxic Organic Contaminants. Vancouver, BC.

Gibeau, P., B. M. Connors, and W. J. Palen. 2016. Run-of-River hydropower and salmonids: potential effects and perspective on future research. Canadian Journal of Fisheries and Aquatic Sciences 74:1135–1149.

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

Gordon, J., M. Arbeider, D. Scott, S. M. Wilson, and J. W. Moore. 2015. When the Tides Don’t Turn: Floodgates and Hypoxic Zones in the Lower Fraser River, British Columbia, Canada. Estuaries and Coasts 38:2337–2344.

Grant, S. C. H., B. L. MacDonald, T. E. Cone, C. A. Holt, A. Cass, E. J. Porszt, J. M. B. Hume, and L. Pon. 2011. Evaluation of Uncertainty in Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy Status using Abundance and Trends in Abundance Metrics. DFO Can. Sci. Advis. Sec. Res. Doc 2011/087. viii + 183 p.

Grant, S.C.H., and G. Pestal. 2012. Integrated biological status assessments under the Wild Salmon Policy using standardized metrics and expert judgement: Fraser River Sockeye salmon (*Oncorhynchus nerka*) case studies. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/106. v + 132 p.

Grant, W. S. 2012. Understanding the adaptive consequences of hatchery-wild interactions in Alaska salmon. Environmental Biology of Fishes 94:325–342.

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

Gregory, R. 1993. Effect of Turbidity on the Predator Avoidance Behaviour of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 50:241–246.

Gregory, R., and T. Northcote. 1993. Surface, plankton, and benthic foraging by juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in turbid laboritory conditions. Canadian Journal of Fisheries and Aquatic Sciences 50:233–240.

Gribanov, V. I. 1948. The Coho Salmon (*Oncorhynchus kisutch* Walbaum) – a biological sketch. Fisheries Research Board of Canada No. 370.

Groot C, and L. Margolis, editors. 1991. Pacific salmon life histories. University of British Columbia Press, University of British Columbia, Vancouver. xv + 564 pp.

Haddock, M. 2018. Professional reliance review: The final report of the review of professional reliance in natural resource decision-making. Victoria, BC.

Hamlet, A. F. 2011. Assessing water resources adaptive capacity to climate change impacts in the Pacific Northwest Region of North America. Hydrology and Earth System Sciences 15:1427–1443.

Harding, T., L. Jaremovic, and G. Kosakoski. 1994. Strategic review of fisheries resources for the North Thompson habitat management area. Vancouver, BC.

Hart, J. L. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada Bulletin 180.

Hartman, G. F., and T. G. Brown. 1988. Forestry-Fisheries Planning Considerations on Coastal Floodplains. The Forestry Chronicle 64:47–51.

Hartman, G. F., C. Groot, and T. G. Northcote. 2000. Science and management in sustainable salmonid fisheries: the ball is not in our court. Pages 31–50 *in* E. E. Knudsen and D. McDonald, editors. Sustainable fisheries management: Pacific salmon. CRC Press, New York, NY.

Healey, M. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon (*Oncorhynchus nerka*) and implications for management. Canadian Journal of Fisheries and Aquatic Sciences 68:718–737.

Heintz, R. A., S. D. Rice, A. C. Wertheimer, R. F. Bradshaw, F. P. Thrower, J. E. Joyce, and J. W. Short. 2000. Delayed effects on growth and marine survival of pink salmon *Oncorhynchus gorbuscha* after exposure to crude oil during embryonic development. Marine Ecology Progress Series 208:205–216.

Hill, N. P., A. E. McIntyre, R. Perry, and J. N. Lester. 1990. Behavior of chlorophenoxy herbicides during primary sedimentation. Journal of the Water Pollution Control Federation 57:60–67.

Holt, C. A., and M. J. Bradford. 2011. Evaluating Benchmarks of Population Status for Pacific Salmon. North American Journal of Fisheries Management 31:363–378.

Holt, C., B. Davis, D. Dobson, L. Godbout, W. Luedke, J. Tadey, and P. Van Will. 2018. Evaluating benchmarks of biological status for data-limited conservation units of Pacific salmon, focusing on chum salmon in southern BC. DFO Can. Sci. Advis. Sec. Res. Doc 2018/011. ix + 87 p.

Holtby, B. L., and K. A. Ciruna. 2007. Conservation Units for Pacific Salmon under the Wild Salmon Policy. DFO Can. Sci. Advis. Sec. Res. Doc 2007/070. viii +350 p.

Hyatt, K. D., D. J. McQueen, K. S. Shortreed, and D. P. Rankin. 2004. Sockeye salmon (*Oncorhynchus nerka*) nursery lake fertilization: Review and summary of results. Environmental Reviews 12:133–162.

Ianelli, J., K. K. Holsman, A. E. Punt, and K. Aydin. 2016. Multi-model inference for incorporating trophic and climate uncertainty into stock assessments. Deep Sea Research II 134:379–389.

IFCRT. 2006. Conservation Strategy for Coho Salmon (*Oncorhynchus kisutch*), Interior Fraser River Populations. Fisheries and Oceans Canada.

Irvine, J.R., R.E. Withler, M.J. Bradford, R.E. Bailey, S. Lehmann, K. Wilson, J. Candy, and W. Shaw. 2000. Stock status and genetics of interior Fraser Coho Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2000/125. 49 p.

Irvine, J.R., C.K. Parken, D.G. Chen, J. Candy, T. Ming, J. Supernault, W. Shaw, and R.E. Bailey. 2001. 2001 assessment of stock status for Coho Salmon from the interior Fraser River. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/083. 67 p.

IIrvine, J.R. 2002. COSEWIC status report on the coho salmon Oncorhynchus kisutch (Interior Fraser population) in Canada, in COSEWIC assessment and status report on the coho salmon Oncorhynchus kisutch (Interior Fraser population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-34 pp..

Irvine, J. R., and M. A. Fukuwaka. 2011. Pacific salmon abundance trends and climate change. ICES Journal of Marine Science 68:1122–1130.

IUCN. 2014. Guidelines for using the IUCN Red List Categories and Criteria. Version 11.

Kelly, B. C., M. G. Ikonomou, N. MacPherson, T. Sampson, D. A. Patterson, and C. Dubetz. 2011. Tissue residue concentrations of organohalogens and trace elements in adult Pacific salmon returning to the Fraser River, British Columbia, Canada. Environmental Toxicology and Chemistry 30:367–376.

Knudsen, E. E., and S. J. Dilley. 1987. Effects of Riprap Bank Reinforcement on Stream Salmonids in the Western United States. North American Journal of Fisheries Management 7:351–356.

Korman, J., J. Sawada, and M. J. Bradford. 2019. Evaluation framework for assessing potential Pacific Salmon Commission reference points for population status and associated allowable exploitation rates for Strait of Georgia and Fraser River Coho Salmon Management Units. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/001. vi + 86 p.

Labelle, M. 1992. Straying Patterns of Coho Salmon (*Oncorhynchus kisutch*) Stocks from Southeast Vancouver Island, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 49:1843–1855.

Lackey, R. T. 2005. Economic growth and salmon recovery: an irreconcilable conflict? Fisheries 30:30–32.

Lackey, R. T. 2006. Axioms of ecological policy. Fisheries 31:286–290.

LaCroix, J. J., A. C. Wertheimer, J. A. Orsi, M. V. Sturdevant, E. A. Fergusson, and N. A. Bond. 2009. A top-down survival mechanism during early marine residency explains coho salmon year-class strength in southeast Alaska. Deep-Sea Research Part II: Topical Studies in Oceanography 56:2560–2569.

Laetz, C. A., D. H. Baldwin, V. R. Hebert, J. D. Stark, and N. L. Scholz. 2013. Elevated temperatures increase the toxicity of pesticide mixtures to juvenile coho salmon. Aquatic Toxicology 146:38–44.

Langer, O., F. Hietkamp, and M. Farrell. 2000. Human population growth and the sustainability of urban salmonid streams in the Lower Fraser Valley. Pages 349–361 *in* E. E. Knudsen, C. R. Cleveland, R. Steward, D. D. MacDonald, J. E. Williams, and D. W. Reiser, editors. Sustainable Fisheries Management: Pacific Salmon. CRC Press, New York, NY.

Lawson, P. W., E. A. Logerwell, N. J. Mantua, R. C. Francis, and V. N. Agostini. 2004. Environmental factors influencing freshwater survival and smolt production in Pacific Northwest coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 61:360–373.

Letey, J. 2001. Causes and consequences of fire-induced soil water repellency. Hydrological Processes 15:2867–2875.

Levin, P. S., and N. Tolimieri. 2001. Differences in the impacts of dams on the dynamics of salmon populations. Animal Conservation 4:291–299.

Li, W., and A. Cruickshank. 2018, April 13. Sewage problems must be fixed if Vancouver wants to be a global role model, say advocates. StarMetro Vancouver. Vancouver, BC.

Liermann M.C., R. Sharma, and C.K. Parken. 2010. Using accessible watershed size to predict management parameters for Chinook salmon, *Oncorhynchus tshawytscha*, populations with little or no spawner-recruit data: a Bayesian hierarchical modelling approach. Fisheries Management and Ecology 17:40–51.

Macdonald, J. S., E. A. MacIsaac, and H. E. Herunter. 2003. The effect of variable-retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. Canadian Journal of Forest Research 33:1371–1382.

Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102:187–223.

Marty, G. D., D. B. Morrison, J. Bidulka, T. Joseph, and A. Siah. 2015. Piscine reovirus in wild and farmed salmonids in British Columbia, Canada: 1974-2013. Journal of Fish Diseases 38:713–728.

Massey, W. 2017. Assessing the impact of riprap bank stabilization on fish habitat: A study of Lowland and Appalachian streams in Southern Québec. Concordia University.

Mastrandrea, M. D., C. B. Field, T. F. Stocker, O. Edenhofer, K. L. Ebi, D. J. Frame, H. Held, E. Kriegler, K. J. Mach, P. R. Matschoss, G.-K. Plattner, G. W. Yohe, and F. W. Zwiers. 2010. Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties. Intergovernmental Panel on Climate Change (IPCC).

McIntyre, J. K., J. W. Davis, C. Hinman, K. H. Macneale, B. F. Anulacion, N. L. Scholz, and J. D. Stark. 2015. Soil bioretention protects juvenile salmon and their prey from the toxic impacts of urban stormwater runoff. Chemosphere 132:213–219.

McPhail, J. D. 2007. The freshwater fishes of British Columbia. The University of Alberta Press, Edmonton, AB.

McRae, C. J., K. D. Warren, and J. Mark Shrimpton. 2012. Spawning site selection in interior Fraser River coho salmon *Oncorhynchus kisutch*: An imperiled population of anadromous salmon from a snow-dominated watershed. Endangered Species Research 16:249–260.

Meador, J.P. 2014. Do chemically contaminated river estuaries in Puget Sound (Washington, USA) affect the survival rate of hatchery-reared Chinook salmon?. Canadian Journal of Fisheries and Aquatic Sciences, 71:162-180.

Meehan, W. R. 1992. Influences of forest and rangeland management on salmonid fishes and their habitat. American Fisheries Society Special Publication No. 19.

MEW. 2008. Fishery Regulation Assessment Model (FRAM) - An Overview for Coho and Chinook - v 3.0. Portland, Oregon.

Michielsens, C.G.J., and M.K. McAllister. (2004). A Bayesian hierarchical analysis of stock-recruit data: quantifying structural and parameter uncertainties. Canadian Journal of Fisheries and Aquatic Sciences. 61:1032-1047.

Miller, K. M., A. Teffer, S. Tucker, S. Li, A. D. Schulze, M. Trudel, F. Juanes, A. Tabata, K. H. Kaukinen, N. G. Ginther, T. J. Ming, S. J. Cooke, J. M. Hipfner, D. A. Patterson, and S. G. Hinch. 2014. Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines. Evolutionary Applications 7:812–855.

Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American Fishes During the Past Century. Fisheries 14:37–41.

Mitchell, D. G., P. M. Chapman, and T. J. Long. 1987. Acute toxicity of Roundup® and Rodeo® herbicides to rainbow trout, chinook, and coho salmon. Bulletin of Environmental Contamination and Toxicology 39:1028–1035.

MOE. 2015. Status of Invasive Species in B.C. State of Environment Reporting. British Columbia, Canada.

Moore, R. D., and S. M. Wondzell. 2005. Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review. Journal of the American Water Resources Association:763–784.

Morrison, J., M. C. Quick, and M. G. G. Foreman. 2002. Climate Change in the Fraser River Watershed : Flow and Temperature Climate change in the Fraser River watershed : flow and temperature projections. Journal of Hydrology 263:230–244.

Mote, P. W., E. A. Parson, A. F. Hamlet, W. S. Keeton, D. P. Lettenmaier, N. Mantua, E. L. Miles, D. W. Peterson, D. L. Peterson, R. Slaughter, and A. K. Snover. 2003. Preparing for climate change: the water, salmon, and forests of the Pacific Northwest. Climatic Change 61:45–88.

Murray, C. B., and M. L. Rosenau. 1989. Rearing of juvenile Chinook salmon in non-natal tributaries of the lower Fraser River, British Columbia. Transactions of the American Fisheries Society 118:284–289.

Myers, R. A., G. Mertz, and J. Bridson. 1997. Spatial scales of interannual recruitment variations of marine, anadromous, and freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences 54:1400–1407.

Myers, R.A. and Mertz, G., 1998. Reducing uncertainty in the biological basis of fisheries management by meta-analysis of data from many populations: a synthesis. Fisheries Research, 37:51-60.

Myers, R.A. 2001. Stock and recruitment: generalizations about maximum reproductive rate, density dependence, and variability using meta-analytic approaches. ICES Journal of Marine Science 58:937-951.

Naiman, R. J. R., T. J. T. Beechie, L. E. Benda, D. D. R. Berg, P. Bison, L. H. L. MacDonald, M. O'Connor, P. P. L. Olson, E. A. Steel, P. A. Bisson, L. H. L. MacDonald, M. D. O'Connor, P. P. L. Olson, and E. A. Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. Watershed management: Balancing Sustainability and Environmental Change:127–188.

Nandor, G.F., J.R. Longwill, and D.L. Webb. 2010. Overview of the coded wire tag program in the Greater Pacific Region of North America. In PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations—A compendium of new and recent science for use in informing technique and decision modalities. Edited by K.S. Wolf and J.S. O'Neal. Pacific Northwest Aquatic Monitoring Partnership Special Publication. 2010-002, pp. 5–46.

Nehlsen, W. 1997. Pacific salmon status and trends – a coastwide perspective. Pages 41–52 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific Salmon & their Ecosystems. Chapman & Hall, New York.

Nelson, T., R. Bocking, and M. Gaboury. 2001. Coldwater River Watershed Recovery Plan. LGL Limited.

Nickelson, T. 2003. The influence of hatchery coho salmon (*Oncorhynchus kisutch*) on the productivity of wild coho salmon poopulations in Oregon coastal basins. Canadian Journal of Fisheries and Aquatic Sciences 60:1050–1056.

Nielsen, J. L. 1992. Microhabitat-Specific Foraging Behavior, Diet, and Growth of Juvenile Coho Salmon. Transactions of the American Fisheries Society 121:617–634.

Nikl, L., B. Wernick, J. Van Geest, C. Hughes, and K. Mcmahen. 2016. Mount Polley Mine Embankment Breach: Overview of Aquatic Impacts and Rehabilitation. Proceedings Tailings and Mine Waste:845–856.

Noakes, D. J., R. J. Beamish, R. Sweeting, and J. King. 2000. Changing the balance: interactions between hatchery and wild Pacific Coho Salmon in the presence of regime shifts. North Pacific Anadromous Fisheries Commission Bulletin 2:155–163.

Northcote, T. G., and P. A. Larkin. 1989. The Fraser River: A major salmonine productive system. Pages 174–204 *in* D. Dodge, editor. Proceedings of the International Large River Symposium. Canadian Special Publications Fisheries Aquatic Science 106.

Olszynski, M. 2015. From 'badly wrong' to worse: an empirical analysis of Canada's new approach to fish habitat protection laws. Journal of Environmental Law and Practice 28:1–51.

Pacific Fishery Management Council (PFMC). 2008. Fisheries Regulation Assessment Model (FRAM) An Overview for Coho and Chinook v 3.0 . (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Patterson, D. A., K. A. Robinson, G. D. Raby, A. L. Bass, R. Houtman, S. G. Hinch, and S. J. Cooke. 2017. Guidance to Derive and Update Fishing-Related Incidental Mortality Rates for Pacific Salmon. DFO Can. Sci. Advis. Sec. Res. Doc 2017/011. vii + 56 p.

Pearcy, W. G. 1992. Ocean ecology of north Pacific salmonids. University of Washington Press, Seattle, WA.

Perry, T. D., and J. A. Jones. 2017. Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA. Ecohydrology 10:1–13.

Peterman, R. M. 1987. Review of the components of recruitment of Pacific salmon. Pages 417–429 *in* M. J. Dadswell, R. J. Klauda, C. M. Moffitt, R. L. Saunders, R. A. Rulifson, and J. E. Cooper, editors. Common Strategies of Anadromous and Catadromous Fishes. American Fisheries Society, Symposium 1, Bethesda, MD.

Peterson, N. P. 1982. Immigration of juvenile coho salmon (*Oncorhynchus kitsutch*) into riverine ponds. Canadian Journal of Fisheries and Aquatic Sciences 39:1308–1310.

Petticrew, E., N. Gantner, S. Albers, and P. Owens. 2015. Initial Impacts of the Mount Polley Tailings Pond Breach on Adjacent Aquatic Ecosystems. Geophysical Research Abstracts 17.

Pollard, W. R., G. F. Hartman, C. Groot, and P. Edgell. 1997. Field Identification of Coastal Juvenile Salmonids. Harbour Publishing, Madeira Park, BC.

Porszt, E. J., R. M. Peterman, N. K. Dulvy, A. B. Cooper, and J. R. Irvine. 2012. Reliability of Indicators of Decline in Abundance. Conservation Biology 26:894–904.

Porter, and Nelitz. 2009. A future outlook on the effects of climate change on coho salmon (*Oncorhynchus kisutch*) habitats in the Cariboo-Chilcotin. Vancouver, BC.

Prakash, A. 1962. Seasonal Changes in Feeding of Coho and Chinook (Spring) Salmon in Southern British Columbia Waters. Journal of the Fisheries Research Board of Canada 19:851–866.

Pritchard, A.L., and A.L. Tester. 1943. Notes on the food of coho salmon in British Columbia. Fish. Res. Board Can. Prog. Rep. Pac. Coast Stn. 55:10-11

Pritchard, A.L., and A.L. Tester. 1944. Food of spring and coho salmon in British Columbia. Bull. Fish. Res. Board Can. 65:23.

PSC. 2013a. Pacific Salmon Commission Joint Coho Technical Committee: 1986-2009 Periodic Report Revised. Pacific Salmon Comm. Tech. Rep. TCCOHO (13)-1

PSC. 2013b. Pacific Salmon Selective Fishery Evaluation Technical Committee: Review of 2011 mass marking and mark-selective fishery proposals. Pacific Salmon Comm. Tech. Rep. SFEC (13)-1

PSC. 2019. Treaty Between the Government of Canada and the Government of the United States of America Concerning Pacific Salmon. Pages 1–142 Pacific Salmon Commision. Canada, USA.

PSCCWTW. 2008. An action plan in response to Coded Wire Tag (CWT) Expert Panel Recommendations. Pacific Salmon Comm. Tech. Rep. No. 25: 170 p.

Quinn, T. P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research 18:29–44.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Raby, G. D., S. G. Hinch, D. A. Patterson, J. A. Hills, L. A. Thompson, and S. J. Cooke. 2015. Mechanisms to explain purse seine bycatch mortality of coho salmon. Ecological Applications 25:1757–1775.

Rahel, F. J., B. Bierwagen, and Y. Taniguchi. 2008. Managing aquatic species of conservation concern in the face of climate change and invasive species. Conservation Biology 22:551–561.

Ricker, W. E. 1989. History and present state of the odd-year pink salmon runs of the Fraser River Region (British Columbia, Canada).

Roed, M. A. 1995. Geology of the Kelowna area and the origin of the Okanagan Valley, British Columbia. Kelowna, BC.

Rood, K. M., and R. E. Hamilton. 1995. Hydrological and water use for salmon streams in the Thompson River watershed, British Columbia. Can. Manuscr. Rep. Fish. Aquatic. Sci 2297. 164 pp.

Rosenau, M., and M. Angelo. 2005. Conflicts Between Agriculture and Salmon in the Eastern Fraser Valley. Vancouver, BC.

Rosenau, M. L., and M. Angelo. 2003. Conflicts between People and Fish for Water: Two British Columbia Salmon and Steelhead Rearing Streams in Need of Flows. Page Pacific Fisheries Resource Conservation Council.

Rosenfeld, J., Porter, M. and Parkinson, E., 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences, 57:766-774.

Ross, P. S., C. J. Kennedy, L. K. Shelley, K. B. Tierney, D. A. Patterson, W. L. Fairchild, and R. W. Macdonald. 2013. The trouble with salmon: relating pollutant exposure to toxic effect in species with transformational life histories and lengthy migrations. Canadian Journal of Fisheries and Aquatic Sciences 70:1252–1264.

Runciman, J. B., and B. R. Leaf. 2009. A Review of Yellow Perch (*Perca flavascens*), Smallmouth bass (*Micropterus dolomieu*), Largemouth bass (*Micropterus salmoides*), Pumkinseed (*Lepomis gibbosus*), Walleye (*Sander vitreus*) and Northern Pike (*Esox lucius*). Canadian Manuscript Report of Fisheries and Aquatic Sciences 2882.

Salafsky, N., D. Salzer, A. J. Stattersfield, C. Hilton-Taylor, R. Neugarten, S. H. Butchart, B. Collen, N. Cox, L. L. Master, S. O'Connor, and D. Wilkie. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conservation Biology 22:897–911.

Salmon River Watershed Society. 2004. Salmon River Watershed Salmon Recovery Plan.

Sandahl, J. F., D. H. Baldwin, J. J. Jenkins, and N. L. Scholz. 2007. A sensory system at the interface between urban stormwater runoff and salmon survival. Environmental Science and Technology 41:2998–3004.

Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pacific Salmon life histories:395–446.

Sappal, R., N. MacDonald, M. Fast, D. Stevens, F. Kibenge, A. Siah, and C. Kamunde. 2014. Interactions of copper and thermal stress on mitochondrial bioenergetics in rainbow trout, *Oncorhynchus mykiss*. Aquatic Toxicology 157:10–20.

Schindler, D. E., X. Augerot, E. Fleishman, N. J. Mantua, B. Riddell, M. Ruckelshaus, J. Seeb, and M. Webster. 2008. Climate Change, Ecosystem Impacts, and Management for Pacific Salmon. Fisheries 33:502–506.

Scholz, N. L., M. S. Myers, S. G. McCarthy, J. S. Labenia, J. K. McIntyre, G. M. Ylitalo, L. D. Rhodes, C. A. Laetz, C. M. Stehr, B. L. French, B. McMillan, D. Wilson, L. Reed, K. D. Lynch, S. Damm, J. W. Davis, and T. K. Collier. 2011. Recurrent die-offs of adult coho salmon returning to spawn in Puget Sound lowland urban streams. PLoS ONE 6.

Schtickzelle, N., and T. P. Quinn. 2007. A metapopulation perspective for salmon and other anadromous fish. Fish and Fisheries 8:297–314.

Scott, D. C., M. Arbeider, J. Gordon, and J. W. Moore. 2016. Flood control structures in tidal creeks associated with reduction in nursery potential for native fishes and creation of hotspots for invasive species. Canadian Journal of Fisheries and Aquatic Sciences 73:1138–1148.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184. x + 966 p.

Sharma, R., and R. Hilborn. 2011. Empirical relationships between watershed characteristics and coho salmon (*Oncorhynchus kisutch*) smolt abundance in 14 western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:1453–1463.

Sherwood, C. R., D. A. Jay, R. Bradford Harvey, P. Hamilton, and C. A. Simenstad. 1990. Historical changes in the Columbia River Estuary : Progress in Oceanography, v. 25, p. 299-357.

Shrimpton, J. M., K. D. Warren, N. L. Todd, C. J. Mcrae, G. J. Glova, K. H. Telmer, and A. D. Clarke. 2014. Freshwater movement patterns by juvenile Pacific salmon *Oncorhynchus* spp. before they migrate to the ocean: Oh the places you'll go! Journal of Fish Biology 85:987–1004.

Simpson, K., M. Chamberlain, J. Fagan, R. Tanasichuk, and D. Dobson. 2004. Forecast for southern and central British Columbia Coho Salmon in 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/135. viii + 69 p.

Small, M. P., T. D. Beacham, R. E. Withler, and R. J. Nelson. 1998a. Discriminating coho salmon (*Oncorhynchus kisutch*) populations within the Fraser River, British Columbia, using microsatellite DNA markers. Molecular Ecology 7:141–155.

Small, M. P., R. E. Withler, and T. D. Beacham. 1998b. Population structure and stock identification of British Columbia coho salmon, *Oncorhynchus kisutch*, based on microsatellite DNA variation. Fishery Bulletin 96:843–858.

Smith, O. R. 1940. Placer mining silt and its relation to salmon and trout on the Pacific coast. Transactions of the American Fisheries Society 69:225–230.

Solazzi, M. F., T. E. Nickelson, S. L. Johnson, and J. D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 57:906–914.

Solomon, K. R., J. A. Carr, L. H. Du Preez, J. P. Giesy, R. J. Kendall, E. E. Smith, and G. J. Van Der Kraak. 2008. Effects of atrazine on fish, amphibians, and aquatic reptiles: A critical review. Critical Reviews in Toxicology 38:721–772.

Springer, J., R. Ludwig, and S. Kienzle. 2015. Impacts of Forest Fires and Climate Variability on the Hydrology of an Alpine Medium Sized Catchment in the Canadian Rocky Mountains. Hydrology 2:23–47.

Stanford, J. A., and J. V Ward. 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. Journal of the North American Benthological Society 12:48–60.

Steen, R. P., and T. P. Quinn. 1999. Egg burial depth by sockeye salmon (*Oncorhynchus nerka*): implications for survival of embryos and natural selection on female body size. Canadian Journal of Zoology 77:836–841.

Swales, S., and C. D. Levings. 1989. Role of Off-Channel Ponds in the Life Cycle of Coho Salmon (*Oncorhynchus kisutch*) and Other Juvenile Salmonids in the Coldwater River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:232–242.

Sweeting, R. M., and R. J. Beamish. 2009. A Comparison of the Diets of Hatchery and Wild Coho Salmon (*Oncorhynchus kisutch*) in the Strait of Georgia from 1997–2007. North Pacific Anadromous Fish Commission Bulletin:255–264.

Sweeting, R. M., R. J. Beamish, D. J. Noakes, and C. Neville. 2003. Replacement of Wild Coho Salmon by Hatchery-Reared Coho Salmon in the Strait of Georgia over the Past Three Decades. North American Journal of Fisheries Management 23:492–502.

Taylor, E. B., and J. D. McPhail. 1985a. Variation in Burst and Prolonged Swimming Performance Among British Columbia Populations of Coho Salmon, *Oncorhynchus kisutch*. Canadian Journal of Fisheries and Aquatic Sciences 42:2029–2033.

Taylor, E. B., and J. D. McPhail. 1985b. Variation in body morphology among British Columbia populations of coho salmon, *Oncorhynchus kisutch*. Canadian Journal of Fisheries and Aquatic Sciences 42:2020–2028.

Thornton, E. 2015. Competition between non-native brook trout and coho salmon in the Elwha River, WA during dam removal. University of Washington.

Tovey, C. P., M. J. Bradford, and L. Herborg. 2008. Biological risk assessment for Smallmouth bass (*Micropterus dolomieu*) and Largemouth bass (*Micropterus salmoides*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc 2008/075. vii + 39 p.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18–30.

Tschaplinski, P. J., and R. G. Pike. 2017. Carnation Creek watershed experiment—long-term responses of coho salmon populations to historic forest practices. Ecohydrology 10.

Van Bruggen, A. H. C., M. M. He, K. Shin, V. Mai, K. C. Jeong, M. R. Finckh, and J. G. Morris. 2018. Environmental and health effects of the herbicide glyphosate. Science of the Total Environment 616–617:255–268.

Vélez-Espino, L. A., R. E. Mcnicol, G. Brown, and C. K. Parken. 2010. Correction factors for numbers of released Chinook salmon reported in commercial troll logbooks: expanding the applications of the observer program. Can. Manuscr. Rep. Fish. Aquat. Sci. 2898. vii + 48 p.

Walters, C., K. English, J. Korman, and R. Hilborn. 2018. The managed decline of British Columbia's commercial salmon fishery. Marine Policy. 101. 10.1016/j.marpol.2018.12.014.

Walthers, L. C., and J. C. Never. 2000. Water temperature monitoring in selected Thompson River tributaries, BC, 1996: implication of measured temperatures for anadromous salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 2306. viii + 69 p.

Wan, M. T., J.-N. Kuo, and J. Pasternak. 2005. Residues of endosulfan and other selected organochlorine pesticides in farm areas of the Lower Fraser Valley, British Columbia, Canada. Journal of Environment Quality 34:11186–93.

Wang, X., D. K. Thompson, G. A. Marshall, C. Tymstra, R. Carr, and M. D. Flannigan. 2015. Increasing frequency of extreme fire weather in Canada with climate change. Climatic Change 130:573–586.

Waples, R. S. 1991. Genetic interactions Between Hatchery and Wild Salmonids: Lessons from the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 48:124–133.

Waples, R. S. 1999. Dispelling Some Myths about Hatcheries. Fisheries 24:12–21.

Warren, K. D. 2010. Factors influencing habitat use by juvenile interior Fraser Coho. University of Northern British Columbia.

Weitkamp, L. 2012. Marine Distributions of Coho and Chinook Salmon Inferred from Coded Wire Tag Recoveries. Advances in Fish Tagging and Marking Technology. American Fisheries Society Symposium 76:191–214.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status Review of Coho Salmon from Washington, Oregon and California. NOAA Technical Memorandum NMFS-NWFSC-24:viii + 258.

Weitkamp, L., and K. Neely. 2002. Coho salmon (*Oncorhynchus kisutch*) ocean migration patterns: insight from marine coded-wire tag recoveries. Canadian Journal of Fisheries and Aquatic Sciences 59:1100–1115.

Welch, D. W., E. L. Rechisky, M. C. Melnychuk, A. D. Porter, C. J. Walters, S. Clements, B. J. Clemens, R. S. McKinley, and C. Schreck. 2008. Survival of migrating salmon smolts in large rivers with and without dams. PLoS Biology 6:2101–2108.

Winkler, R., D. Spittlehouse, and S. Boon. 2017. Streamflow response to clear-cut logging on British Columbia's Okanagan Plateau. Ecohydrology 10:1–15.

Wise, M. P., G. D. Moore, and D. F. VanDine. 2004. Landslide risk case studies in forest development planning and operations. B.C. Min. For., Res. Br. Victoria, B.C. Land Manage. Handb. No. 56.

Withler, R. E., M. J. Bradford, D. M. Willis, and C. Holt. 2018. Genetically Based Targets for Enhanced Contributions to Canadian Pacific Chinook Salmon Populations. DFO Can. Sci. Advis. Sec. Res. Doc 2018/019. xii + 88 p.

APPENDIX 1. ASSOCIATED DOCUMENTS TO INTERIOR FRASER COHO SALMON

List of Documents that discuss the status, decline, or recovery of Interior Fraser Coho Salmon. Ordered chronologically.

Irvine, J.R., R.E. Bailey, M.J. Bradford, R.K. Kadowaki, and W.S. Shaw. 1999a. 1999 Assessment of Thompson River/Upper Fraser River Coho Salmon. DFO Canadian Stock Assessment Secretariat Research Document 99/128. 40 p.

Irvine, J.R., K. Wilson, B. Rosenberger, and R. Cook. 1999b. Stock assessment of Thompson River/Upper Fraser River coho salmon. Canadian Stock Assessment Secretariat Research Document 99/28. 66 p.

DFO. 1999. Upper Fraser/Thompson coho salmon. DFO Science Stock Status Report D6-08.

Bradford, M. J., and J. R. Irvine. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Canadian Journal of Fisheries and Aquatic Sciences. 57. 13–16.

Irvine, J.R., R.E. Withler, M.J. Bradford, R.E. Bailey, S. Lehmann, K. Wilson, J. Candy, and W. Shaw. 2000. Stock status and genetics of interior Fraser coho salmon. Canadian Stock Assessment Secretariat Research Document 2000/125. 49 p.

Irvine, J., C.K. Parken, D.G. Chen, J. Candy, T. Ming, J. Supernault, W. Shaw, and R.E. Bailey. 2001. 2001 stock status assessment of coho salmon from the interior Fraser River. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/083. 68 p.

Chen, D.G., J.R. Irvine, and A. Cass. 2002. Incorporating allee effects in fish stock-recruitment models and applications for determining reference points. Canadian Journal of Fisheries and Aquatic Sciences 59:242-249.

Irvine, J. R. 2002. COSEWIC status report on the coho salmon *Oncorhynchus kisutch* (Interior Fraser population) in Canada, *in* COSEWIC assessment and status report of the coho salmon *Oncorhynchus kisutch* (Interior Fraser population) in Canada. Page Committee on the Status of Endangered Wildlife in Canada.

Bradford, M., and C. Wood. 2004. A review of biological principles and methods involved in setting minimum population sizes and recovery objectives for the September 2004 drafts of the Cultus and Sakinaw Lake sockeye salmon and Interior Fraser coho salmon recovery plans. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/128. iv + 48.

Folkes, M., B. Ionson, and J. R. Irvine. 2005. Scientific advice for input to the Allowable Harm Assessment for Interior Fraser Coho Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/083. 51 p.

IFCRT. 2006. Conservation Strategy for Coho Salmon (*Oncorhynchus kisutch*), Interior Fraser River Populations. Fisheries and Oceans Canada.

Decker, A. S., and J. R. Irvine. 2013. Pre-COSEWIC Assessment of Interior Fraser Coho Salmon (*Oncorhynchus kisutch*). DFO Can. Sci. Advis. Sec. Res. Doc. 121. x + 57 p.

Decker, A. S., M. A. Hawkshaw, B. A. Patten, J. Sawada, and A. L. Jantz. 2014. Assessment of the Interior Fraser Coho Salmon (*Oncorhynchus kisutch*) Management Unit Relative to the 2006 Conservation Strategy Recovery Objectives. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/086. xi + 64 p.

Parken, C., L. Ritchie, B. Macdonald, R. Bailey, P. Nicklin, M. Bradford, H. Ward, P. Welch, I. Boyce, A. Tompkins, M. Maxwell, K. Beach, J. Irvine, S. Grant, P. Van Will, D. Willis, M. Staley, M. Walsh, J. Sawada, J. Scroggie, and E. McGrath. (*Unpublished*). Wild Salmon Policy Biological Status Assessment for Conservation Units of Interior Fraser River Coho Salmon (*Oncorhynchus kisutch*).

COSEWIC. 2016. COSEWIC assessment and status report on the coho salmon *Oncorhynchus kisutch* Interior Fraser population, in Canada. Committee on the Status of Endangered Wildlife in Canada. xi + 50 p.

Korman, J., J. Sawada, and M. J. Bradford. 2019. Evaluation framework for assessing potential Pacific Salmon Commission reference points for population status and associated allowable exploitation rates for Strait of Georgia and Fraser River Coho Salmon Management Units. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/001. vi + 86 p.

APPENDIX 2. GROUPS AND ORGANIZATIONS ASSOCIATED WITH INTERIOR FRASER COHO SALMON

Active organizations involved in habitat stewardship initiatives within the range of Interior Fraser River Coho Salmon.

Stewardship Groups – NGOs

Baker Creek Enhancement Society
Bonaparte River Roundtable
Cariboo Chilcotin Conservation Society
Ducks Unlimited
Eagle River Watershed Roundtable
Kingfisher Environmental Interpretive Centre
Nicola River Community Watershed Roundtable
Penny Hatchery/Community of Dome Creek
Regional District of Fraser-Fort George
Rivershed Society of BC
Salmon River Watershed Roundtable
Spruce City Wildlife Association
Upper Fraser Headwaters Alliance
Williams Lake Naturalists

Partnerships

Fraser Basin Council – Thompson Region
City of Kamloops
BC Cattleman’s Association

First Nations (including Nations and Bands that work with DFO and/or community roundtables on fish habitat stewardship initiatives)

Adams Lake Indian Band
Bridge River Indian Band
Northern Shuswap Tribal Council
Carrier Sekani Tribal Council
Cayoose Indian Band
Coldwater Indian Band
L’heidl Tenneh Indian Band
Lillooet Indian Band
Lillooet Tribal Council
Lower Nicola Indian Band
Nazko First Nation
Nicola Watershed Fisheries Stewardship Authority
North Thompson Indian Band
Secwepemc Fisheries Commission
Spallumcheen Indian Band
Tŝilhqot’in National Government
Upper Fraser Fisheries Conservation Alliance
Upper Nicola Indian Band
Xeni Gwet’in First Nation

APPENDIX 3. HISTORY OF MANAGEMENT OF INTERIOR FRASER COHO SALMON

Chronology of management actions taken by Fisheries and Oceans Canada to conserve IFC.

Fraser River Commercial Fisheries

Early 1980s	No directed net fisheries for Coho Salmon since the early 1980s, although Coho Salmon were harvested incidentally in Sockeye, Pink, and Chum Salmon fisheries.
1980s	Commercial net fisheries were closed from approximately the first week of September until the end of October to protect Steelhead Salmon, Harrison River Chinook Salmon, and Coho Salmon
1997	A minimum mesh size of 158 mm (6 ¼”) was instituted in the gill net fishery to minimize Coho Salmon and reduce Steelhead Salmon by- catches.
1998	Non-retention of Coho Salmon was implemented. Revival boxes were required. Moving window closures (i.e. variable start and end dates of closures in specified sections of the Fraser River mainstem to coincide with the presence of migrating Coho) from September through October were implemented to avoid Interior Fraser River Coho Salmon. Daylight gill net fishing only.
1999-2005	Measures implemented in 1998 were maintained with some modification to the timing of the moving window closure as the Coho Salmon migration period was more precisely defined. In 2005 the window closure below Mission was September 6 to October 7.
2006-2018	Similar management measures continue to be implemented annually.

Fraser River In-River Coho Salmon Recreational Fishery

Early 1980s	The bag limit was reduced from four to two Coho Salmon per day. 1997 Non-retention of Coho Salmon and a 10-day angling closure (October 21-31) was implemented.
1998	A ban on fishing for salmon when IFC were migrating in the river was implemented, as was a ban on retention of any Coho Salmon throughout the year. Barbless hooks became a coast wide requirement.
2001	Retention of two hatchery Coho Salmon (i.e. those without an adipose fin) was allowed following the IFC migration window closure (i.e. the period with no fishing for salmon). Night fishing for salmon was prohibited in the Fraser River from September 1 to December 31. Retention of wild Coho Salmon continued to be prohibited at all times.
2002-2005	Retention of two hatchery (adipose fin absent) Coho Salmon per day was allowed from mid-October to December 31. The ban on salmon fishing during the IFC migration period (September to mid-October) was continued during even numbered years (i.e. when Pink Salmon were not present). In 2003 and 2005, fishing for Pink Salmon was allowed during the IFC migration window; however, all fishing with bait was prohibited.
2006-2013	Retention of two hatchery marked Coho Salmon per day was allowed from early-mid October to December 31. Non-retention of wild Coho Salmon is maintained. Coho Salmon migration window closure from early September to early-mid

October in tidal and non-tidal Fraser River downstream of Alexandra Bridge. The use of bait is prohibited during Coho Salmon window closures.

Fraser River First Nations Fishery

1989-1990	Fishing times were restricted in October from three to one day/week from Mission to North Bend to reduce Steelhead Salmon catch.
1992	Coho Salmon allocations were established for the first time; 6,500 fish for native bands below Sawmill Creek. Allocations were not set for bands above Sawmill Creek. Below Sawmill Creek, the fishery was closed from mid-August to mid-October and opened for restricted times beginning in late October, for one week below the Port Mann Bridge and for three weeks from the Port Mann Bridge to Sawmill Creek.
1993	Coho Salmon allocations for bands below Sawmill Creek were 17,000 and approximately 10,000 Coho Salmon for bands above Sawmill Creek. As in 1992, fishing times were restricted in order to meet allocations.
1994	Coho Salmon allocations for bands below Sawmill Creek were 2,500 and 3,800 for bands above Sawmill Creek. The fishery below Sawmill Creek was closed for three weeks in October and opened for restricted periods in late October and early November.
1995	Coho Salmon allocations for bands below Sawmill Creek were 2,500 and 3,500 for bands above Sawmill Creek. The fishery below Sawmill Creek was closed for five weeks from mid/late September to mid/late October, but was opened for restricted periods for three weeks beginning in late October and then closed.
1996	No Coho Salmon allocation was established for bands below Sawmill Creek. The combined allocation for all bands above Sawmill Creek was 395. The fishery below Sawmill Creek was closed from early September until late October, and opened for restricted periods each week in November. Above Sawmill Creek, the fishery was closed from Sawmill Creek to Deadman Creek after September 28. In addition, a number of Shuswap bands voluntarily agreed to zero Coho allocations.
1997-1 998	No fishing for salmon when IFC were migrating through the river was authorized. Voluntary non-retention of all Coho Salmon was requested. The use of selective fishing techniques was encouraged. Some opportunities for Coho Salmon harvest were provided in those terminal areas with hatchery surpluses.
1999-2005	First Nations directed fishing for Coho Salmon has been restricted. Harvest of Pink and Chum salmon has been authorized, by selective means only (beach seine, etc.), in the Fraser River during the IFC migration period with the requirement that wild Coho Salmon are to be released. First Nations fishers are authorized to retain Coho Salmon mortalities during gill net and set net fisheries after the migration window for IFC has passed. All live wild Coho Salmon are to be released unharmed.
2007	First Nations were authorized 8” mesh drift fishery targeting Chinook, Pink, Chum Salmon and hatchery marked Coho Salmon for 6 days during the window closure to test the selectivity of 8” mesh on Coho Salmon. This was not authorized in subsequent years.

2006-2018	First Nations directed fishing for Coho Salmon has been restricted. During non-Pink Salmon years the Coho Salmon migration window closure is in place from early September to early mid-October with the exception of 2007 which is noted above. Terminal fisheries in locations where there are fishways and fences is permitted in some years and systems, primarily allowing retention of hatchery marked Coho Salmon.

South Coast Net Fisheries – Johnstone Strait (Area 12/13) & Juan de Fuca Strait (Area 20)

1977	Permanent area closures of Parson Bay, Goletas Channel, and Mainland Inlets (except for Pink Salmon surplus) in Johnstone Strait (Area 12/13), and gill net mesh size restriction.
1978	Permanent closure of Loughborough Inlet and Phillips Arm.
1979	Reduced fishing season (initial fishery openings delayed until July). Permanent closure of Bute Inlet (except for Chum Salmon surplus fisheries).
1980	A coast-wide (except Area 20) gear restriction limiting the maximum seine depth to 52m.
1981	Area 12/13 closed to all commercial fishing April 14 – June 17. Permanent closure of Deepwater Bay. Area closure known as the “Ribbon Boundary corridor” from Hanson Island (Area 12) to Discovery Passage (Area 13). Juan de Fuca seine fishery limited to a minimum 100 mm mesh size.
1982	Permanent closures of lower Knights Inlet and Growler Cove. Seine net gear restricted to so-called “fall bunts” implemented earlier in season.
1983	Reduced fishing times (number of days) in Areas 12 and 13 under the “Clockwork Chum Strategy”.
1985-1986	Compliance boundary set at the 30 fathom contour in the Area 20 seine fishery. By-catch monitoring program ran from 1986- 1990 in Areas 12 and 13.
1987	By-catch monitoring program ran from 1987-1990 in Area 20.
1989	Further reduction in fishing time in Areas 12 and 13.
1994	Reduced fishing times in Area 20. Coho Salmon catch ceiling established with a monitoring program. Gear restrictions in Areas 12 and 13. Voluntary non-retention of Coho Salmon.
1995	Reduced fishing times in Area 20, no gill net fishing. Coho Salmon catch ceiling established with a monitoring program. Reduced fishing areas and gear restrictions in Areas 12 and 13. Voluntary non-retention of Coho Salmon.
1996	Reduced fishing times in Area 20. Reduced fishing areas and gear restrictions in Areas 12 and 13. Voluntary non-retention of Coho Salmon in the seine fishery.
1997	In-season monitoring and closures in Coho Salmon sensitive areas. Mandatory non-retention of Coho Salmon in all seine fisheries. Implementation of Coho Salmon mortality ceilings for each net fishery. “Yellow Line/Red Line” fishing zone strategy for managing Coho Salmon mortality rates. Sorting and live release of Coho Salmon in seine fisheries in Juan de Fuca and Johnstone straits. Voluntary non-retention of Coho Salmon for gill net fisheries.

1998	No fishing for salmon in red zones (i.e. areas where Coho Salmon were prevalent). Mandatory non-retention of Coho Salmon in all fisheries. Functioning revival boxes required on all vessels actively fishing. Gill net length and set time shortened in some fisheries to reduce Coho Salmon encounters and mortalities in yellow zones. Daylight only fisheries implemented. Seine net fishers required to brail and sort catch with Coho Salmon released back to the water with least possible harm.
1999	Per the pre-season fishing plan, the chum assessment fishery in the third week of September was cancelled to protect returning Coho Salmon. Non-retention and non-possession of all Coho Salmon and mandatory revival tanks were license requirements. All Coho Salmon were to be released to the water with the least possible harm. Specific areas and times where Coho Salmon were expected to be present were closed.
2000-2001	No fishing for Coho Salmon and no possession of Coho Salmon in all Special Management Zones (i.e. those areas and times where or when Thompson River Coho Salmon or other Coho Salmon populations of concern are prevalent). Fishing for other salmon species within Special Management Zones has been permitted in some areas. Special Management Zones include: West Coast of Vancouver Island (Areas 23 to 27 and 123 to 127) from May 1 to September 30; Johnstone Strait and the mainland inlets (Areas 11-13) from May 1 to September 30; Strait of Georgia (Areas 14-18 and Area 28) May 1 to September 20; Southern Vancouver Island (Areas 19-21 and 121) May 1 to September 30; and vicinity of Fraser River (Area 29) August 1 to October 15. All Coho Salmon were to be released to the water with the least possible harm. Mandatory brailing and wet sorting of seine catch was required in some areas. Revival tanks were required.
2002-2018	Conservation measures for the protection of IFC were similar to those implemented in 2001. In 2014, fisheries targeting the dominant Sockeye Salmon return had high numbers of Coho Salmon bycatch. Although no directed Coho Salmon fisheries exist, some years allow retention of Coho Salmon during the Chum Salmon fishery (e.g. in Area E, 2016-2018).

South Coast Troll

The west coast Vancouver Island (WCVI) commercial troll fishery has undergone major changes to address Coho Salmon conservation concerns. In summary, the WCVI troll fishery has gone from a 1.75M Coho Salmon catch in 1985, to 1.3M in 1993, to 1.0M in 1996, to no troll fishery in 1997. Management actions since 1990 include:

1990-1993	The “red line/green line” management strategy was implemented to extend the season and minimize “shaker” mortality. Selected conservation areas were closed. In-season catch monitoring via the hail-in program was started. Non-retention of Coho Salmon after the catch ceiling was reached was required.
1994	Continued the red line/green line management strategy to extend the season and minimize shaker mortality. Selected conservation areas were closed. Monitored Coho Salmon catch via the hail-in program. Reduced fishing time. Non-retention of Coho Salmon after catch ceiling was reached was required.

1995	Selected conservation areas were closed. Time and area closures implemented to reduce exploitation rate. Monitored in-season catches via the hail-in program. Reduced fishing time. Non-retention of Coho Salmon after catch ceiling was reached was required.
1996	Closure of Chinook Salmon sensitive areas off WCVI to address conservation concerns for WCVI Chinook Salmon stocks. This action also minimized access by the fishery to other salmon species including Coho Salmon. Area closures used to reduce exploitation rate on Coho Salmon. In-season catch monitoring program via a hail-in program. Managers used data to conduct in- season alterations to time and area openings. Non-retention of Coho Salmon after catch ceiling reached was required.
1997	No directed commercial fishery for Coho Salmon in southern B.C. Non-retention and non-possession of Coho Salmon in the WCVI troll fishery. Closure of Coho Salmon sensitive areas off WCVI to address conservation concerns for southern BC Coho Salmon. This action minimized access by the fishery to other salmon species. In-season catch monitoring program along with a hail-in program to record catches. Managers used data to conduct in-season changes to time and area openings to minimize Coho Salmon by-catch.
1998-1999	No fishing for salmon in red zones. Non-retention of all Coho Salmon. A functioning revival box was required on all boats actively fishing. All Coho Salmon were to be released to the water with the least possible harm. Barbless hooks became a requirement.
2000-2001	No fishing for Coho Salmon and no possession of Coho Salmon in all Special Management Zones (i.e. those areas and times where or when Thompson River Coho or other Coho stocks of concern are prevalent). Fishing for other salmon species within Special Management Zones permitted in some areas. Special Management Zones included: West Coast of Vancouver Island (Areas 23 to 27 and 123 to 127) from May 1 to September 30; Johnstone Strait and the mainland inlets (Areas 11-13) from May 1 to September 30; Strait of Georgia (Areas 14-18 and Area 28) May 1 to September 20; Southern Vancouver Island (Areas 19-21 and 121) May 1 to September 30; and vicinity of Fraser River (Area 29) August 1 to October 15. All Coho Salmon were to be released to the water with the least possible harm. Mandatory brailing and wet sorting of seine catches were required in some areas. Revival tanks were required.
2002-2005	Conservation measures for the protection of IFC were similar to those implemented in 2001.
2003 -2018	Selective hatchery mark Coho Salmon fisheries became more prevalent. They expanded to include most of DFO’s South Coast recreational fishing areas. In 2005 retention of marked Coho Salmon was allowed in some commercial South Coast fisheries (e.g. WCVI Chinook Salmon fisheries after mid-Sept). Modifications that allow for the retention of hatchery and wild Coho Salmon in WCVI inlets inside the surfline have also been implemented in the later years

Marine Recreational Fishery

1995	Reduction of the daily catch and possession limit in Juan de Fuca Strait to two and four Coho Salmon from four and eight Coho Salmon.

1997	Effective July 2, reduction of the daily catch and possession limit for Coho Salmon to two and four fish from four and eight on the west coast of Vancouver Island from Port Renfrew to Cape Scott. Effective July 2, the daily bag and possession limits in the Strait of Georgia remained at the previously reduced levels of two and four Coho Salmon. Non retention of Coho Salmon was instituted in the mainstem Fraser River, including the mouth, tidal, and non-tidal waters. Effective July 2, existing area closures in the majority of Vancouver Island, Sunshine Coast, and southern mainland stream areas were re-instituted. In-season area closures were expanded in a number of areas to increase the amount of protected area for Coho Salmon.
1998	No fishing for Coho Salmon in red zones. Non-retention of Coho Salmon in all South Coast fishery areas was required. Barbless hooks required when salmon fishing. The only Coho Salmon retention fisheries allowed were in terminal areas where hatchery fish (adipose fin absent) were available for harvest.
2000	Some expansion of areas open to selective fishing for hatchery marked fish. Non-retention of wild Coho Salmon maintained.
2001	Some retention of wild Coho Salmon was allowed in areas where local populations were in abundance and where IFC were not present (i.e. north end of Johnstone Strait and some WCVI inlets).
2002	Selective hatchery marked Coho Salmon fishing opportunities were expanded from those provided in 2001. Selective hatchery mark Coho Salmon fisheries in the recreational fishery were allowed in marine areas targeting on Coho Salmon which have a hatchery mark (i.e. adipose fin absent). These fisheries also occurred in some terminal areas adjacent to hatchery facilities where there was a surplus of Coho Salmon. These measures were subject to in- season changes if additional conservation concerns developed. Effective August 1 the retention of two hatchery marked Coho Salmon was permitted in Queen Charlotte Sound and Strait (Area 11 and 12), Johnstone Strait and Strait of Georgia (Areas 23-19, 28 and 29 excluding the tidal waters of the Fraser River, the West Coast Vancouver Island (Areas 23-27 and 123-127), and Juan de Fuca Strait (Area 20). Fraser River tidal and non-tidal waters downstream of Alexandra Bridge (Area 29) daylight only selective hatchery marked Coho Salmon fishery were permitted during October.
2003 -2018	Selective hatchery mark Coho Salmon fisheries became more prevalent. They expanded to include most of DFO's South Coast recreational fishing areas.

APPENDIX 4. DATA

Table 19. Historical data series from DFO Fraser Stock Assessment Data for Interior Fraser Coho. Values under each Conservation Unit represent the total escapement for a given return year. Total escapement includes both hatchery-origin and natural-origin spawners after any removals by the Salmon Enhancement Program (for hatchery brood stock) or from First Nations' Food, Social, and Ceremonial harvest. Exploitation rates (ER) are an estimate of the exploitation rate of adipose present (unclipped) fish. Smolt-to-adult survival (STAS) corresponds to the age 3_2 fish from the given return year.

Return Year	Brood Year	Fraser Canyon	Middle Fraser	Lower Thompson	North Thompson	South Thompson	ER	STAS
1984	1981	14925	4726	6808	41396	16946	0.681	0.049
1985	1982	10084	5189	4365	17986	18294	0.681	0.049
1986	1983	11403	1876	4002	30692	16884	0.657	0.049
1987	1984	13187	3529	5923	31262	23281	0.537	0.036
1988	1985	16060	7940	6059	35039	27552	0.712	0.055
1989	1986	11206	6673	6519	24556	18610	0.645	0.056
1990	1987	7110	2593	8172	17551	10320	0.737	0.061
1991	1988	4674	2962	7017	12243	4612	0.677	0.04
1992	1989	7506	6193	7976	15929	13565	0.815	0.048
1993	1990	2406	7624	15556	6552	2534	0.876	0.038
1994	1991	4348	1912	10389	14898	4918	0.433	0.035
1995	1992	3519	2367	5345	12463	4055	0.562	0.01
1996	1993	1473	1183	1854	5923	1373	0.835	0.024
1997	1994	1964	1665	7521	8518	1420	0.405	0.011
1998	1995	5460	4851	2165	9786	5155	0.07	0.012

Return Year	Brood Year	Fraser Canyon	Middle Fraser	Lower Thompson	North Thompson	South Thompson	ER	STAS
1999	1996	4096	1652	3992	10696	3137	0.09	0.02
2000	1997	2719	3920	4739	8054	3307	0.036	0.032
2001	1998	5971	6162	9522	27238	13063	0.071	0.041
2002	1999	3817	4170	16053	22083	10544	0.078	0.034
2003	2000	4552	3809	2933	7211	3422	0.129	0.013
2004	2001	5872	4760	4304	10661	15850	0.131	0.012
2005	2002	2269	2189	2614	4518	2302	0.13	0.008
2006	2003	1605	1301	1082	3670	2003	0.094	0.003
2007	2004	2739	9958	10169	24500	12345	0.112	0.012
2008	2005	1138	1464	3800	3849	6688	0.098	0.006
2009	2006	2308	2306	4768	9631	3821	0.115	0.011
2010	2007	2227	4689	12217	12159	8946	0.104	0.01
2011	2008	3189	3920	7289	8803	4771	0.126	0.014
2012	2009	5134	7126	11559	20058	13303	0.112	0.013
2013	2010	5398	11625	11887	16271	13132	0.162	0.01
2014	2011	1048	3081	7447	5244	2270	0.318	0.021
2015	2012	352	1354	5182	3178	2392	0.178	0.008
2016	2013	1160	13600	13527	16914	15023	0.073	0.014
2017	2014	1657	4001	4353	11908	2831	0.097	0.011

Table 20. Data since brood year 1998 from DFO Stock Assessment. Spawners are equivalent to the total escapement of hatchery- and natural-origin fish in the given brood year (i.e. that return year). Total pre-fishery recruits are the sum of Age 3 and Age 4 recruits. Smolt-to-adult survival (STAS) and exploitation rate (ER) are separated by Age 3 and 4 due to their difference in which year they resided in the ocean. Hatchery-origin (%) is the estimated percentage of Spawners from that CU that were returns from a hatchery. This table was used in modelling analysis.

Conservation Unit	CUid	Brood Year	Spawners	Total Recruits	Age 3 Recruits	Age 4 Recruits	STAS Age 3	STAS Age 4	ER Age 3	ER Age 4	Hatchery-origin (%)
Middle_Fraser	1	1998	4851	5562	5361	201	0.041	0.034	0.071	0.078	0
Middle_Fraser	1	1999	1652	4475	4175	300	0.034	0.013	0.078	0.129	3
Middle_Fraser	1	2000	3920	4409	4074	335	0.013	0.012	0.129	0.131	2
Middle_Fraser	1	2001	6162	5385	5145	240	0.012	0.008	0.131	0.13	6
Middle_Fraser	1	2002	4170	2390	2276	114	0.008	0.003	0.13	0.094	3
Middle_Fraser	1	2003	3809	2395	1322	1073	0.003	0.012	0.094	0.112	0
Middle_Fraser	1	2004	4760	10335	10141	194	0.012	0.006	0.112	0.098	0
Middle_Fraser	1	2005	2189	1788	1429	359	0.006	0.011	0.098	0.115	0
Middle_Fraser	1	2006	1301	2481	2247	234	0.011	0.01	0.115	0.104	0
Middle_Fraser	1	2007	9958	5525	5000	525	0.01	0.014	0.104	0.126	0
Middle_Fraser	1	2008	1464	4536	3963	573	0.014	0.013	0.126	0.112	0
Middle_Fraser	1	2009	2306	8604	7452	1152	0.013	0.01	0.112	0.162	0
Middle_Fraser	1	2010	4689	13202	12710	492	0.01	0.021	0.162	0.318	0
Middle_Fraser	1	2011	3920	4349	4026	323	0.021	0.008	0.318	0.178	0
Middle_Fraser	1	2012	7126	5058	1324	3734	0.008	0.014	0.178	0.073	0
Middle_Fraser	1	2013	11625	12033	11007	1026	0.014	0.011	0.073	0.097	0
Fraser_Canyon	2	1998	5460	5711	5521	190	0.041	0.034	0.071	0.078	0
Fraser_Canyon	2	1999	4096	4310	3951	359	0.034	0.013	0.078	0.129	0
Fraser_Canyon	2	2000	2719	5281	4868	413	0.013	0.012	0.129	0.131	0
Fraser_Canyon	2	2001	5971	6595	6347	248	0.012	0.008	0.131	0.13	0
Fraser_Canyon	2	2002	3817	2501	2360	141	0.008	0.003	0.13	0.094	0
Fraser_Canyon	2	2003	4552	1926	1631	295	0.003	0.012	0.094	0.112	0
Fraser_Canyon	2	2004	5872	2940	2789	151	0.012	0.006	0.112	0.098	0
Fraser_Canyon	2	2005	2269	1471	1111	360	0.006	0.011	0.098	0.115	0
Fraser_Canyon	2	2006	1605	2359	2248	111	0.011	0.01	0.115	0.104	0
Fraser_Canyon	2	2007	2739	2801	2374	427	0.01	0.014	0.104	0.126	0

Conservation Unit	CUid	Brood Year	Spawners	Total Recruits	Age 3 Recruits	Age 4 Recruits	STAS Age 3	STAS Age 4	ER Age 3	ER Age 4	Hatchery-origin (%)
Fraser_Canyon	2	2008	1138	3659	3220	439	0.014	0.013	0.126	0.112	0
Fraser_Canyon	2	2009	2308	5877	5342	535	0.013	0.01	0.112	0.162	0
Fraser_Canyon	2	2010	2227	6075	5908	167	0.01	0.021	0.162	0.318	0
Fraser_Canyon	2	2011	3189	1454	1370	84	0.021	0.008	0.318	0.178	0
Fraser_Canyon	2	2012	5134	661	344	317	0.008	0.014	0.178	0.073	0
Fraser_Canyon	2	2013	5398	1359	934	425	0.014	0.011	0.073	0.097	0
Lower_Thompson	3	1998	2165	4814	4434	380	0.041	0.034	0.071	0.078	78
Lower_Thompson	3	1999	3992	4648	4437	211	0.034	0.013	0.078	0.129	67
Lower_Thompson	3	2000	4739	2402	2196	206	0.013	0.012	0.129	0.131	48
Lower_Thompson	3	2001	9522	2650	2440	210	0.012	0.008	0.131	0.13	49
Lower_Thompson	3	2002	16053	2105	1999	106	0.008	0.003	0.13	0.094	73
Lower_Thompson	3	2003	2933	2139	1231	908	0.003	0.012	0.094	0.112	36
Lower_Thompson	3	2004	4304	9229	8581	648	0.012	0.006	0.112	0.098	49
Lower_Thompson	3	2005	2614	3369	2786	583	0.006	0.011	0.098	0.115	33
Lower_Thompson	3	2006	1082	5059	3643	1416	0.011	0.01	0.115	0.104	1
Lower_Thompson	3	2007	10169	11375	10951	424	0.01	0.014	0.104	0.126	18
Lower_Thompson	3	2008	3800	7502	6950	552	0.014	0.013	0.126	0.112	21
Lower_Thompson	3	2009	4768	11725	11313	412	0.013	0.01	0.112	0.162	24
Lower_Thompson	3	2010	12217	14188	13199	989	0.01	0.021	0.162	0.318	11
Lower_Thompson	3	2011	7289	9159	8096	1063	0.021	0.008	0.318	0.178	13
Lower_Thompson	3	2012	11559	12019	4358	7661	0.008	0.014	0.178	0.073	10
Lower_Thompson	3	2013	11887	7646	5931	1715	0.014	0.011	0.073	0.097	5
North_Thompson	4	1998	9786	22576	22576	0	0.041	0.034	0.071	0.078	5
North_Thompson	4	1999	10696	21136	20933	203	0.034	0.013	0.078	0.129	2
North_Thompson	4	2000	8054	7757	6987	770	0.013	0.012	0.129	0.131	32
North_Thompson	4	2001	27238	11119	10871	248	0.012	0.008	0.131	0.13	11
North_Thompson	4	2002	22083	4777	4471	306	0.008	0.003	0.13	0.094	14
North_Thompson	4	2003	7211	6686	3546	3140	0.003	0.012	0.094	0.112	16
North_Thompson	4	2004	10661	24542	24074	468	0.012	0.006	0.112	0.098	7

Conservation Unit	CUid	Brood Year	Spawners	Total Recruits	Age 3 Recruits	Age 4 Recruits	STAS Age 3	STAS Age 4	ER Age 3	ER Age 4	Hatchery-origin (%)
North_Thompson	4	2005	4518	4889	3454	1435	0.006	0.011	0.098	0.115	13
North_Thompson	4	2006	3670	9042	8968	74	0.011	0.01	0.115	0.104	8
North_Thompson	4	2007	24500	13806	13075	731	0.01	0.014	0.104	0.126	2
North_Thompson	4	2008	3849	9630	8886	744	0.014	0.013	0.126	0.112	10
North_Thompson	4	2009	9631	22737	21173	1564	0.013	0.01	0.112	0.162	6
North_Thompson	4	2010	12159	18107	17267	840	0.01	0.021	0.162	0.318	4
North_Thompson	4	2011	8803	7640	6873	767	0.021	0.008	0.318	0.178	5
North_Thompson	4	2012	20058	5754	3147	2607	0.008	0.014	0.178	0.073	3
North_Thompson	4	2013	16271	16496	15542	954	0.014	0.011	0.073	0.097	4
South_Thompson	5	1998	5155	12420	11909	511	0.041	0.034	0.071	0.078	1
South_Thompson	5	1999	3137	10139	9872	267	0.034	0.013	0.078	0.129	2
South_Thompson	5	2000	3307	4110	3241	869	0.013	0.012	0.129	0.131	2
South_Thompson	5	2001	13063	17091	16733	358	0.012	0.008	0.131	0.13	14
South_Thompson	5	2002	10544	2406	2233	173	0.008	0.003	0.13	0.094	12
South_Thompson	5	2003	3422	2473	2003	470	0.003	0.012	0.094	0.112	12
South_Thompson	5	2004	15850	13443	12850	593	0.012	0.006	0.112	0.098	5
South_Thompson	5	2005	2302	6619	6036	583	0.006	0.011	0.098	0.115	10
South_Thompson	5	2006	2003	4241	3644	597	0.011	0.01	0.115	0.104	2
South_Thompson	5	2007	12345	10021	9019	1002	0.01	0.014	0.104	0.126	5
South_Thompson	5	2008	6688	5366	3458	1908	0.014	0.013	0.126	0.112	13
South_Thompson	5	2009	3821	14218	12730	1488	0.013	0.01	0.112	0.162	5
South_Thompson	5	2010	8946	12776	12526	250	0.01	0.021	0.162	0.318	6
South_Thompson	5	2011	4771	2525	2048	477	0.021	0.008	0.318	0.178	22
South_Thompson	5	2012	13303	6067	1955	4112	0.008	0.014	0.178	0.073	4
South_Thompson	5	2013	13132	11933	10876	1057	0.014	0.011	0.073	0.097	11

APPENDIX 5. DATA TREATMENT

Text modified from unpublished report: Parken et al.[1]. Wild Salmon Policy Biological Status Assessment for Conservation Units of Interior Fraser River Coho Salmon (*Oncorhynchus kisutch*).

Data sources and Treatment

IFC spawner assessments have changed over the years based on management priorities and available resources, both in terms of the number of systems surveyed and the extent of coverage. Though IFC spawner estimates exist for a few systems prior to 1975, the accuracy and precision of those estimates are not understood, therefore data from that period have been omitted from this assessment. Between 1975 and 1997, more effort was expended to estimate IFC escapement in the North and South Thompson CUs. Survey coverage was extended in 1984 to include several key tributaries of the Lower Thompson CU, as well as the Seton and Bridge tributaries of the Middle Fraser CU. Surveys were mainly conducted by Fisheries Officers and hatchery staff; however, the repeatability, and accuracy of these estimates remain poorly understood.

Beginning in 1998, coverage within all CUs increased both for the number of systems assessed and for the extent of coverage within previously assessed systems. Coverage was increased to include the Nahatlatch River (Fraser Canyon CU) and Quesnel watershed in the Middle Fraser CU; in 1999, the Chilko watershed was added (Middle Fraser CU). In addition, more robust methods were employed that fall into either high precision or medium precision escapement estimates (Figure 25). High precision methods that result in absolute abundance estimates are from mark-recapture projects and fence counts. Medium precision estimates that result in relative abundance are from Area-Under-the-Curve methodologies or peak count expansions based on paired assessments using high precision methods and visual surveys.

Recently, escapement estimates for 1975 to 1997 were revised (IFCRT 2006). Revisions were based on calibration studies where paired assessments were conducted between 1998 and 2000. The calibration approach was described in detail in the Conservation Strategy for Coho Salmon, Interior River Populations (IFCRT 2006).

In 2014, Parken et al.[1] reviewed spawner estimates from return years 1998 to 2013 to ensure that data were generated appropriately from field survey information, and to ensure that all estimates were classified appropriately using the NuSEDS data quality standards. For the purposes of assessing data completeness, and infilling missing data values to provide consistent time series of information, all escapement estimates of a Type-5 or lower quality were excluded from further analyses. Type-5 and lower quality data are deemed unsuitable for quantitative analysis. They can be derived from a single site survey or when part of the known spawning areas was not surveyed.

Missing spawner data were common in the IFC data set, and an infilling algorithm was used to generate estimates for missing data. Prior to infilling for missing values, the site data were reviewed for completeness and sites were retained for analysis if they had Type-4 or better data quality for at least 50% of years between the CU data series start year and 2013. This was the same approach used for WSP assessments for Southern BC Chinook Salmon (Brown et al. 2014[7]) and Fraser River Sockeye Salmon (Grant and Pestal 2012; DFO 2013b)-though a different algorithm was used for the cyclic Sockeye CUs. Infilling of missing escapement values by year was completed by CU using the methods outlined in English et al. (2007).

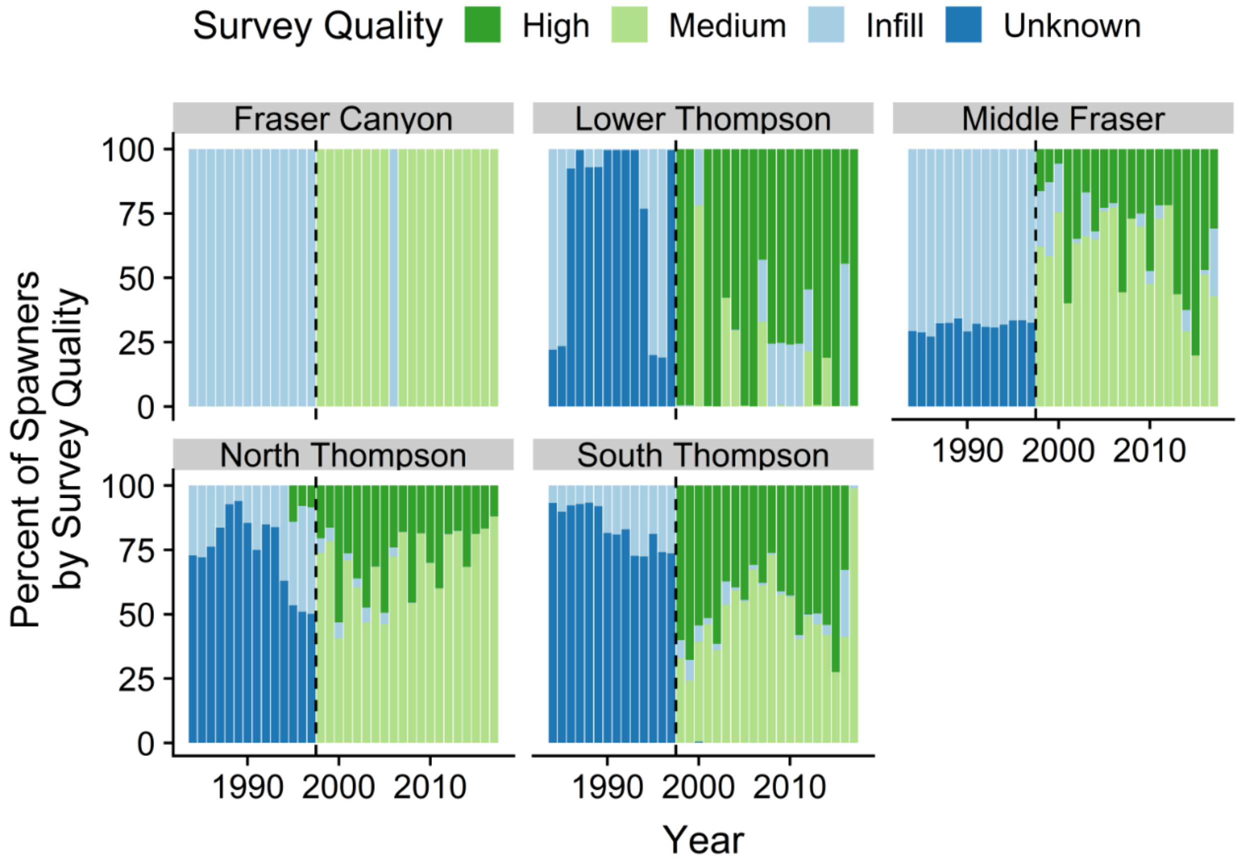

Figure 25. Percentage of spawners by survey quality across CUs. High survey quality = absolute abundance. Medium survey quality = relative abundance. Infill = abundance was infilled during data preparation steps. Unknown survey qualities only occur before 1998 (denoted by the black dashed line).

Age Data

Since 1998, 6,259 adults from spawning sites have been sampled for scales and the scales were analyzed by the Pacific Biological Station aging lab. Scale samples were collected from all CUs; however very few samples were from the Fraser Canyon and Middle Fraser CUs. In virtually all previous stock assessments on IFC, all adults were assumed to be age- 3, however the scale analysis revealed approximately 10% (at the time of the WSP assessment, updated and is now 12%) of the samples were age-4. The scale patterns indicate these individuals spent two summers rearing in freshwater and the pattern on the freshwater portion of the scale is

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[7] Brown, G., M.E. Theiss, G. Pestal, C.A. Holt, and B. Patten. 2014. 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. (document in preparation)

similar to the pattern observed for other stocks where age-4 Coho are more common (e.g. North Coast, D. Gillespie, DFO Aging Lab, pers. comm.). Because very few (n = 3) age samples were available for the Fraser Canyon CU, age composition was based on samples collected from all the CUs.

Exploitation Rate Data

Exploitation rates (ER) on IFC have been estimated using four different approaches since 1975 (Decker et al. 2014). During return years 1975 to 1985, ER was estimated using the arithmetic average ER for return years 1986 to 1996 due to a lack of information to directly reconstruct annual estimates of ER (Irvine et al. 2001). From 1986 through 1997, catch and escapement sampling programs collected coded-wire-tag (CWT) data to estimate exploitation rates and ocean distribution patterns (Simpson et al. 2004). While some CWT programs have continued, issues resulting from mark-selective fisheries, low smolt-adult survival rates, and low sampling rates in fisheries contributed to changes in the methods afterward.

From 1998 to 2000 genetic samples were collected annually in most retention, non-retention and mark-selective fisheries where IFC were presumed to be encountered. Genetic stock identification (GSI) was used to determine the proportion of IFC fishing mortalities in US, Canadian marine and Fraser River fisheries (Irvine et al. 2001; Simpson et al. 2004). Since 2001, fisheries impacts on IFC were estimated by three models; the Fisheries Regulation Assessment Model (FRAM), the Canadian Spreadsheet Model (CSM) and the Fraser River Decay Model. These models were used to estimate exploitation in the U.S. marine, Canadian marine and the Fraser River fisheries respectively.

Pacific Salmon Treaty (PST) Coho fisheries and U.S. (including Alaska) fishery impacts are estimated annually using the Coho FRAM. The Coho FRAM is a deterministic model used for both pre-season fishery planning and post-season estimation of escapements and ER. Coho FRAM is essentially an accounting tool that evaluates 246 stocks coast wide (marked and unmarked) in 198 fisheries over five time periods. The FRAM is founded on a base period constructed from stock-specific ocean distributions by fishery and time period (January to June, July, August, September, and October to December) developed from CWT recoveries in coast-wide fisheries between 1986 and 1992. Annual exploitation rates are determined using past Coho encounters from the base period scaled to current stock abundances and catch. The FRAM is the only model that assumes release, drop-off and natural mortality. Neither the CSM nor the Fraser River Decay Models represent drop-off or natural mortality. A complete description of the Coho FRAM model can be found at MEW (2008) and PFMC (2008).

Canadian marine exploitation rates were estimated using the CSM. The CSM scales average exploitation rate from a base period (1987-1997) by the amount of fishing effort expended in the current year (Simpson et al. 2004). The base period had significant recreational and commercial Coho fisheries to represent most spatial-temporal strata. The CWT data were mainly from the Eagle and Salmon rivers.

There are several important assumptions used by the FRAM and CSM. The largest uncertainty in the FRAM and CSM ER estimates is due to the assumption that current and base period (16-28 years ago for FRAM and 17-27 years ago for CSM) effort and exploitation rates are linearly related. This assumption may be violated by observed changes to the yearly distribution of Coho between the Strait of Georgia and the west coast of Vancouver Island (WCVI). The FRAM base period years generally represent an inside (Salish Sea) Coho distribution. It assumes fishing gear, target species, effort and distribution patterns are relatively stable between the base and the current period. Fisheries that intercept Coho have changed substantially since the base period; in the past, they were directed at Coho Salmon whereas in recent years Coho

Salmon were mainly intercepted as by-catch in fisheries targeting other species. There have also been several shifts in the spatial-temporal distribution of fishing effort in the WCVI sport and troll fisheries due to restrictions designed to protect WCVI-origin Chinook Salmon. Since 1996, Chinook retention has been restricted or entirely prohibited in many WCVI inlets and inshore areas (a.k.a. conservation corridor), and this has shifted recreational fishing effort to WCVI terminal areas with abundant hatchery Chinook or to offshore areas. These fine scale changes in recreational effort distribution are not represented in the CSM. Another change in recreational fishing effort is the increasing popularity of fishing for Pacific Halibut (*Hippolglossus stenolepis*) since the base period, and this has also contributed to a shift in fishing effort distribution to WCVI offshore areas and difficulty representing the variation in Coho Salmon fishing effort.

Canadian in-river (below Hells Gate on the Fraser River) ER was estimated using the Decay Model which sums estimates of total daily Coho mortalities, including release mortality (using gear-specific release mortality rates), for each fishery, multiplied by the modeled proportion of IFC present in the daily catch (Simpson et al. 2004). Modeled declines over time in the proportion of IFC present in the daily catch (‘decay model’) and the parameters of this decay are derived from an empirical fit of a Bayesian model to GSI samples collected from a tangle net that operated in the Fraser River near New Westminster from 1997-1999 (Irvine et al. 2000; Simpson et al. 2004). Standard error of this fit was used to capture the uncertainty of the estimates. In-river drop-off mortality and unauthorized catch are not represented in the model. The model assumes the stock composition ratio is stationary among years and among fisheries from the mouth of the Fraser River to Hells Gate despite major spawning populations leaving the Fraser River at the Pitt, Chilliwack and Harrison rivers which are located upstream of New Westminster. Other sources of uncertainty that were not represented in the model include error in the catch estimates, release mortality estimates, and fishing gear selectivity (Simpson et al. 2004; PSC 2013a).

The reliability of IFC ER estimates from 1998 onward is uncertain for several reasons. Recently, the absence of significant directed fisheries on Coho Salmon has also meant that monitoring of fishing effort has declined, thus there is increased uncertainty in recent estimates of fishing effort (all models) and an increased reliance on fishery scalars provided by fishery managers. With the implementation of mark-selective fisheries, fishery mortalities on unmarked (wild and natural) stocks can no longer be directly estimated and this potentially introduces a new bias: underestimation of the harvest of wild stocks and unknown sources of mortality associated with the non-retention of unmarked fish. Finally, release mortality rates for Coho in commercial and recreational fisheries are based on data from only a few studies and are also highly uncertain (PSC 2013a).

The IFC ER series was recently reported by Decker et al. (2014) through return year 2012. Exploitation rate estimates for 1975-2003 are summarized in Simpson et al. (2004). FRAM-based ER for 1986-2009 are summarized by the PSC Joint Coho Technical Committee (PSC-JCohoTC 2013). Canadian ER for 2010-2013 were provided by DFO South Coast and Fraser Areas. Though the FRAM model has been reviewed by Coho Salmon experts on the PSC Coho Technical Committee, no IFC ER model has undergone a formal peer review process such as CSAS. However, these are the best estimates currently available, and have been used to make inferences about fishing impacts on IFC in recent CSAS assessments (Decker et al. 2014; Decker and Irvine 2013; Irvine et al. 2001; Simpson et al. 2004; Folkes et al. 2005).

Hatchery Contribution Data

The number of first generation hatchery-origin spawners must be estimated for each CU in order to estimate the number of natural-origin spawners. Natural-origin spawner estimates are needed for two purposes. First, they are necessary to estimate the natural-origin adult recruitment using the ER for unmarked IFC, and to subsequently estimate abundance-based benchmarks using stock-recruitment analysis. Second, they are needed to generate several statistics that are compared WSP benchmarks for metrics of abundance, trends and distribution.

To determine the naturally produced total returns and escapements, it was necessary to estimate the hatchery-origin contributions to the total returns by following a consistent framework for all CUs over the time series. Releases of hatchery-origin juveniles have occurred from a variety of enhancement strategies and facilities including releases of unfed and fed fry, as well as yearling smolts since 1982 and 1984 respectively. In many, but not all cases, enhanced releases were marked to identify their enhanced-origin and facilitate assessment. Enhancement production data were downloaded from the Regional Mark Processing Center in August 2014.

The spawning escapement of enhanced-origin fish was estimated by multiplying the estimated Enhanced Contribution (EC) by the total spawner abundance. The EC is the fraction of the total return (includes hatchery removals) that originated from enhancement activities (RetH,i). The hatchery return was estimated from survival rates (Surv), for the life stages between release and adult, and exploitation rates (ER) for adipose clipped or unclipped fish depending on the fishery regime. Survival rates were estimated using mark recovery data for CWT release stages and data from the Mark Recovery Program (MRP) database. The MRP operates by utilizing CWTs that are inserted into known numbers of hatchery-origin fish that are adipose fin clipped prior to their release to provide hatchery-specific marks (Nandor et al. 2010). Since 1984, CWT indicator stock studies have occurred at Coldwater, Salmon and Eagle rivers. Data are also available for Lemieux, Louis and Dunn creeks for many but not all years. Less intensive CWT studies were conducted at Deadman River, and Fennel and Spius creeks. Marked and unmarked juvenile releases without any corresponding adult assessments have also occurred at several IFC locations.

The methodology used to estimate smolt- or fry-adult survival rates within a river or creek (deme) is consistent throughout the time series. Where the data are available, deme-specific smolt or fry survival rates are calculated by dividing the estimated CWTs in catch and escapement by the total CWT smolt or fry released. Specifically, fish were pooled among tag codes and the survival rate was calculated for a deme-brood year combination. During the fishery regime with mark selective fisheries, the return of unmarked hatchery fish was estimated from the survival rate for marked fish ($\mathrm{Surv}_{L,M,i}$), the ER for unmarked fish ($\mathrm{ER}_{M,i}$) and the number of hatchery fish released ($\mathrm{Rel}_{L,M,i}$) for release stage *L*, mark status *M*, and brood year *i*.

$$\text{(1)} \qquad \mathrm{Ret}_{H,L,i} = \mathrm{Rel}_{L,M,i} * \mathrm{Surv}_{L,M,i} * (1\text{-}\mathrm{ER}_{M,i})$$

Because the quality and amount of data for smolt- or fry-adult survival rates varied considerably throughout the time series, a set of decision rules was developed to create a transparent and repeatable approach for the analysis.

MU survival rate was used—it was the arithmetic average of the CU-brood year survival rates.

CWT data exists for several other systems that were not used because of insufficient or incomplete CWT sampling where marked fish were likely to return. In addition, some survival data were excluded because of fish health issues or when releases happened at non-representative releases sites. Survival data were excluded when there was evidence of poor record keeping and inaccurate estimates of the number of CWTs released. Lastly, two-year-old Coho Salmon (jacks) were omitted as the objective was to represent adult spawner abundance (jack Coho abundance cannot be reliably estimated and is essentially undetectable and extremely rare for IFC).

Unassociated hatchery fry and smolt releases occurred at a few locations prior to the start of the IFC CWT program when the first CWTs were applied to fry in 1982 and smolts in 1984. The smolt-adult survival rate for this time frame (1979-1983) was calculated by averaging the MU survival rates from the first three years of smolt CWT application. The fry-adult survival rate used during the similar time frame (1979-1981) prior to the first fry CWT application was calculated by multiplying the smolt MU survival rate by the CU fry-smolt survival rate conversion factor.

The natural spawner abundance was estimated by multiplying the total spawner abundance by the natural contribution (1-EC), and the EC was the fraction of the total return that was enhanced-origin.

Hatchery-based Smolt-to-Adult Marine Survival Rate Index

An index of wild smolt production was back-calculated by brood year using the age-specific adult recruitment estimates and the smolt-adult survival, measured from IFC hatchery-origin fish, for Ocean Entry Year t-1. This is an index because wild Coho smolts have higher survival than hatchery-origin smolts on average, thus the index likely overestimates true natural wild smolt abundance. Previous IFC assessments (Folkes et al. 2005; Decker and Irvine 2013) used smolt-adult survival measured at Strait of Georgia wild indicator stocks, however we found that the IFC MU index explained a higher proportion of the variation in adult recruitment than wild indicator stock data from the Strait of Georgia MU (i.e. Salmon River, lower Fraser). Thus, the IFC MU series was used because it appears to better represent the variation in recruitment caused by trends in smolt-adult survival.

APPENDIX 6. ACCESSIBLE AND USABLE STREAM HABITAT

Table 21. Total, accessible, and useable stream distances in the Interior Fraser Watershed broken down by Conservation Unit (CU), River Mainstem, and their Tributaries. Note that these data are likely an underestimate of total useable habitat. Each CU is blocked into either a grey or white set of rows. The methods to calculate these data are also unknown (UK) but no better alternative is available.

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
Fraser Canyon	Nahatlatch River		85.9	85.9	85.9
	Kwoiek Cr.		31.4	7.0	7.0
Middle Fraser	Bridge River		154.5	40.7	40.7
		Yalakom River	59.6	59.6	59.6
	Seton River		2.1	2.1	2.1
		Cayoosh Cr	64.7	1.3	1.3
	Portage Creek		2.9	2.9	2.9
		Spider	10.8	2.1	2.1
		Whitecap	16.3	1.0	1.0
	Gates Cr		16.1	16.1	16.1
		Haylemore Cr	19.9	5.0	5.0
	Stein River		63.3	42.0	42.0
	Baker Cr.		113.6	47.0	47.0
	Blackwater R (West Rd.)		218.0	218.0	UK
		Baezaeko R.	138.0	50.0	
		Clisbako R.	100.1	7.0	
		Coglistiko R.	69.4	14.0	
		Euchiniko R.	44.5	44.5	44.5
		Nataniko R.	39.8	39.8	39.8
		Nazko R.	125.4	45.7	45.7
	Chilcotin R.		319.3	279.0	UK
		Brittany Cr	48.4		

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
		Chilcotin R. (upper)	UK		
		Chilko R	89.0	89.0	35
		Clusko Cr	59.9		
		Minton Cr	34.8	34.8	34.8
		Taseko R	131.7	116.0	
	Cottonwood R. (swift)		160.6	160.6	160.6
		Ahbau Cr	73.9	37.0	0.1
		John-Boyd Cr.	18.8	16.0	13.2
		Little Swift R.	28.7	28.7	28.7
		Sovereign Cr.	24.9	24.9	24.9
		Victoria Cr.	53.7	53.7	53.7
	Hawks Cr.		54.9	54.9	54.9
	Hixon Cr		24.3	2.4	2.4
		Government Cr	25.3	7.6	7.6
	Mackin Cr.		69.4	8.4	8.4
	Meldrum Cr.		42.6	12.7	12.7
	Narcosli Cr.		100.7	45.0	45.0
		Twan Creek	53.7	7.3	7.3
	Nechako R.		284.8		UK
		Chilako R.	219.4		
	Quesnel R.		109.6	109.6	UK
		Beaver Cr	55.8	20.0	20.0
		Bill Miner	14.0		
		Bluelead Cr	16.6	3.0	3.0
		Edney Cr.	13.2	9.0	9.0

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
		Horsefly R.	131.1	54.7	54.7
		Little Horsefly R.	4.8	4.8	4.8
		McKinley Cr.	32.5	32.5	32.5
		Upper Mckinly	UK		
		Off-set Creek	UK		
		Mitchell R.	31.2	16.0	16.0
		Moffat Cr.	UK		
		Penfold Cr	31.6	12.0	12.0
		Polly Creek	7.2	7.2	7.2
		Summit Cr	4.7	4.7	
		Wasko Cr.	7.3	7.3	7.3
		Woodjam Cr.	20.8	20.8	20.8
		Tisdale Cr.	6.3	6.3	6.3
	Watson Bar Cr.		29.4	7.6	7.6
	French Bar Creek		28.8	28.8	28.8
	Williams Cr.		18.1	18.1	18.1
North Thompson	Albreda R		30.2	30.2	27.91
		Allan Cr	21.8	2.5	0.97
		Clemina Cr	17.4	1.6	0.53
		Dominion Cr	16.7	1.1	0.62
		Dora Cr	7.5	0.7	0.44
	Blue R		30.1	17.1	
	Canvas Cr		16.1	3.9	0.75
	Cedar Cr		6.0	3.3	1.73
	Chappell Cr		11.7	2.2	0.52

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
	Cook Cr		7.3	1.2	1.23
	Goose Cr		4.7	4.7	2.97
	Lempriere Cr		34.3	20.7	8.81
	Manteau Creek		18.2	11.2	7.36
	Miledge Cr		20.2	1.8	1.03
	Mud Cr		35.2	9.1	9.05
	U.North Thompson R*		132.3	132.3	
	Peddie Cr		8.5	0.4	0.44
	Pyramid Cr		9.6	0.5	0.46
	Serpentine Cr		14.1	0.9	0.49
	Thunder Cr		28.0	4.8	2.58
	Avola Cr		4.2	1.0	1.0
	Brookfield Cr		19.2	1.1	1.1
	Clearwater R		119.6	48.4	48.4
		Mahood R	5.6	2.8	2.8
	Crossing Cr		3.3	0.5	0.5
	Finn Cr		25.8	4.2	4.2
	Lion Cr		16.6	2.5	2.5
	Mid N. Thompson R		94.5	94.5	40
		Pig Channel	1.3	1.3	1.3
		Birch Island	1.0	1.0	1
		Slate Channel	UK		
	Raft R		78.0	4.7	4.7
	Shannon Cr		10.2	1.2	1.2
	Tumtum Cr		7.0	0.8	0.8

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
	Reg Christie Cr		20.9	0.4	0.4
	Wire Cache Cr		8.3	1.4	1.4
	Barriere R		64.3	64.3	50
		E. Barriere R	29.2	18.8	18.8
		Haggard Cr	17.7	17.7	14.588
		Fennell Cr	21.5	21.5	21.5
		Harper Cr	26.2	26.2	26.2
		Vermelin Cr	13.5	0.9	0.495
		Birk Cr	15.1	1.7	0.912
		Saskum Cr	UK		
	Darlington Cr		12.0	2.0	2.0
	Dunn Cr		14.4	14.4	14.4
		McTaggart Cr	4.5	2.4	2.4
	Fishtrap Cr		22.2	5.6	1.088
	Heffley Cr		17.3	0.0	0
	Jamieson Cr		34.1	4.7	1.799
	Lemieux Cr		30.8	13.4	13.4
	Lindquist Cr		18.7	3.3	3.3
	Louis Cr		57.9	57.9	57.9
	L. N Thompson R		138.7	138.7	138.7
	Mann Cr		50.4	6.4	6.4
	Paul Cr		35.9	1.0	1.767
	Peterson Cr		27.2	1.0	1.0
Lower Thompson	Bonaparte River		145.1	145.1	145.1
	Deadman River		113.6	48.9	48.9

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
	Tranquille Cr		57.2	5.0	5.0
	Coldwater River		91.7	91.7	91.7
		Brook Creek	17.4	5.0	5.0
		Juliet Cr.	15.6	15.6	15.6
	Nicola River (lower)		80.0	80.0	40.0
		Clapperton Cr.	29.5	2.0	2.0
		Guichon Cr.	80.6	50.0	50.0
		Skuhun Cr.	32.7	12.8	12.8
		Nooaitch Cr.	14.5	1.1	12.3
	Nicola River (upper)		52.0	22.0	22.0
		Spahomin Cr.	26.5	26.5	26.5
	Spius Creek		48.6	48.6	48.6
		Maka Cr.	34.9	18.5	18.5
South Thompson	Shuswap R (lwr)		88.6	88.6	88.6
		Ashton Cr.	14.5	0.2	0.2
		Brash Cr.	12.7	0.5	0.5
		Blurton Cr.	12.3	1.5	1.5
		Cooke Cr.	17.1	0.5	0.5
		Danforth Cr.	13.6	13.6	13.6
		Fortune Cr	21.5	21.5	21.5
		Johnson Cr	11.0	11.0	11.0
		Kingfisher Cr	28.3	28.3	28.3
		Trinity Cr	28.6	0.2	0.2
	Shuswap R (mid)		76.1	21.0	21.0

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
		Bessette Cr	38.0	38.0	38.0
		Creighton Cr	30.7	4.1	4.1
		Duteau Cr	49.6	10.8	10.8
		Harris Cr	31.8	18.1	18.1
		Ireland Cr	25.3	3.2	3.2
	Tsuius Cr		30.6	0.5	0.5
	Noisey Cr		15.4	1.1	1.1
	Wap Cr		47.7	29.3	29.3
	Anstey R		30.1	7.0	7.0
	Canoe Cr		10.6	4.5	4.5
	Celista Cr		29.2	1.8	1.8
	Eagle R		75.9	75.9	75.9
		Crazy Cr	20.3	0.5	0.5
		Loftus Cr	UK		
		Owlhead Cr.	5.8	0.8	0.8
		Perry R.	41.5	28.0	28.0
		Senn Cr.	10.1	1.0	1.0
		South Pass Cr.	9.8	1.2	1.2
		Teto Cr	UK		
		Yard Cr.	21.2	0.4	0.4
	Hunakwa Cr		7.5	7.5	7.5
	Onyx Cr		16.7	2.0	2.0
	Ross Cr		22.9	0.5	0.5
	Salmon R		148.7	80.0	80.0
		Bolean Cr	23.3	23.3	23.3

CU	River Mainstems	Tributaries	Total (km)	Accessible Distance (km)	Useable Distance (km)
		Palmer Cr	9.8	0.5	0.5
	Scotch Cr		56.5	16.0	16.0
	Seymour R		71.0	14.6	14.6
		McNomee Cr	20.3	8.7	8.7
	Tappen Cr		6.8	1.5	1.5
	Wright Cr.		2.7	2.6	2.6
	Adams R (lwr)		11.3	11.3	11.3
		Hiuihill Cr	15.0	0.9	0.9
		Nikwikwaia Cr (Gold)	21.4	1.2	1.2
	Momich R.		9.9	9.9	9.9
		Cayenne Cr	42.9	2.2	2.2
	Sinmax Cr		19.5	9.4	9.4
	Tsikwustum Cr.		13.2	0.3	0.3
	Adams R (upper)		130.0	130.0	65.0
		Burton Cr.	13.6	2.0	2.0
		Gollen Cr.	18.2	1.0	1.0
		Harbour Cr.	12.6	2.7	2.7
		Dudgeon Cr.	14.4	0.5	0.5
		Sunset Cr.	15.6	1.3	1.3
		Gold Cr.	11.0	11.0	11.0
		Oliver Cr.	26.7	23.3	23.3
		Hemlock Cr.	11.1	0.7	0.7

APPENDIX 7. THREATS ASSESSMENT ADDITIONAL INFORMATION

Here, a summary of the standardized COSEWIC and DFO approaches are summarized from their respective guiding documents (COSEWIC 2012, DFO 2014a).

COSEWIC Assessment

The COSEWIC assessment is based on the IUCN-CMP (International Union for Conservation of Nature-Conservation Measures Partnership) standardized threat classifications. The classification system uses strictly defined categories of threats; however, they were developed in a general context and thus are not specific to salmonids nor aquatic species. For the assessment done here, a chair with experience using the classification system guided the working group through each threat and how it may relate to salmonids. It is recommended to use either the same chair or a highly experienced chair for subsequent iterations of assessing IFC using the COSEWIC assessment process.

The COSEWIC assessment considers the potential impact of present and future threats. The level of impact is calculated after identifying the threat's scope and severity (Table 22). Scope is defined as the proportion of the species or ecosystem that can reasonably be expected to be affected by the threat within 10 years (Table 23). Severity is the level of damage to the species or ecosystem from the threat in the context of the timeframe of 10-years or 3-generations, whichever is longer (Table 24). Timing is also identified, though not part of calculating the level of impact. Timing identifies the temporal extent or probability the threat may occur presently or in the future (or if it only occurred in the past) (Table 25).

The COSEWIC assessment is completed in several steps. A meeting is scheduled and area and species experts are invited. In the case of IFC, a pre-existing working group and list of experts was used for invitations. A few additional members from DFO-SARA were also invited. Those who were able to attend were primarily authors (likely because these people were those who had originally identified themselves as having the availability to participate in the RPA process for IFC). The chair provided an example assessment to the working group to work from; in this case it was the assessment done for the 2016 COSEWIC report (COSEWIC 2016). The chair then provides an introduction to the definitions of scope, severity, and timing, and then guides the working group through the definitions of each threat category. The working group comes to a broad consensus around each Level 2 category's impact level. The Level 2 threats are more specific sub-headings under the Level 1 threats. The Level 1 threat levels are based on the most conservative (highest threat) levels within its Level 2 sub-headings. Notes are taken during the meeting that are used to fill the comments section, which are then reviewed by the chair for completeness and correctness. Finally, an overall threats impact is assigned based on the cumulative impacts of the Level 1 threats. All of the above information is summarized in Table 26.

Table 22. Using scope and severity to derive the impact of a threat. Copied from (COSEWIC 2012).

		Scope					
		Pervasive	Large	Restricted	Small	Negligible	Unknown
Severity	Extreme	Very High	High	Medium	Low	Negligible	Unknown
	Serious	High	High	Medium	Low	Negligible	Unknown
	Moderate	Medium	Medium	Low	Low	Negligible	Unknown
	Slight	Low	Low	Low	Low	Negligible	Unknown
	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Unknown

		Scope					
		Pervasive	Large	Restricted	Small	Negligible	Unknown
	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
	Neutral or Potential Benefit	Not a threat	Not a threat	Not a threat	Not a threat	Not a threat	Unknown

Red = Very High	Yellow = High	Grey = Medium	Green = Low

Table 23. Scoring the scope of identified threats. Ranking levels for scope, copied from (COSEWIC 2012).

Scope of threats scoring	
Pervasive	Affects all or most (71-100%) of the total population or occurrences
Large	Affects much (31-71%) of the total population or occurrences
Restricted	Affects some (11-30%) of the total population occurrences
Small	Affects a small (1-10%) proportion of the total population or occurrences
Negligible	Affects a negligible (<1%) proportion of the total population or occurrences

*Table 24. Scoring the severity of a threat. Ranking levels for severity, copied from (COSEWIC 2012). *Threat may have some localized negative effects, but overall is thought to not affect or be a benefit to the species. For example, a forest fire may directly affect some individuals of a browsing ungulate, and produce a short term loss of habitat, however, over the three generation time window there is a benefit to the population as a whole due to regeneration of browse species post fire.*

Severity of threats scoring	
Extreme	Within the scope, the threat is likely to destroy or eliminate the occurrences of an ecological community, system, or species, or reduce the species population by 71-100%.
Serious	Within the scope, the threat is likely to seriously degrade/reduce the affected occurrences or habitat, or for species, to reduce the species population by 31-70%.
Moderate	Within the scope, the threat is likely to moderately degrade/reduce the affected occurrences or habitat, or for species, to reduce the species population by 11-30%.
Slight	Within the scope, the threat is likely to only slightly degrade/reduce the affected occurrences or habitat, or for species, to reduce the species population by 1-10%.
Negligible	Within the scope, the threat is likely to negligibly degrade/reduce the affected occurrences or habitat, or for species, to reduce the species population by <1%.
Neutral of Potential Benefit*	Within the scope, the "threat" is likely to improve or not affect occurrences, or habitat, for species, to be neutral or to improve (net benefit) the species population by > 0%.

Table 25. Scoring the timing of a threat. Copied from (COSEWIC 2012).

Timing of threats scoring	
High	Continuing
Moderate	Only in the future (could happen in the short term [<10 years or three generations]), or now suspended (could come back in the short term)
Low	Only in the future (could happen in the long term), or now suspended (could come back in the long term)

Timing of threats scoring	
Insignificant/ Negligible	Only in the past and unlikely to return, or no direct effect but limiting

Table 26. COSEWIC Threats Assessment.

THREATS ASSESSMENT WORKSHEET

See instructions in 'Instructions' worksheet. Scroll down in top pane to view the entire table.

Species or Ecosystem Scientific Name	*Oncorhyncus kisutch Coho Salmon, Interior Fraser* River DU		
Element ID		**Elcode**	

Date (Ctrl + ";" for today's date):	2/20/2019
Assessor(s):	Teleconference attendants: Richard Bailey (DFO), Lynda Ritchie (DFO), Michael Arbeider (DFO), Kaitlyn Dionne (DFO), Doug Braun (DFO), Brittany Jenewein (DFO), Karen Rickards (DFO), Paul Grant (DFO), Peter Hall (DFO), Robyn Kenyon (DFO), Patricia Woodruff (DFO), Marc Labelle (ONA). Facilitator: Dwayne Lepitzki (COSEWIC).
References:	Refer to RPA text for more specific descriptions of threats and supporting evidence.

Overall Threat Impact Calculation Help:

		Level 1 Threat Impact Counts	
Threat Impact		**high range**	**low range**
A	Very High	0	0
B	High	1	1
C	Medium	4	1
D	Low	0	3
Calculated Overall Threat Impact:		Very High	High

Assigned Overall Threat Impact:	**AB = Very High - High**
Impact Adjustment Reasons:	No adjustments because the severity of many threats are uncertain and population declines between 10-100% in the next 10 years are possible, especially in the context of cumulative impacts
Overall Threat Comments	Generation time = 3.16 years, therefore timeframe for severity and timing is 10 years into the future. Five CUs within the single DU (Fig. 1 of RPA). Different abundances among CUs were considered when scoring scope.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential & commercial development						
1.1	Housing & urban areas						See 7.3 & 9.1
1.2	Commercial & industrial areas						See 7.3 & 9.2
1.3	Tourism & recreation areas						Potentially new marinas and docks on Shuswap Lake lakeshores that are near spawning grounds and littoral habitat used by juveniles. Other impacts, see 6.1
2	Agriculture & aquaculture		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	
2.1	Annual & perennial non-timber crops						Agricultural development of the riparian zone results in habitat alteration including sedimentation (threat 9.3), temperature increases (threat 7.3), and hydrological changes (threat 7.2) and is not scored here.
2.2	Wood & pulp plantations						No plantations foreseen to be built in Coho habitat
2.3	Livestock farming & ranching		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	Cattle and other livestock have potential to crush redds. Particularly in South Thompson (e.g. Lower Shuswap, Bessette), North Thompson (Louis, Dunn, Lemieux), Lower Thompson (Nicola), Middle Fraser (Quesnel, Horsefly, Chilcotin). Sedimentation and pollution from manure (9.3).
2.4	Marine & freshwater aquaculture						See 8.2. No physical aquaculture development impacts are foreseen in the next 10 years
3	Energy production & mining		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	
3.1	Oil & gas drilling						There is currently a moratorium on drilling for oil and gas on the coast and there are no proposed natural gas projects near IFC habitat
3.2	Mining & quarrying		Negligible	Negligible (<1%)	Negligible (<1%)	High (Continuing)	Placer mining occurs in Cottonwood and Quesnel basin (apprx 10% of Middle Fraser CU). Gravel extraction south of Mission in habitat used briefly by rearing juvenile Coho in Lower Fraser. There is some mitigation.
3.3	Renewable energy						See 7.2

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4	Transportation & service corridors		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	
4.1	Roads & railroads		Negligible	Restricted - Small (1-30%)	Negligible (<1%)	High (Continuing)	Maintenance, widening, and new or modifications of bridges, abutments, culverts highways, logging and mining roads are all ongoing, but there is uncertainty in their extent over IFC streams. Threat severity is negligible given effective mitigation.
4.2	Utility & service lines		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	Maintenance/replacement of pipelines, new pipelines, including Transmountain Pipeline, which runs the length of the North Thompson and part of the Lower Thompson (e.g. Coldwater). Existing lines may also displace sediment that blocks or changes streams. Threat severity may be negligible given effective mitigation.
4.3	Shipping lanes		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	Dredging in the Lower Fraser, which is a migratory route for all adults & smolts; proper mitigation (e.g. dredging when migrations are not occuring) may reduce severity, though there are IFC juveniles that rear in the Lower Fraser for 9-12 months.
4.4	Flight paths						NA
5	Biological resource use	CD	Medium - Low	Pervasive (71-100%)	Moderate – Slight (1-30%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						NA
5.2	Gathering terrestrial plants						NA
5.3	Logging & wood harvesting						See 7.3 & 9.3
5.4	Fishing & harvesting aquatic resources	CD	Medium - Low	Pervasive (71-100%)	Moderate – Slight (1-30%)	High (Continuing)	Estimated average Commercial exploitation rate (since 1998) is 12% SD 6%; however, accuracy of estimates is variable and there is a chance of underestimation. Additionally, the current population trajectory is uncertain, thus, there is a possibility that fisheries are having a larger impact than 12% of IFC abundance. The 1-30% range was chosen because of the uncertainty of ER estimates. Recreational Fishing is Restricted to Hatchery-Adipose-Fin-Clipped, unknown impact on natural-origin by poaching or misidentification. Most FSC harvest is minimal.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
6	Human intrusions & disturbance		Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities		Negligible	Negligible (<1%)	Unknown	High (Continuing)	Wake from boats may strand juveniles in freshwater. There is low likelihood of ATVs crushing redd's due to the winter spawning times, but juveniles may still be affected.
6.2	War, civil unrest & military exercises						Unpredictable
6.3	Work & other activities		Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	Research and Stock Assessment capture and handling of fish may increase stress related mortality or sub-lethal effects. Research suggests spawning success is not impacted by stock assessment activities. Scope is likely toward the lower end than the higher end of the range.
7	Natural system modifications	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	
7.1	Fire & fire suppression		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	Water heated by fire may have acute effects. Water scooped for fighting fires may capture fish. Frequency of fires in the interior is increasing. See 7.3 and 9.3
7.2	Dams & water management/use	CD	Medium - Low	Pervasive (71-100%)	Moderate – Slight (1-30%)	High (Continuing)	1) Water extraction for irrigation in Lower, South, and North Thompson Rivers and some sections of Middle Fraser. Related issues: warmer water, low productivity in riffles, sucked in when lack of exclusion devices, added pressure from poaching pipes. 2) Run of River (hydro) projects (as barriers) are present and more are expected to be built, but so far are above Coho habitat. 3) Temperature and flow regime changes from ROR and Bridge and Seton Dams. Dam passage and entrainment - Seton dam particularly problematic for this deme (in Middle Fraser). Flow management from Bridge River dam also an issue - cutting off fish from habitat. 4) Dykes that reduce connectivity and other water management dams are also included in this threat. The severity is likely at the higher end of the uncertainty range.

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)	1) Alteration of temperature and flow regimes as the result of vegetation clearing or increases in impervious surfaces through i) forestry and pine beetle induced forestry, ii) agriculture, iii) urban and commercial development, iv) forest fires (also association with pine beetle effects). 2) Loss of instream habitat by increased channelization associated protection of agriculture and urban development (e.g. rip-rapping, dyking, flood-gates). 3) Increased number of competitors through introduction of hatchery Coho and other hatchery salmonids in the Strait of Georgia and Southeast Alaska (~1% of SEA catch is IFC). 4) Introduced and invasive vegetation (e.g. Reed Canary Grass, Milfoil) can modify hydrology and fish communities. 5) Changes in marine environment (e.g. low productivity regime, "The Blob") that affect productivity, competition, and predator abundance. 6) Change in predator distribution associated with log booms in e.g. Shuswap Lake and Lower Fraser River. Many changes are associated with increases in human population with decreases in regulation.
8	Invasive & other problematic species & genes		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
8.1	Invasive non-native/alien species/diseases		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Freshwater-Bass spp, Yellow Perch can eat fry and parr, Beaver Lake has populations with potential to spread to whole Nicola Valley (Lower Thompson), eradications have reduced risk of range expansions in South Thompson, biggest threat is to smolts rearing (some of population) and migrating through (all of population) Lower Fraser.
8.2	Problematic native species/diseases		Unknown	Small (1-10%)	Unknown	High (Continuing)	Here just sea lice are considered because human activity (open-net pen salmon farming) exacerbates the propagation of sea lice. In the next 4 years, many open-net pens may be moved from the Broughton Archipelago so there will be fewer encounters in the future and typically the majority of the population does not migrate past many salmon farms. Depesatory effects from predators is not considered here but will be addressed in the RPA.
8.3	Introduced genetic material						Given the limited space of hatcheries in the Interior Fraser Watershed, it's unlikely hatchery populations will provide much influence in an IFC context. Hatchery brood are also targeted to be from natural-origin fish to reduce possible detrimental effects of subsequent breeding.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8.4	Problematic species/diseases of unknown origin						None observed
8.5	Viral/prion-induced diseases		Unknown	Small (1-10%)	Unknown	High (Continuing)	Potential viruses from sea lice include PRV and HSMI, which are known to have lethal and sublethal effects on salmon; however, the estimated effected population is small and the population level effects are unknown for IFC.
8.6	Diseases of unknown cause						None observed
9	Pollution	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	
9.1	Domestic & urban waste water	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Includes heavy metals (e.g. Cu), hormones, microplastics, and nutrients (e.g. fertilizers, ammonia). Some research states that Coho are particularly vulnerable to road run offs. CU-instream specific effects are variable, but all IFC migrate through the Lower Fraser River which will have some (estimated slight) severity
9.2	Industrial & military effluents	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Includes operations effluent and spills e.g. from Mines like Mount Polley in 2014, diesel fuel from truck spills, and spills from pipelines. Transmountain pipeline follows almost the entire length of the North Thompson River and the Coldwater River (L. Thompson). An oil spill could be a catastrophic long term effect if the spill got into the ground water. Pulp mill effluent is encapsulated in this section (e.g. Kamloops Mill).
9.3	Agricultural & forestry effluents	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	Includes pesticides, herbicides, and fertilizers from agricultural and forestry runoff. Bark from booms is included in this category as is siltation and soil erosion from cattle. All CUs may be affected by these effluents in varying degrees, but all smolts pass through the Lower Fraser River, which is why the entire population may be exposed to effects.
9.4	Garbage & solid waste						NA
9.5	Air-borne pollutants						NA
9.6	Excess energy						NA

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
10	Geological events	CD	Medium - Low	Restricted (11-30%)	Moderate – Slight (1-30%)	High - Moderate	
10.1	Volcanoes						Nazko Cone had activity under it in 2007 but has a low probability of eruption and would only possibly effect one deme. Other volcanoes in the Fraser Watershed have not had activity recently.
10.2	Earthquakes/tsunamis						NA
10.3	Avalanches/landslides	CD	Medium - Low	Restricted (11-30%)	Moderate – Slight (1-30%)	High - Moderate	Several systems have highly unstable banks as the result of forest fires, forestry, pine beetle, and changing climates, e.g. Bonaparte, and it is estimated that at least a few populations may be affected within the next 10 years.
11	Climate change & severe weather	CD	Medium - Low	Pervasive (71-100%)	Moderate – Slight (1-30%)	High (Continuing)	
11.1	Habitat shifting & alteration	CD	Medium - Low	Pervasive (71-100%)	Moderate – Slight (1-30%)	High (Continuing)	Shifting hydrographs due to changes in snow melt etc. is included in this category. Climate may also be associated with changes in productivity, competition, and predator abundance, but these threats were included in 7.3.
11.2	Droughts						Difficult to tease out droughts and temperature extremes. Therefore they are ranked together in the category below.
11.3	Temperature extremes	CD	Medium - Low	Pervasive (71-100%)	Moderate – Slight (1-30%)	High (Continuing)	This includes both marine and FW temperatures. Frequency and intensity of these episodes shift where they occur through time.
11.4	Storms & flooding		Unknown	Restricted (11-30%)	Unknown	High (Continuing)	Catastrophic rain on snow event has the greatest likelihood around Williams Lake and South. Has potential benefits (renewing cobbles) but also potential negatives (redd destruction/egg mortality, fry mortality), therefore the impacts are unknown.
11.5	Other impacts						

Classification of Threats adopted from IUCN-CMP, Salafsky et al. (2008).

DFO Assessment

The DFO assessment has no standardized threat classifications, which was a primary driver of using the COSEWIC assessment first. The unified threat categories from COSEWIC were used for their reproducibility; however, because of the categories' specificity, it was deemed beneficial to be guided through a complete COSEWIC threats assessment by an experienced chair. Once the exercise was complete, the "Other Ecosystem's Modifications" COSEWIC category was divided into more salmonid-specific threats. Climate change was also removed as a ranked threat because climate change itself is not a human activity but one that is exacerbated by human activity. Climate change also exacerbates/interacts with the subsequent natural limiting factors categories that were developed for assessment. Other categories that did not receive a COSEWIC level because they were not applicable to IFC were not discussed in the context of the DFO assessment.

The DFO assessment uses a similar approach to assess threat risk as COSEWIC does to assess the level of impact of a threat. The DFO assessment considers the threat risk of present and future threats, as well as impacts that have already occurred. The threat risk is calculated after identifying the threat's likelihood of occurrence, level of impact, and causal certainty (Table 27). Likelihood of occurrence is defined as the probability of a threat occurring for a given population over 10 years of 3-generations, whichever is shorter (Table 28). Level of impact is the magnitude of the impact of a threat and the level to which it affects the survival or recovery of a population (Table 29). Causal certainty reflects the strength of evidence linking the threat to the survival and recovery of the population (Table 30). In addition to these aspects, the DFO assessment also identifies the threat occurrence, threat frequency, and threat extent. Threat occurrence refers to the timing of the occurrence of the threat as either, historical, current, and/or anticipatory (Table 31). Threat frequency refers to the temporal extent of the threat (Table 32). Threat extent refers to the proportion of the population affected by the threat (Table 33).

Several of the aspects used in the DFO and COSEWIC assessments are either analogous or may be considered partial components of each other. The threat risk and level of impact in the DFO assessment are similar to impact and severity in the COSEWIC assessment, respectively. The threat occurrence in the DFO assessment captures some of the aspects of timing from the COSEWIC assessment; however, other aspects of timing are captured in the likelihood of occurrence level. Threat extent is the DFO aspect most analogous to the COSEWIC scope aspect; however, threat frequency may also be considered a part of scope. Causal certainty is the only DFO aspect that is completely novel and has no connection to the COSEWIC calculator.

Due to the analogous nature of many of the aspects between the DFO and COSEWIC assessments, the transcription of the levels ascribed in the COSEWIC assessment was done by the authors and did not include the whole group involved with the initial assessment. A minor change in assessment was made around the possible impacts of hatchery practice and genetics, mostly incorporating the uncertainty about historical impacts that may be pervasive in the future. Other than the above change, effort was made to conserve the initial COSEWIC assessment's rankings.

Table 27. Threat risk matrix. Copied from (DFO 2014a).

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	Low	Medium	High	Extreme	Unknown
	Likely	Low	Medium	High	High	Unknown
	Unlikely	Low	Medium	Medium	Medium	Unknown
	Remote	Low	Low	Low	Low	Unknown
	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

Table 28. Levels of likelihood of occurrence. Copied from (DFO 2014a).

Likelihood of Occurrence	**Definition**
Known	This threat has been recorded to occur 91-100%
Likely	There is 51-90% chance that this threat is or will be occurring
Unlikely	There is 11-50% chance that this threat 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 now or in the future

Table 29. Levels of level of impact. Copied from (DFO 2014a).

Level of Impact	**Definition**
Extreme	Severe population decline (e.g. 71-100%) with the potential for extirpation
High	Substantial loss of population (31-70%) or Threat would jeopardize the survival or recovery of the population
Medium	Moderate loss of population (11-30%) or Threat is likely to jeopardize the survival or recovery of the population
Low	Little change in population (1-10%) 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

Table 30. Levels of causal certainty linked to a threat. Copied from (DFO 2014a).

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

Table 31. Levels of threat occurrence. Any combination of levels is possible. Copied from (DFO 2014a).

Threat Occurrence	Definition
Historical	A threat that is known to have occurred in the past and negatively impacted the population
Current	A threat that is ongoing, and is currently negatively impacting the population
Anticipatory	A threat that is anticipated to occur in the future, and will negatively impact the population

Table 32. Levels of threat frequency. Copied from (DFO 2014a).

Threat Frequency	Definition
Single	The threat occurs once
Recurrent	The threat occurs periodically, or repeatedly
Continuous	The threat occurs without interruption

Table 33. Levels of threat extent. Copied from (DFO 2014a).

Threat Extent	Definition
Extensive	71-100% of the population is affected by the threat
Broad	31-70% of the population is affected by the threat
Narrow	11-30% of the population is affected by the threat
Restricted	1-10% of the population is affected by the threat

APPENDIX 8. ADDITIONAL RECOVERY TARGET ANALYSIS

Several alternative sub-DU-level recovery targets (Table 34) and how their DU-level targets were derived are discussed here. Several of these targets relate to 80% S_{MSY} (80% of spawner abundance at Maximum Sustainable Yield) benchmarks at the CU-level from prior assessments of IFC (Table 35). Korman et al. (2019) and Parken et al.[1] both recommended possible CU-level benchmarks. Korman et al. (2019) suggested benchmarks from the output of three different models developed for the Pacific Salmon Commission (PSC), referred to here as PSC Ricker, PSC PriorCap, and PSC Dep. The PSC Ricker targets are from a hierarchical Bayesian Ricker model with uninformative priors; the PSC PriorCap targets are from the above model with a highly informative prior on the carrying capacity to minimize over-compensatory dynamics that appeared to be driven by low smolt-to-adult survival years; and the PSC Dep targets are from the PSC Prior Cap model with an additional parameter that described a depensatory effect below 1000 spawners. The suggested benchmarks from Parken et al.[1] are from an analysis associated with the Wild Salmon Policy (WSP) and will be referred to as the WSP upper benchmark. Additionally, Korman et al.'s (2019) analysis was redone using only data from indicator stocks and 80% S_{MSY} targets at the CU-level for systems with indicator stocks were created. Indicator stocks in the Lower Thompson CU included Bonaparte River, Coldwater River, and Deadman River; the North Thompson CU included Dunn Creek; and the South Thompson CU included Eagle River. Finally, CU-level targets were also derived based on the IFCRT long-term goal objective of 1000 spawners per subpopulation using the same 95 percent mark logistic regression method described below (but with the additional step of determining CU-level targets before determining the DU-level target).

The DU-level benchmarks associated with each alternative sub-DU-level targets were assessed using the same methods as in Element 12. The DU-level abundance target was informed by the probability that each sub-DU target was met for a given DU abundance. A logistic-type regressions was used to identify 95 percent mark that a sub-DU target was met across known DU abundances. A generalized linear model was used with a binomial family error distribution and logit link function. This analysis was done in R (R Core Team 2018) using the package lme4 (Bates et al. 2015). The dataset included natural-origin escapements from 1998-2016.

Table 34. Alternative sub-DU-level recovery targets.

Target Name	Description
IFCRT long-term target (for reference)	The 3-year geometric average, natural-origin escapement in all of the subpopulations within each of the five populations is to exceed 1,000 spawning Coho Salmon, excluding hatchery fish spawning in the wild
PSC: Ricker, PriorCap, Dep	The 3-year geometric average, natural-origin escapement in all of the populations exceeds the mean of the posterior estimate of 80% of S_{MSY} for each of the PSC models.
WSP upper benchmark	The 3-year geometric average, natural-origin escapement in all of the populations exceeds the mean of the posterior estimate of the WSP Upper Benchmark, which is 80% of S_{MSY}.
Indicator Stock	The 3-year geometric average, natural-origin escapement in the CU-aggregated indicator stocks reaches 80% of S_{MSY}.

Target Name	Description
IFCRT-LT-CU-Level	CU targets are determined from the IFCRT long-term subpopulation target. The 3-year geometric average, natural-origin escapement in the CU reaches these targets.

*Table 35. Conservation Unit (CU)-level targets for each of the alternative recovery target approaches. *The average model predictions of the CU abundance when the probability of success is set to 95% from historic data where success is determined at the subpopulation-level IFCRT long-term (LT) goal. [a]The model for Fraser Canyon did not converge because there was complete separation between success and failures.*

Population (CU)	PSC Ricker 80% Smsy	PSC PriorCap 80% Smsy	PSC Dep 80% Smsy	WSP 80% Smsy	IFCRT-LT-CU-Level*
Middle Fraser	1 722	2 686	3 180	2 940	3 498
Fraser Canyon	1 066	1 781	2 088	1 582	1 043[a]
Lower Thompson	2 376	3 599	4 312	3 133	4 004
North Thompson	4 300	6 850	8 220	5 301	9 851
South Thompson	2 908	4 453	5 316	4 735	8 128

Most of the DU-level targets from the alternative models were within 2000 of the target recommended in Element 12 (Table 36). The PSC Ricker model had a considerably lower target; however, it is noted in the methods of Korman et al. (2019) that the other models were developed because they may be more biologically accurate. The IFCRT-LT-CU-Level target was the largest and may represent a may conservative approach at reaching a DU-level target based on the IFCRT's long-term recovery goal. It is important to note that several models did not converge because there was complete separation between the sub-DU target success and failures, so these estimates may not represent as much of a buffer from the largest observed failure.

A significant source of uncertainty in all of the Stock-Recruit analysis was that there are few spawner-recruitment observations at high spawner abundance. If the capacity of each model's output is revised (i.e. the combined effects of alpha and beta) upward after observation of higher spawner abundances, the net effect may be an increase in a benchmark. Thus a benchmarks should always be updated when there are more data. Also, the benchmarks should be updated if exploitation rates (hence recruits) are revised, as abundance-based benchmark analysis can be sensitive to exploitation rate back-calculation of recruits.

*Table 36. Designated Unit (DU)-level targets for each of the alternative recovery target approaches. * The models for PST Dep, IFCRT-LT-CU-Level, and Indicator Stock did not converge because there was complete separation between success and failures*

Sub-DU Target Name	DU-Level Target
Recommended in Element 12	35 935
PST Ricker	26 573

Sub-DU Target Name	DU-Level Target
PST PriorCap	34 162
PST Dep	35 405*
WSP upper target	33 881
Indicator Stock	36 292*
IFCRT-LT-CU-Level	39 595*

APPENDIX 9. RECRUITMENT RECONSTRUCTION COMPARISON

To inform the decision on picking how to assign an age distribution and construct recruitment for each brood year, several preliminary analysis were done. First, likelihood ratio tests compared null models to models of the i) proportion of age 3_2 in returns as predicted by the number of total returns, and the ii) proportion of age 3_2 in recruits as predicted by the number of recruits. If there is support for including the predictors, returns or recruits, in the models i) then the assumption that the proportion of age 3_2s is constant with returns is not favourable, whereas in model ii) then the assumption that the proportion of age 3_2s is constant by brood is not favourable. Only data from the Lower Thompson (n = 7) and South Thompson (n = 13) CUs are used for these tests because once removing samples with 50 or fewer individuals, the North Thompson only had 5 CU-years with data. In addition to the likelihood ratio tests, each recruitment reconstruction was performed and a hierarchical, Bayesian Ricker stock-recruitment model was applied (details in Element 13) to observe differences in their behaviour and parameters. The model included a shared (hierarchical) covariate to describe the effect of smolt-to-adult survival in addition to the alpha and beta parameters.

The inference from three out of four likelihood ratio tests was that adding a predictive covariate was not supported compared to a null model. The proportion of 3_2 returns did not appear to vary with different sizes of total returns, suggesting that treating the data with a constant proportion of age 3_2 in returns may be reasonable (Figure 26). The only likelihood ratio test that showed statistical significance was for hypothesis test ii with the South Thompson CU dataset (Figure 27). The rejection that the model was the same as the null suggests that there may be a difference in the proportion of age 3_2 recruits across brood years based on the number of fish that return as recruits. Because the observed variation (Figure 27) is due to applying measured values, it may be interpreted as evidence that supports using the data-infill method for reconstructing recruitment. However, because regional climate patterns are complex and difficult to distill into a single covariate, the hypothesis that the proportion of age 3_2 fish in returns varies by some type of shared environmental factors was not tested directly.

All three datasets performed well with the base Ricker (maximum $\hat{R} < 1.05$). The constant-brood-based reconstruction appeared to deviate the most from the other two models in parameter estimates, number of effective parameters, and DIC value (Table 37 andTable 38). The behaviour of the constant-brood-based reconstruction curve was also most dissimilar to the other two reconstructions, which were almost identical in three of the CUs (Figure 28).

For Elements 2, 3, 13, 15, and 22, the data-infill method was used to recreate brood-year-based recruitment from annual returns. The data-infill method was chosen because a) there was evidence that the proportion of age 3_2 fish in returns covaried across CUs, b) the proportion of age 3_2 fish by brood year was not constant in the CU with the most data (i.e. suggesting that there is variation), and c) the behaviour of the models were not much different than the constant-returns method but the data-infill method is not constrained by the biologically unreasonable assumption of a constant proportion of age 3_2 fish across all return years.

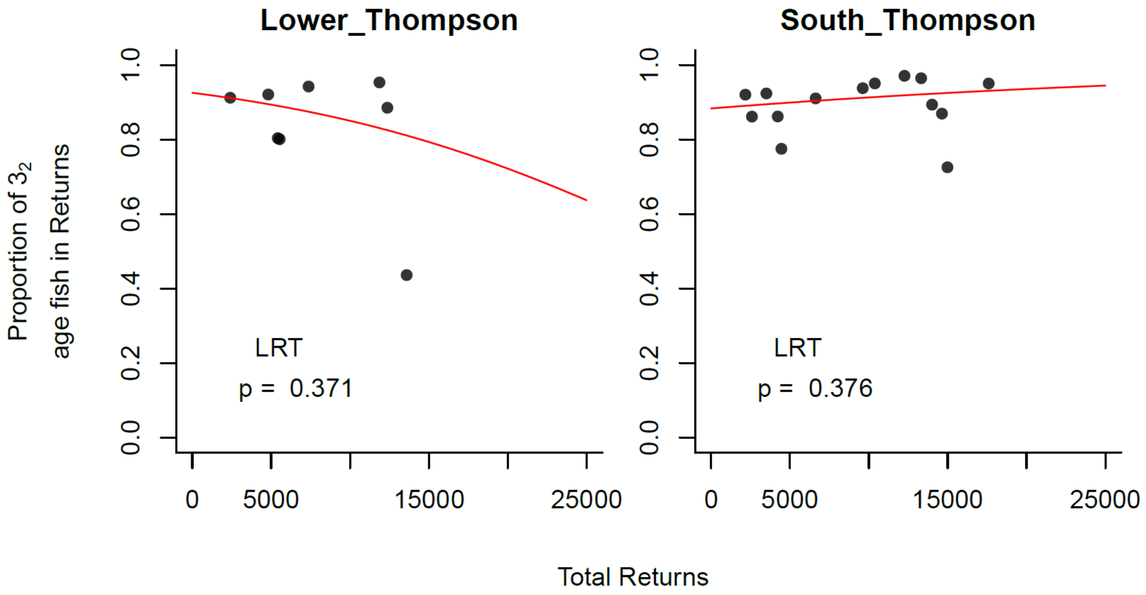

Figure 26. The proportion of age 32 fish by return year as predicted by the total returns in that year. Results from the Likelihood Ratio Test (LRT) against a null model are also presented. Note that the lowest point in the Lower Thompson panel (left) is an outlier and even if removed the LRT result is still not significantly different.

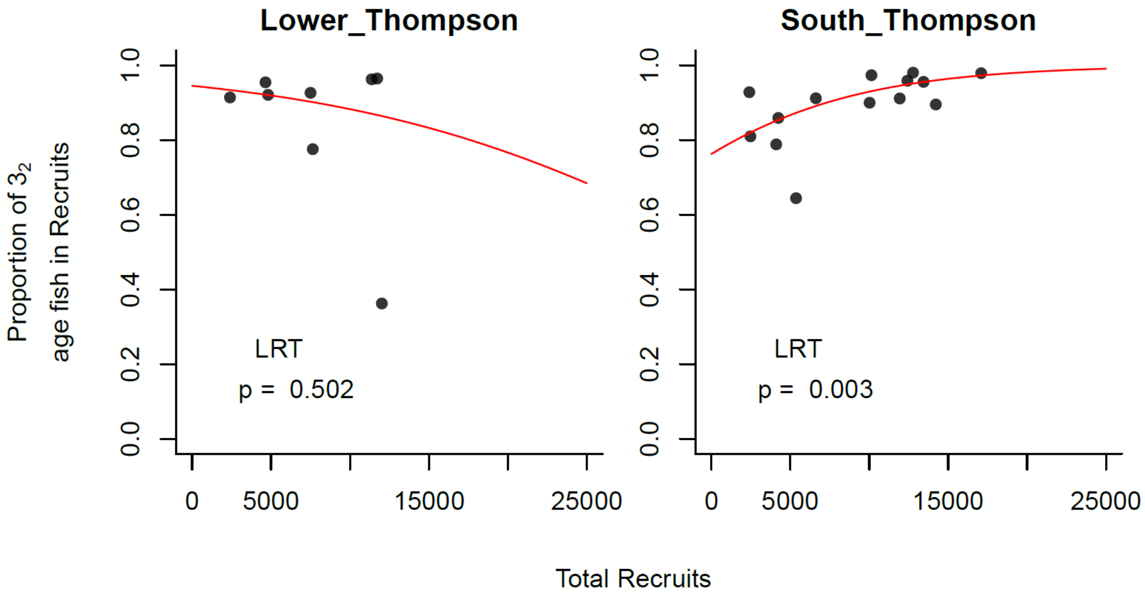

Figure 27. The proportion of age 32 fish by brood year as predicted by the total recruits in that year. Results from the Likelihood Ratio Test (LRT) against a null model are also presented. Note that the lowest point in the Lower Thompson panel (left) is an outlier and even if removed the LRT result is still not significantly different.

Table 37. Median parameter estimates from Ricker stock-recruitment models based on recruitment reconstruction from a data-infill method or from assuming constant proportion of age 32 in returns or by brood year (i.e. in total recruits).

Recruitment Reconstruction	**Data**	**Returns$_C$**	**Brood$_C$**	**Data**	**Returns$_C$**	**Brood$_C$**	**Data**	**Returns$_C$**	**Brood$_C$**
CUnm	**alpha**			**beta**			**gamma**		
Middle Fraser	2.44	2.48	3.26	0.00012	0.00013	0.00011	-	-	-
Fraser Canyon	2.65	2.68	3.53	0.00033	0.00034	0.00031	-	-	-
Lower Thompson	2.53	2.56	3.38	0.00012	0.00013	0.00011	0.373	0.37	0.606
North Thompson	2.63	2.66	3.49	0.00008	0.00008	0.00007	-	-	-
South Thompson	2.47	2.52	3.32	0.00009	0.0001	0.00009	-	-	-

Table 38. Median model performance estimates from Ricker stock-recruitment models based on recruitment reconstruction from a data-infill method or from assuming constant proportion of age 32 in returns or by brood year (i.e. in total recruits). $\hat{R}$ is the potential scale reduction factor, used here as a convergence diagnostic. pD is the number of effective parameters.

Recruitment Reconstruction	**Max $\hat{R}$**	**pD**
Data Infill	1.04	14.6
Returns Constant	1.01	14.6
Brood Constant	1.05	14.0

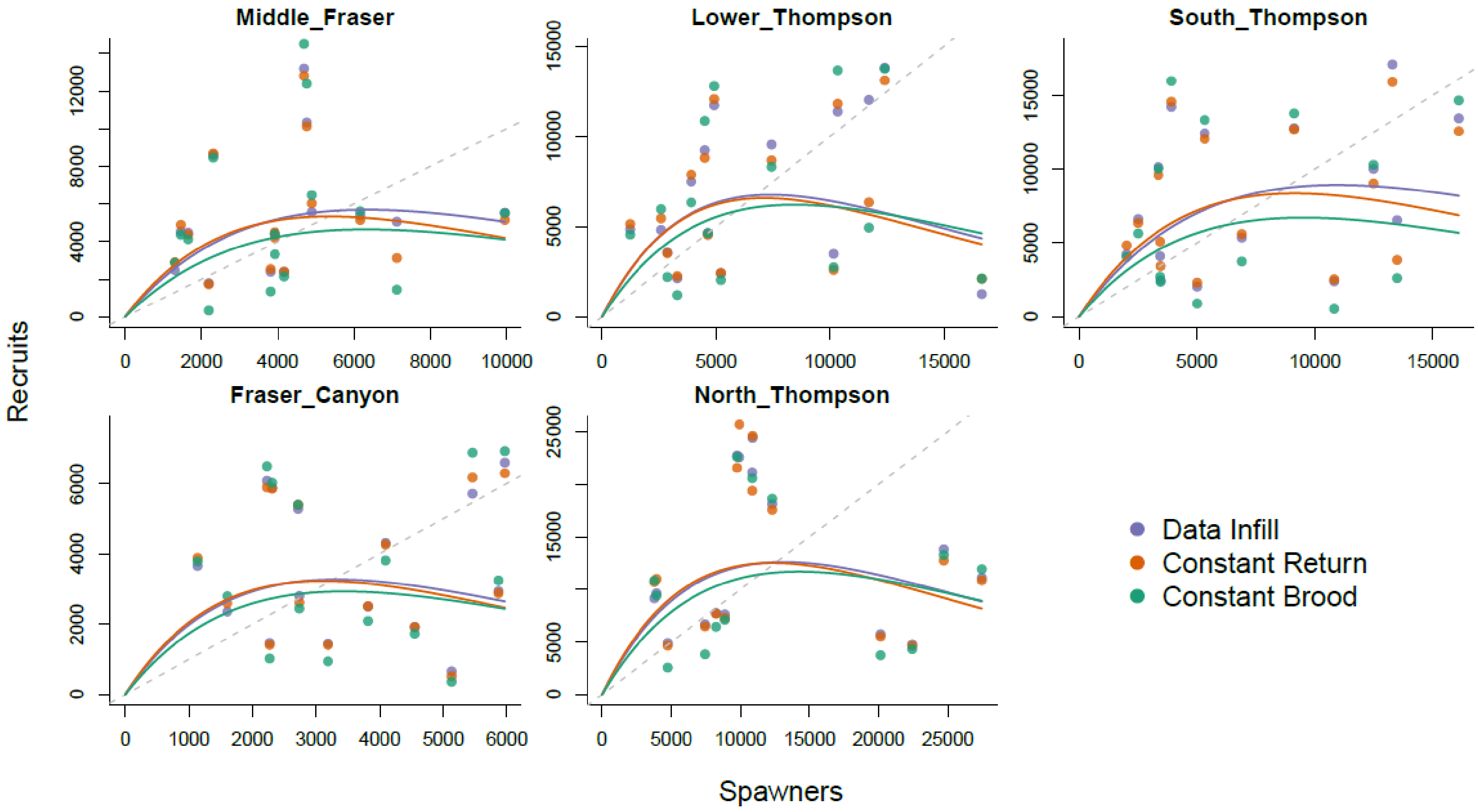

Figure 28. Behaviour of Ricker stock-recruitment models from median parameter estimates based on recruitment reconstruction from a data-infill method (purple) or from assuming constant proportion of age 32 in returns (orange) or by brood year (i.e. in total recruits, green). The grey, dashed line represents 1:1 replacement.

APPENDIX 10. UPDATES TO THE PRECISION OF THE PRIOR IN THE PRIORCAP AND DEP MODELS

As noted in 5.2.2 Data and Model Preparation: Stock-Recruitment Parameter Estimates, the precision on the prior that influenced the estimate of carrying capacity and the parameter β was relaxed from the previous iteration of the model. The following figures highlight why the change was made and provide context of why the previous report’s results may differ relative to this report. Most notably, although the average or median of the estimated parameters appeared to behave in the desired pattern in the previous iteration, the rest of the posterior did not. The two subsequent figures that plot the whole posterior at average smolt-to-adult survival use the same precision for *cap_prior* as in the previous assessment (precision = 1 million). All posterior trajectories were forced through the point that was estimated as carrying capacity.

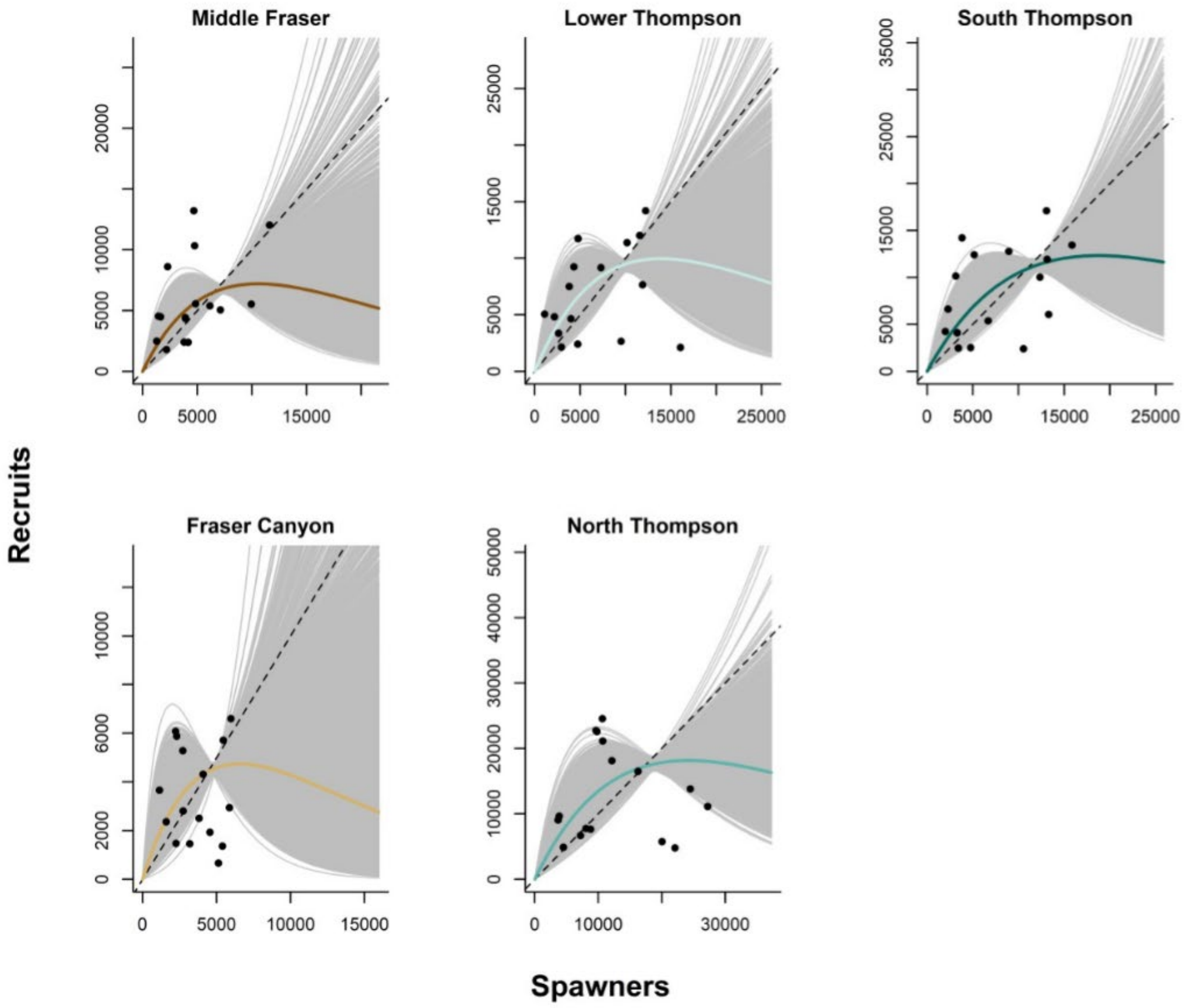

Figure 29. PriorCap model behaviour with an informative prior on carrying capacity that used the same precision as the previous report (1 million), plotted at the average smolt-to-adult survival (0.010). Thick coloured lines are the result of a combination of median parameter values. Thin grey lines are each posterior parameter set and represent the uncertainty in parameter estimates and model behaviour. Solid black points are the observed data, which are not necessarily a result of average smolt-to-adult survival values. Black dashed line is the 1:1 S:R replacement line

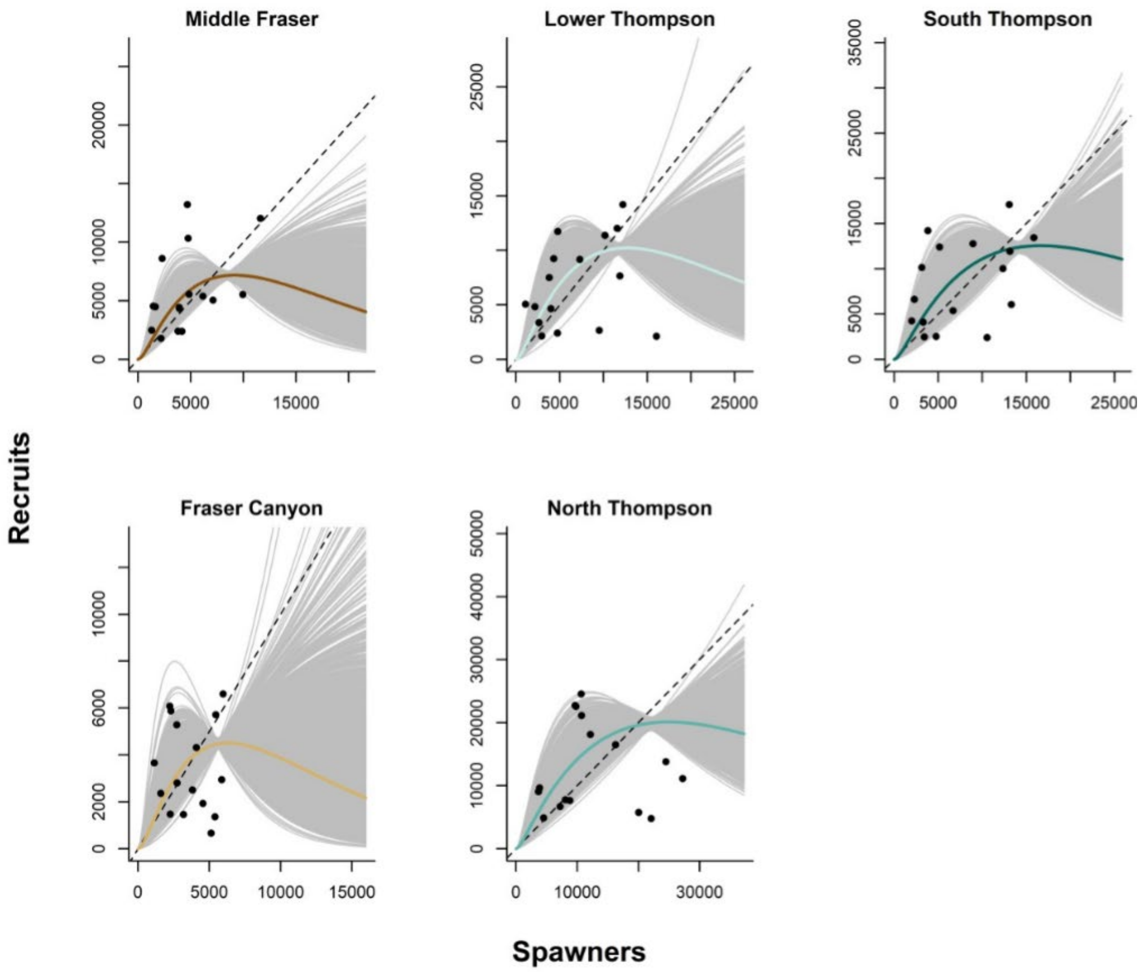

Figure 30. PriorCap model behaviour with an informative prior on carrying capacity that used the same precision as the previous report (1 million), plotted at the average smolt-to-adult survival (0.010)Thick coloured lines are the result of a combination of median parameter values. Thin grey lines are each posterior parameter set and represent the uncertainty in parameter estimates and model behaviour. Solid black points are the observed data, which are not necessarily a result of average smolt-to-adult survival values. Black dashed line is the 1:1 S:R replacement line.

APPENDIX 11. MODEL AND SIMULATION CODE

WinBUGS Code for Ricker (WinBUGS version 1.4.3)

```
model{

      mu_alpha~dnorm(1,0.5)
      tau_alpha~dgamma(0.1,0.1)
      gamma~dnorm(0,0.01)

      for(i in 1:Ncu){
            beta[i]~dlnorm(1,1.0E-01)
            tau[i]~dgamma(0.01,0.01)
            alpha[i]~dnorm(mu_alpha,tau_alpha)I(0,)
      }

      for(i in 1:Nrecs){


            Pred_RecAge3[i]<-pAge3[i]*Sp[i]*exp(alpha[CUid[i]]
+gamma*LSurvAge3[i] -beta[CUid[i]]*Sp[i])
            Pred_RecAge4[i]<-(1-pAge3[i])*Sp[i]*exp(alpha[CUid[i]]
+gamma*LSurvAge4[i] -beta[CUid[i]]*Sp[i])
            Pred_Rec[i]<-Pred_RecAge3[i]+Pred_RecAge4[i]

            Pred_LRS[i]<-log(Pred_Rec[i]/Sp[i])

            LRS[i]~dnorm(Pred_LRS[i],tau[CUid[i]])
            Resid[i]<-LRS[i]-Pred_LRS[i]

            #For historical simulations
            Resid3[i]<-Rec_Age3[i]-Pred_RecAge3[i]
            Resid4[i]<-Rec_Age4[i]-Pred_RecAge4[i]

      }

      #Some outputs
      for(i in 1:Ncu){
            Smax[i]<-1/beta[i]
            prod[i]<-exp(alpha[i] + gamma*muLSurv)
            #prod[i]<-exp(alpha[i])
      }
}
```

WinBUGS Code for Ricker-PriorCap

```
model{

      mu_alpha~dnorm(1,0.5)
      tau_alpha~dgamma(0.1,0.1)
      gamma~dnorm(0,0.01)
```

```
	for(i in 1:Ncu){
		alpha[i]~dnorm(mu_alpha,tau_alpha)I(0,)

		cap[i]~dnorm(cap_prior[i],0.5)I(1,)
		beta[i]<-(alpha[i]+gamma*muLSurv)/(cap[i]*1000)

		tau[i]~dgamma(0.01,0.01)
	}

	for(i in 1:Nrecs){

		Pred_RecAge3[i]<-pAge3[i]*Sp[i]*exp(alpha[CUid[i]]
+gamma*LSurvAge3[i] -beta[CUid[i]]*Sp[i])
		Pred_RecAge4[i]<-(1-pAge3[i])*Sp[i]*exp(alpha[CUid[i]]
+gamma*LSurvAge4[i] -beta[CUid[i]]*Sp[i])
		Pred_Rec[i]<-Pred_RecAge3[i]+Pred_RecAge4[i]

		Pred_LRS[i]<-log(Pred_Rec[i]/Sp[i])

		LRS[i]~dnorm(Pred_LRS[i],tau[CUid[i]])
		Resid[i]<-LRS[i]-Pred_LRS[i]

		#For historical simulations
		Resid3[i]<-Rec_Age3[i]-Pred_RecAge3[i]
		Resid4[i]<-Rec_Age4[i]-Pred_RecAge4[i]
	}

	#Some outputs
	for(i in 1:Ncu){
		Smax[i]<-1/beta[i]
		prod[i]<-exp(alpha[i] + gamma*muLSurv)
		#prod[i]<-exp(alpha[i])
	}
}
```

WinBUGS Code for Ricker-Dep

```
model{

	mu_alpha~dnorm(1,0.5)
	tau_alpha~dgamma(0.1,0.1)
	gamma~dnorm(0,0.01)

	for(i in 1:Ncu){
		alpha[i]~dnorm(mu_alpha,tau_alpha)I(0,)

		cap[i]~dnorm(cap_prior[i],0.5)I(1,)
		beta[i]<-(alpha[i]+gamma*muLSurv)/(cap[i]*1000)

		tau[i]~dgamma(0.01,0.01)
```

```
      }


      for(i in 1:Nrecs){

           Pred_RecAge3[i]<-pAge3[i]*Sp[i]*exp(alpha[CUid[i]]
+gamma*LSurvAge3[i] -beta[CUid[i]]*Sp[i])
           Pred_RecAge4[i]<-(1-pAge3[i])*Sp[i]*exp(alpha[CUid[i]]
+gamma*LSurvAge4[i] -beta[CUid[i]]*Sp[i])
           Pred_Rec[i]<-
Sp[i]/(Sp[i]+Soff)*(Pred_RecAge3[i]+Pred_RecAge4[i])

           Pred_LRS[i]<-log(Pred_Rec[i]/Sp[i])

           LRS[i]~dnorm(Pred_LRS[i],tau[CUid[i]])
           Resid[i]<-LRS[i]-Pred_LRS[i]

           #For historical simulations
           Resid3[i]<-Rec_Age3[i]-Pred_RecAge3[i]
           Resid4[i]<-Rec_Age4[i]-Pred_RecAge4[i]
      }

      #Some outputs
      for(i in 1:Ncu){
           Smax[i]<-1/beta[i]
           prod[i]<-exp(alpha[i] + gamma*muLSurv)
           #prod[i]<-exp(alpha[i])
      }
}
```

R code for Forward Simulation (R version 3.5.2)

```
### Forward simulation to look at performance of alternate harvest
rates given productivity and assumed future smolt-to-adult survival
rm(list=ls(all=TRUE))
start_time <- Sys.time()

library(nlme)
library(scales)

Ncu=5 # number of CUs

Ntrials=500     # of trials to simulate

CUname=c("Middle_Fraser","Fraser_Canyon","Lower_Thompson","North_Thomp
son","South_Thompson","IFC MU")
MUbench=35935                    #IFC DU Target

fyr=2014;lyr=fyr+14;Yr=seq(fyr,lyr);Nyrs=length(Yr)
fyrToUse=2018;lyrToUse=2027;NyrsToUse=lyrToUse-fyrToUse+1
```

```
imin=which(Yr==fyrToUse);imax=which(Yr==lyrToUse)#range of years to
include in status assessment



d0=read.table(file="SR.dat",header=T)
pAge3=vector(length=Ncu)
for(icu in 1:Ncu){
      d1=subset(d0,CUid==icu)
      pAge3[icu]=mean(d1$Rec_Age3/d1$Rec_total)
}

lnSDms = sd( c(log(d0$MS_Age3[which(d0$CUid == 1 & d0$Byr > 1999)] ),
log(d0$MS_Age4[nrow(d0)]) )) # Standard Deviation of MS to calculate
lognormal error of MS later

sigma <- sd( c(d0$ER_Age3[d0$CUid == 1], d0$ER_Age4[nrow(d0)] ))  #
Standard Deviation of ER to calculate lognormal error of MS later

d0=read.table(file="SpRecByCalYr.dat",header=T)

ERset= c(0.068, # 1 SD below current (also 50% of current)
          0.125, # current average
          0.183, # 1 SD above current
          seq(0, 0.3, by = 0.01))

MSset= c(0.003, # minimum observed, worst case scenario
          #0.010, # current mean
          0.041, # max in the current regime, best case scenario
          seq(0.004, 0.04, by = 0.001))

today <- format(Sys.Date(), format = "%b %d")
#today <- "Mar 26 No Dev"
modeldate <- "Apr 05"

fnout3 <- "./Fsim_Full_Output/Fsim_All_Models_Full_Output.out"
write(file = fnout3, "Model baseER baseMS trial end.suc freq.suc
traj_slope traj_percent", ncolumns = 1, append = F)


for(itype in 1:3){

      ModName=switch(itype,"Ricker","Ricker_PriorCap","Ricker_Dep")
      BaseFN=paste("Fsim_", today, "_", ModName,sep="")

      fnout=paste("./Fsim_Full_Output/", BaseFN,".out",sep="")

      write(file=fnout,"ConObj MS ER Mean.end Mean Ci0.1 Ci0.25 Ci0.50
Ci0.75 Ci0.90 traj_b traj_m traj_hi traj_lo", ncolumns=1, append=F)

      fnout2 = paste("./Fsim_Full_Output/", BaseFN, "_Esc.out", sep="")
```

```
     write(file = fnout2, "Model baseER baseMS Ncu trial ry esc",
ncolumns = 1, append = F)

     #Posterior distribution from Ricker, Ricker-PriorCap, and Ricker-
Dep of parameter sets to drive production dynamcs
     p=read.table(file=paste(ModName, "_", modeldate,
"_post.out",sep=""),header=T)
     Nmcmc=dim(p)[1]
     postrecs=round(runif(n=Ntrials,min=1,max=Nmcmc),digits=0)
     #random pick of parameter sets for Ntrial simulations from
posterior
     write.table(matrix(postrecs, ncol = 1), file =
paste("./Fsim_Full_Output/", BaseFN, "_postrecs.out", sep = ""),
row.names = F, col.names = "set")

     #####Simulate deviates for each selected trial for each CU and
year based on an aggregate residual patterns and CU-correlations to
that pattern#########
     NByrs=2013-1998+1
     Resid=matrix(data=0,nrow=NByrs,ncol=Ncu)
     dev=array(dim=c(Ntrials,Nyrs,Ncu))

     #Variables required to test whether deviate simulation is working
correctly
     TestSimRho=rep(0,Ncu);TestRho=rep(0,Ncu);TestSimCUsd=rep(0,Ncu);T
estCUsd=rep(0,Ncu);TestMUsd=0
     TestCUmu=rep(0,Ncu); TestSimCUmu=rep(0,Ncu)
     TestMUmu=0;TestSimMUmu=0


     TestResid=matrix(data=0,nrow=NByrs,ncol=Ncu)

     for (isim in 1:Ntrials){
       irow=postrecs[isim]
       k=0
       for(icu in 1:Ncu){
         j=0
         for(iyr in 1:NByrs){
           j=j+1
           k=k+1
           icol=which(names(p)==paste("Resid.",k,sep=""))
           Resid[j,icu]=p[irow,icol]
           TestResid[j,icu]=TestResid[j,icu]+Resid[j,icu]
         }
       }


       MU_mu=mean(rowMeans(Resid))   #Mean of yr-specific mean
residuals across CUs (MU mean for aggregate)
       MU_sd=sd(rowMeans(Resid))          #SD of yr-specific mean
residuals across CUs (variance over time for aggregate)
```

```
        MUdev=rnorm(n=Nyrs,mean=MU_mu,sd=MU_sd)        #aggretate
residual series across simulation years for this trial

        CU_sd=vector(length=Ncu);rho=CU_sd;CU_mu=CU_sd
        for(icu in 1:Ncu){ # for every CU
          CU_mu[icu]=mean(Resid[,icu]) # calculate the mean of the
residuals
          CU_sd[icu]=sd(Resid[,icu])   # calculate the SD of the
residuals
          CUdev=rnorm(n=Nyrs,mean=CU_mu[icu],sd=CU_sd[icu]) #CU-
specific residual series

          rho[icu]=cor(rowMeans(Resid),Resid[,icu]) # correlation
between aggregate residuals and residuals for given CU

          for (iyr in 1:Nyrs){
            # dev[ , , icu] will have the same SD as CU_sd and
cor(MUdev, dev[ , , icu]) will have the same value as rho

            #See SimDevTest in Results.xls where Test stuff is dumped.
It shows that these calculations reproduce error patterns in data.

            #use this version of including means in MUdev and CUdev
rnorm statements
            dev[isim,iyr,icu]=MUdev[iyr]*rho[icu] + CUdev[iyr]*sqrt(1-
rho[icu]^2)

            #use this version of if means in MUdev and CUdev rnorm
statements =0
            #dev[isim,iyr,icu]=(CU_sd[icu]/MU_sd)*MUdev[iyr]*rho[icu] +
CUdev[iyr]*sqrt(1-rho[icu]^2)
          }
          TestCUsd[icu]=TestCUsd[icu]+CU_sd[icu]
          TestSimCUsd[icu]=TestSimCUsd[icu]+sd(dev[isim,,icu])

          TestCUmu[icu]=TestCUmu[icu]+CU_mu[icu]
          TestSimCUmu[icu]=TestSimCUmu[icu]+mean(dev[isim,,icu])

          TestRho[icu]=TestRho[icu]+rho[icu]

TestSimRho[icu]=TestSimRho[icu]+cor(MUdev[1:Nyrs],dev[isim,1:Nyrs,icu]
)     #to determine average correlation of each CU to aggregate trend
        }
        TestMUsd=TestMUsd+MU_sd

        TestMUmu=TestMUmu+MU_mu
        TestSimMUmu=TestSimMUmu+mean(MUdev)
      }
      #finish test calculations
      TestCUsd=TestCUsd/Ntrials;TestSimCUsd=TestSimCUsd/Ntrials
      TestRho=TestRho/Ntrials;TestSimRho=TestSimRho/Ntrials
```

```
     TestMUsd=TestMUsd/Ntrials;TestSimCUsd=TestSimCUsd/Ntrials
     TestCUmu=TestCUmu/Ntrials;TestMUmu=TestMUmu/Ntrials
     TestSimCUmu=TestSimCUmu/Ntrials;TestSimMUmu=TestSimMUmu/Ntrials
     TestResid=TestResid/Ntrials

     fnt="Resid.out"

     write(file=fnt,"MF FC LT NT ST IFC",ncolumns=1,append=F)
     write.table(file=fnt,cbind(TestResid,rowMeans(TestResid)),col.nam
es=F,row.names=F,append=T)

     write(file=fnt,"",ncolumns=1,append=T)
     write(file=fnt,c(TestCUmu,TestMUmu),ncolumns=Ncu+1,append=T)
     write(file=fnt,c(TestSimCUmu,TestSimMUmu),ncolumns=Ncu+1,append=T
)

     write(file=fnt,"",ncolumns=1,append=T)
     write(file=fnt,c(CU_sd,MU_sd),ncolumns=Ncu+1,append=T)
     write(file=fnt,c(TestCUsd,TestMUsd),ncolumns=Ncu+1,append=T)

     write(file=fnt,"",ncolumns=1,append=T)
     write(file=fnt,rho,ncolumns=Ncu,append=T)
     write(file=fnt,TestRho,ncolumns=Ncu,append=T)


     ####### End deviate computation
######################################################################
#################################################################


     Soff=0;if(ModName=="Ricker_Dep") Soff=1000 # Soff is for
Depensatory model
     for(ims in MSset){ # for every value in the smolt-to-adult
survival set

           BaseMS=ims

           for(ih in ERset){ # for every value in the exploitation
rate set

             BaseER=ih

             if(BaseER != 0) ERshape1 <- BaseER^2 * (((1-
BaseER)/sigma^2) - (1/BaseER))
             if(BaseER != 0) ERshape2 <- ERshape1 * (1/BaseER - 1)

                TotEsc=matrix(nrow=Ntrials,ncol=Nyrs,data=0) # empty
matrix to be filled with DU escapement values
                Status=0   # To be filled by Mean Frequency of Success
```

```
                Esc=array(data=0,dim=c(Ntrials,Nyrs,Ncu)) # empty
array to be filled with CU escapement values

                for (icu in 1:Ncu){

                      IniEsc=vector(length=4) #Get initial escapements
2012-2015
                      d1=subset(d0,CUid==icu & Year>=fyr & Year<=fyr+3)
                      IniEsc=d1$Sp

                      # For selecting parameters later, combining
paramater name with icu number

     icol1=which(names(p)==paste("alpha.",icu,sep=""));icol2=which(nam
es(p)==paste("beta.",icu,sep=""));icol3=which(names(p)=="gamma")

                      for(isim in 1:Ntrials){
                           irow=postrecs[isim]   # assign initial
posterior distribution starting row

                           for(iyr in 1:Nyrs){

                             # assign parameter values from set for CU
                             alpha=p[irow,icol1]
                             b=p[irow,icol2]
                             g=p[irow,icol3]

                                 if(Yr[iyr]<=2017){
                                      Sp=IniEsc[iyr]
                                      Esc[isim,iyr,icu]=IniEsc[iyr]
     #Use observed escapements for '14-'17

                                 } else {
                                      Sp=Esc[isim,iyr,icu]

                                 }

                                 if(iyr<=Nyrs-4){

                                   if(iyr==1)LSurv4=log(rlnorm(1,
meanlog = log(BaseMS), sdlog = lnSDms))
                                   if(iyr== 1 &
LSurv4>log(0.0671))LSurv4=log(0.0671);if(iyr== 1 &
LSurv4<log(0.0027))LSurv4=log(0.0027)

                                   LSurv3 = LSurv4 # Smolt-to-adult of
this years Age 3s is the same as prior years Age 4s

                                      LSurv=log(rlnorm(1, meanlog =
log(BaseMS), sdlog = lnSDms))    #account for variation in smolt-to-
adult survival among years, adding lognormal variability
```

```
	if(LSurv>log(0.0671))LSurv=log(0.0671);if(LSurv<log(0.0027))LSurv
=log(0.0027) # bind LSurv by % above and below historic max and min

					LSurv4 = LSurv # Age 4s get new
MS

					# Aplpha, b, and g, are shared
between Age 3 and 4 but LSurv is different
					Rec3 = pAge3[icu] *
(Sp/(Sp+Soff)) * Sp*exp(alpha - b*Sp + g*LSurv3)# + dev[isim,iyr,icu])
	#deviates account for correlation among CUs
					Rec4 = (1-pAge3[icu]) *
(Sp/(Sp+Soff)) * Sp*exp(alpha - b*Sp + g*LSurv4)# + dev[isim,iyr,icu])
	#deviates account for correlation among CUs

					#Rec is NaN or Inf because Sp is
too large so X>700 in exp(X).
					if(is.na(Rec3)==T | Rec3>1e6/2)
Rec3=1e6/2
					if(is.na(Rec4)==T | Rec4>1e6/2)
Rec4=1e6/2 # I have however added an additional line for Rec4

					if(iyr==1 & BaseER != 0){
					  ER4=rbeta(1, ERshape1,
ERshape2)
					} else if(iyr== 1 & BaseER == 0)
{
					  ER4 = BaseER # assuming
perfect 0 fishing rate, rbeta does not sample well at mu = 0
					  }

					ER3 = ER4 # Exploitation Rate of
this years Age 3s is the same as prior years Age 4s

					if(BaseER != 0) {
					  ER4=rbeta(1, ERshape1,
ERshape2) #account for variation in ER among years, adding beta
distributed variability

					} else if(BaseER == 0) {
					  ER4 = BaseER # assuming
perfect 0 fishing rate
					}


					#Predict escapement in 3 and 4
years given recruitment and age structure
					if(Yr[iyr+3]>=fyr)
Esc[isim,iyr+3,icu]=Esc[isim,iyr+3,icu]+Rec3*(1-ER3)

	Esc[isim,iyr+4,icu]=Esc[isim,iyr+4,icu]+Rec4*(1-ER4)
```

```
                                      # Quasi-extirpation Threshold of
100 (from literature, i.e. an assumption).
                                      if(Esc[isim,iyr+1,icu] <= 100 &
                                         Esc[isim,iyr+2,icu] <= 100 &
                                         Esc[isim,iyr+3,icu] <= 100)
Esc[isim,c(iyr+1, iyr+2,iyr+3, iyr+4),icu] = 0

                                 }
                           }

                      }#isim

                      icuEsc <- data.frame(Model = rep(ModName,
Ntrials*length(Yr)),
                                           baseER = rep(BaseER,
Ntrials*length(Yr)),
                                           baseMS = rep(BaseMS,
Ntrials*length(Yr)),
                                           Ncu = rep(icu,
Ntrials*length(Yr)),
                                           trial = rep(c(1:Ntrials),
each = length(Yr)),
                                           ry = rep(Yr, Ntrials),
                                           esc = as.vector(t(Esc[ , ,
icu])))

                      write.table(file=fnout2, icuEsc, append=T,
row.names = F, col.names = F) # Save Simulation Data

                      CP=matrix(data=0,nrow=Ntrials,ncol=5) #Compute
confidence intervals on conservation performance

                }#icu


                #Calculate DU geomean and proportion of simulation-
years where geometric mean escapent for all CUs exceed the 1000
spawner requirements (for all subpops) for all CUs in same year
                for(isim in 1:Ntrials){
                      for(iyr in 1:Nyrs){
                           TotEsc[isim,iyr]=sum(Esc[isim,iyr,1:Ncu])
                      }
                }

                Pass2=matrix(data=0,nrow=Ntrials,ncol=NyrsToUse)
                GeoMean=matrix(data=0,nrow=Ntrials,ncol=NyrsToUse)
                for(isim in 1:Ntrials){
                      jj=0
                      for(ii in imin:imax){
                           jj=jj+1
```

```
                           GeoMean[isim,jj]=prod(TotEsc[isim,ii-
2],TotEsc[isim,ii-1], TotEsc[isim,ii])^(1/3)
                      }


     CP[isim,5]=length(which(GeoMean[isim,1:NyrsToUse]>=MUbench))/Nyrs
ToUse #proportion of years where target exceeded for each trial
                      CP[isim,1]=
ifelse(GeoMean[isim,NyrsToUse]>=MUbench, 1, 0)   #was target exceeded
for each trial's last year
                }


     Status=length(which(GeoMean>=MUbench))/(Ntrials*NyrsToUse)
                Status2 = mean(CP[ , 1])

                CI_MUhi=as.numeric(quantile(CP[,5],prob=c(0.1, 0.25,
0.50, 0.75, 0.9)))

                #### Population Trajectory Estimate ###

                AriMean=matrix(data=0,nrow=Ntrials,ncol=NyrsToUse)
                for(isim in 1:Ntrials){
                  jj=0
                  for(ii in imin:imax){
                    jj=jj+1
                    AriMean[isim,jj]=mean(TotEsc[isim,ii-2],
TotEsc[isim,ii-1], TotEsc[isim,ii])
                  }
                }

                traj <- data.frame(trial = rep(c(1:Ntrials), each =
NyrsToUse),
                                   ry = rep(Yr[imin:imax], Ntrials),
                                   esc = as.vector(t(AriMean)))

                traj$lnesc <- log(traj$esc+1) # can't have ln(0), i.e.
when fish were extirpated

                traj_out <- matrix(data=0,nrow=Ntrials,ncol=2)

                for(sim in 1:Ntrials){
                  traj.mod <- gls(lnesc~ry, data = traj[traj$trial ==
sim, ], corr = corAR1(), method = "ML", control = lmeControl(opt =
"optim"))
                  traj_out[sim,1] <- round(coef(traj.mod)[2],3)
                  traj_out[sim,2] <- round((exp(coef(traj.mod)[2]*10)-
1)*100, 1)
                }

                traj_b <- mean(traj_out[ , 1])
                traj_m <- mean(traj_out[ , 2])
```

```
                traj_quantile <- quantile(traj_out[,2],prob=c(0.1,
0.25, 0.5, 0.75, 0.9))

                write(file=fnout,c("MU_Target", BaseMS, BaseER,
Status2, Status, CI_MUhi,
                                  traj_b, traj_m, traj_out),
ncolumns=14,append=T)

                full_out <- data.frame(Model = rep(ModName, Ntrials),
                                    baseER = rep(BaseER, Ntrials),
                                    baseMS = rep(BaseMS, Ntrials),
                                    trial = c(1:Ntrials),
                                    suc.end = CP[ , 1],
                                    suc.freq = CP[ ,5],
                                    traj_slope = traj_out[ ,1],
                                    traj_percent = traj_out[ ,2]
                                    )

                write.table(file=fnout3, full_out, append=T, row.names
= F, col.names = F) # Save FULL Simulation Data


           }#end harvest
      }#end smolt-to-adult survival
}#end model types


end_time <- Sys.time()

end_time - start_time
```

APPENDIX 12. ADDITIONAL MODEL AND SIMULATION DIAGNOSTICS AND RESULTS

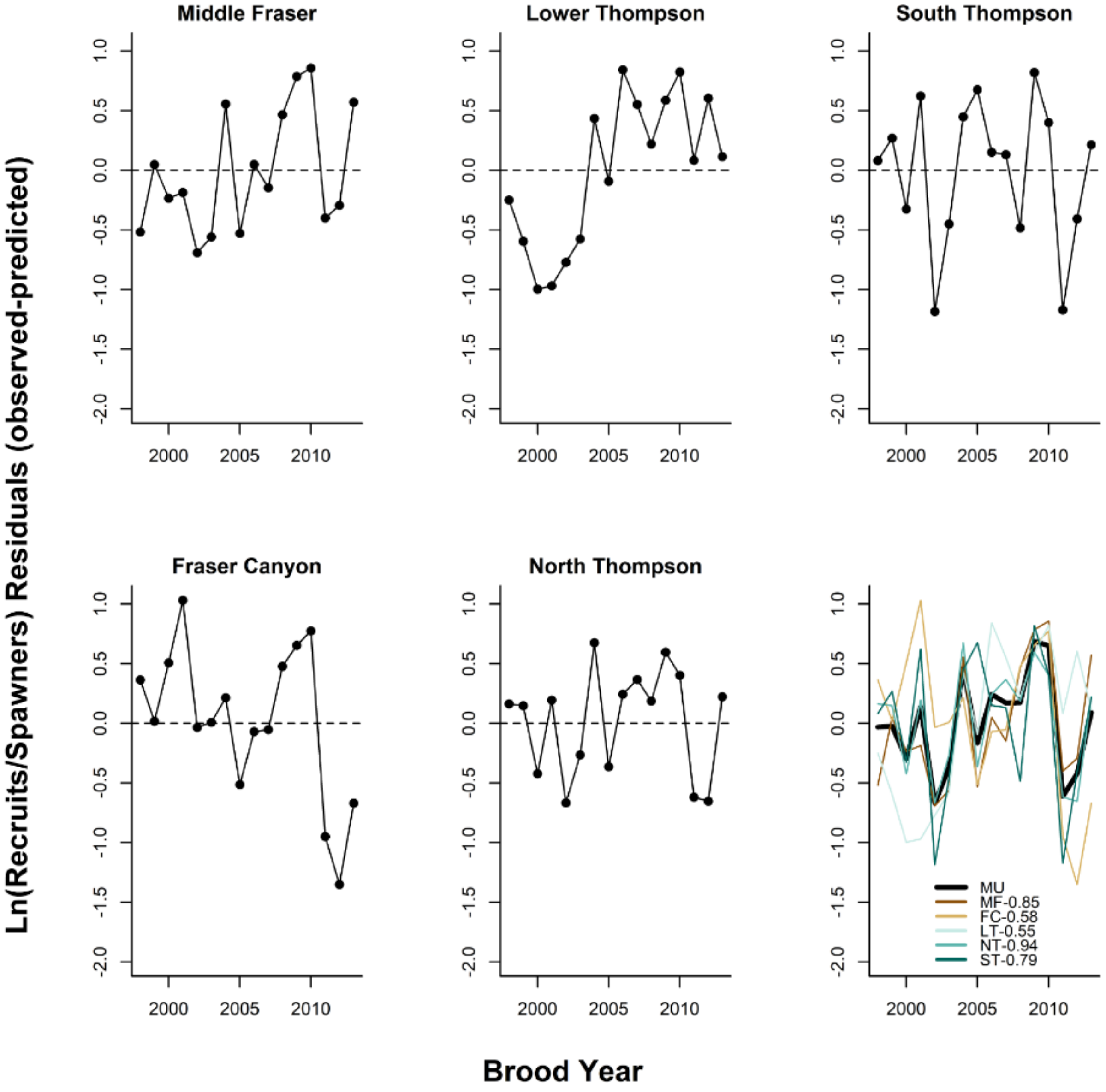

Figure 31. Median Residuals over time for ***Ricker model*** *with vague priors* ***with smolt-to-adult survival*** *covariate. The lower-right plot shows the mean annual deviations across CUs (thick black line) and CU-specific deviations (colored lines). The values in the legend of the lower-right plot are the correlations (Pearson 'r' values) of residuals between each CU and the aggregate trend.*

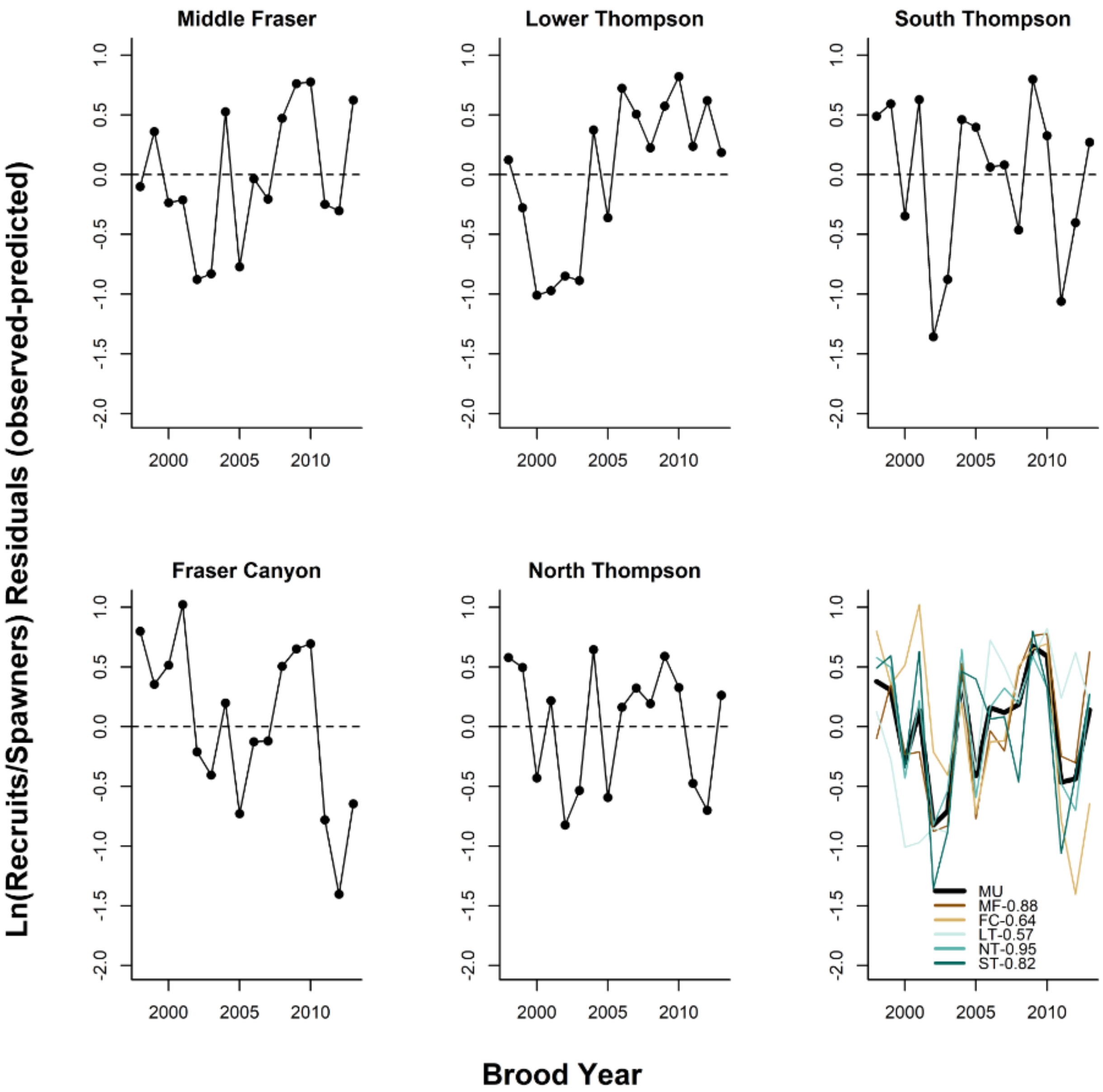

*Figure 32. Median Residuals over the time series for **Ricker model** with vague priors and **no smolt-to-adult survival** covariate. See Figure 31 for caption details.*

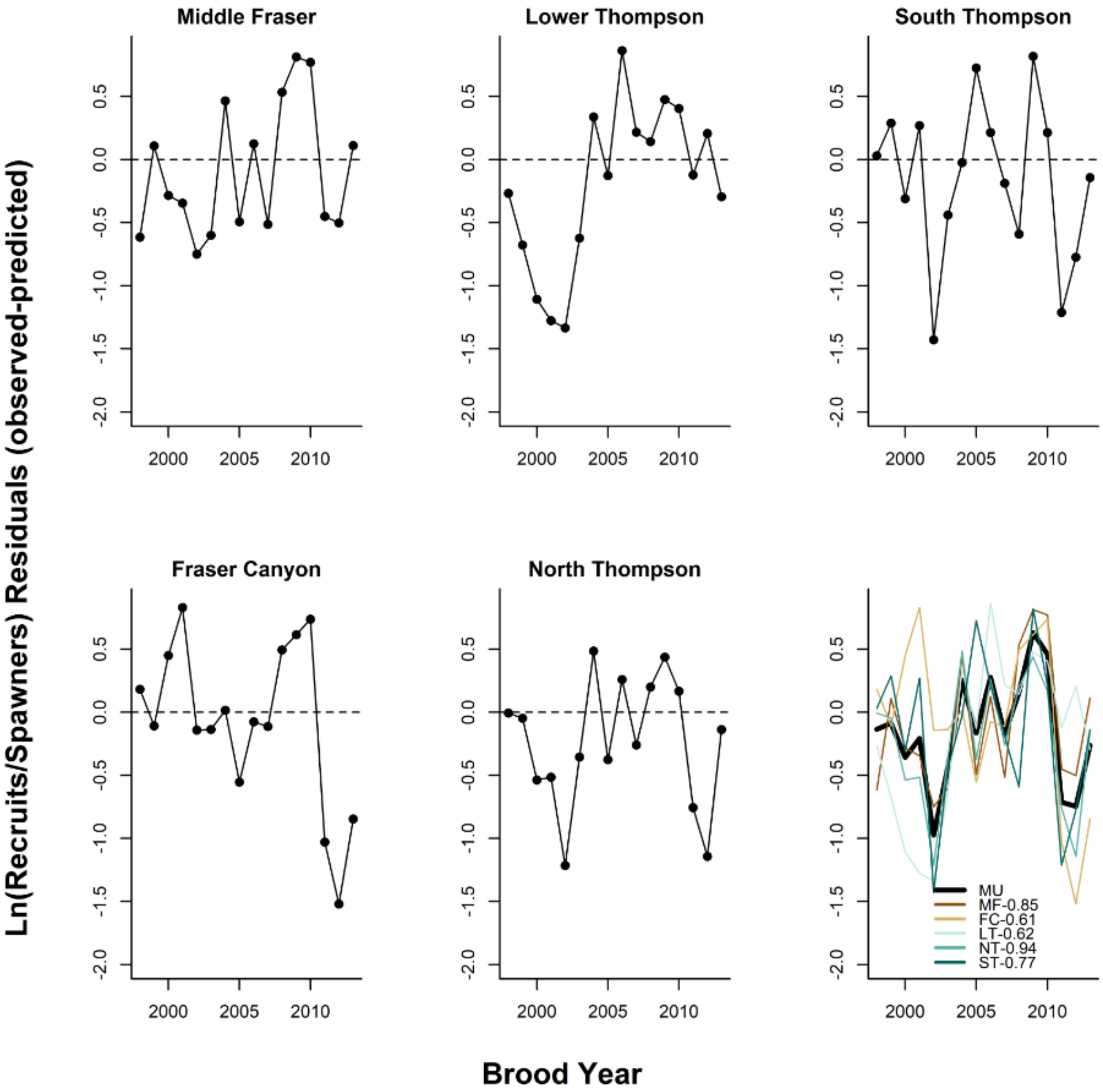

Figure 33. Median Residuals over the time series for ***Ricker-PriorCap*** *model with informative prior on carrying capacity* ***with smolt-to-adult survival*** *covariate. See Figure 31 for caption details.*

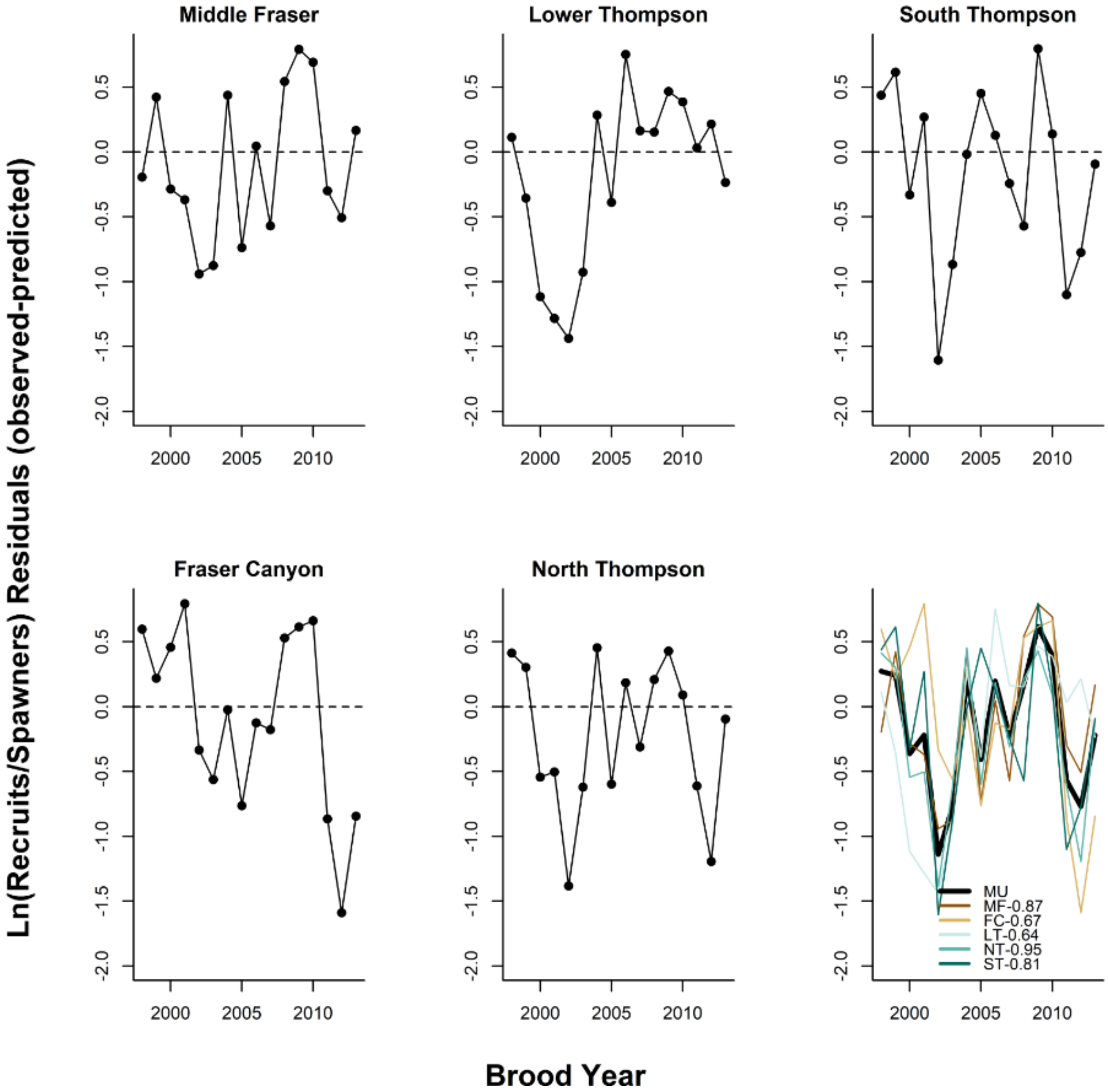

*Figure 34. Median Residuals over the time series for **Ricker-PriorCap** model with informative prior on carrying capacity and **no smolt-to-adult survival** covariate. See Figure 31 for caption details.*

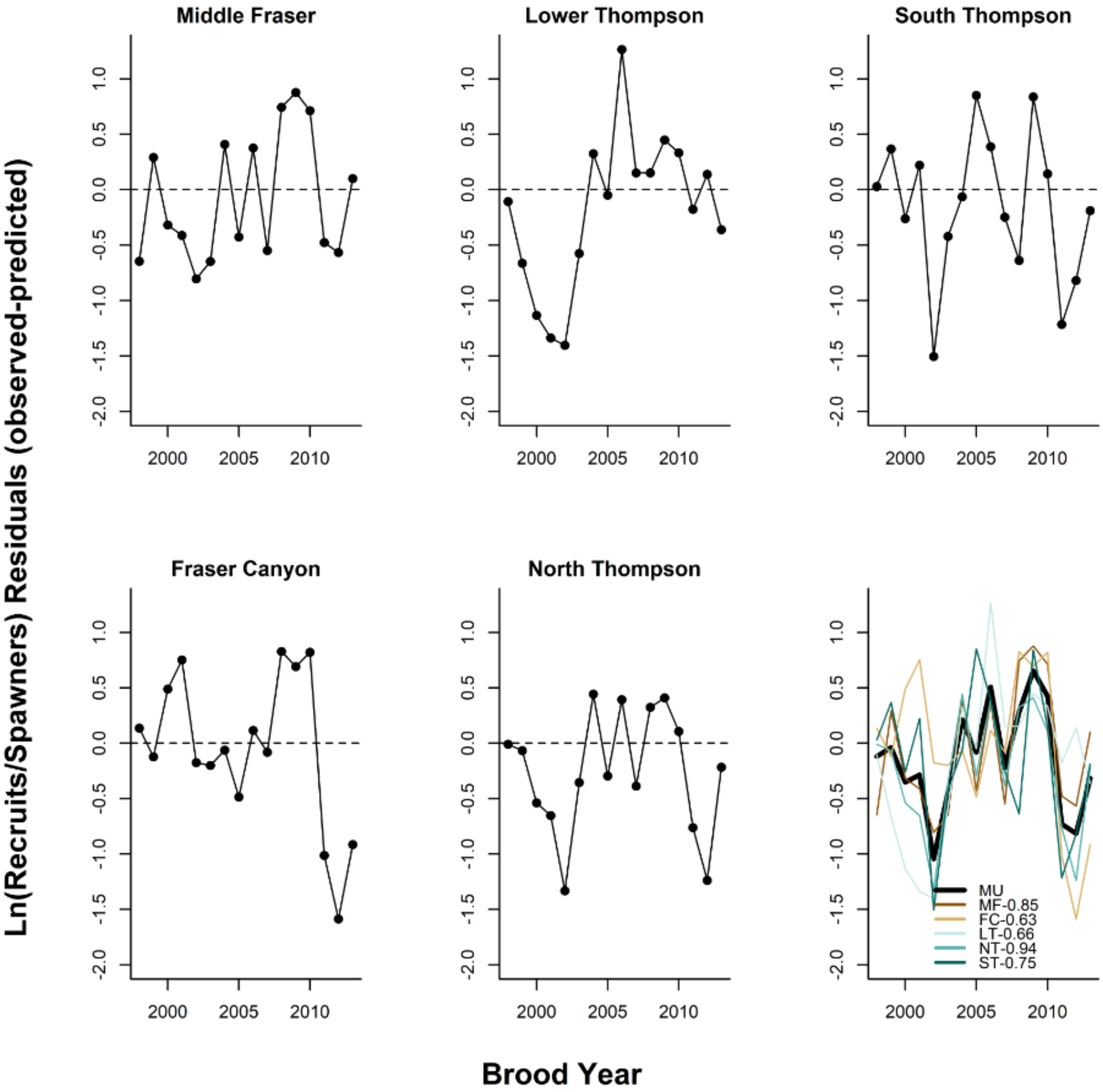

Figure 35. Median Residuals over the time series for ***Ricker-Dep*** *model with informative prior on carrying capacity, assumed depensatory dynamics, and* ***with smolt-to-adult survival*** *covariate. See Figure 31 for caption details.*

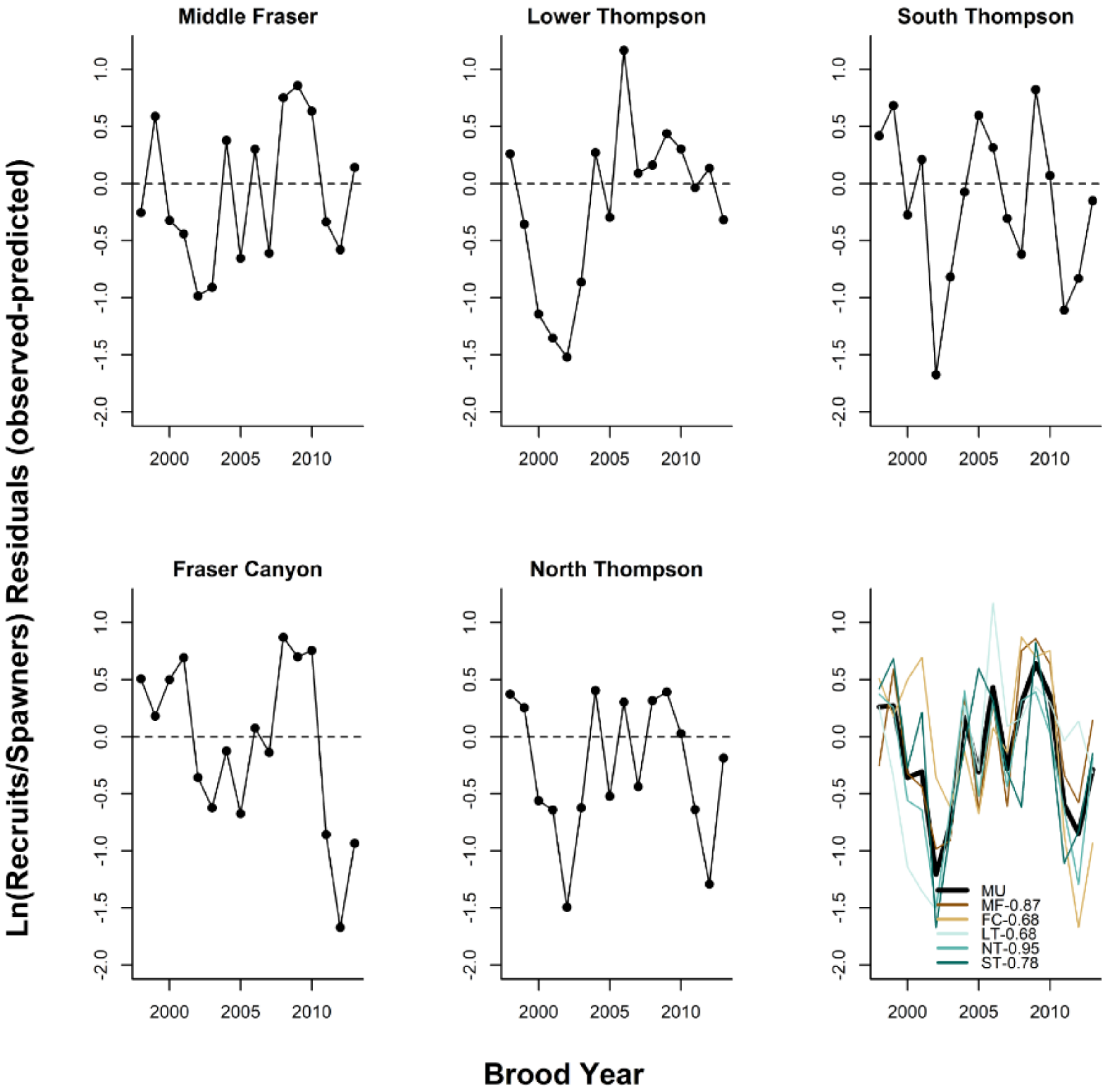

Figure 36. Median Residuals over the time series for ***Ricker-Dep*** *model with informative prior on carrying capacity, assumed depensatory dynamics, and* ***no smolt-to-adult survival*** *covariate. See Figure 31 for caption details.*

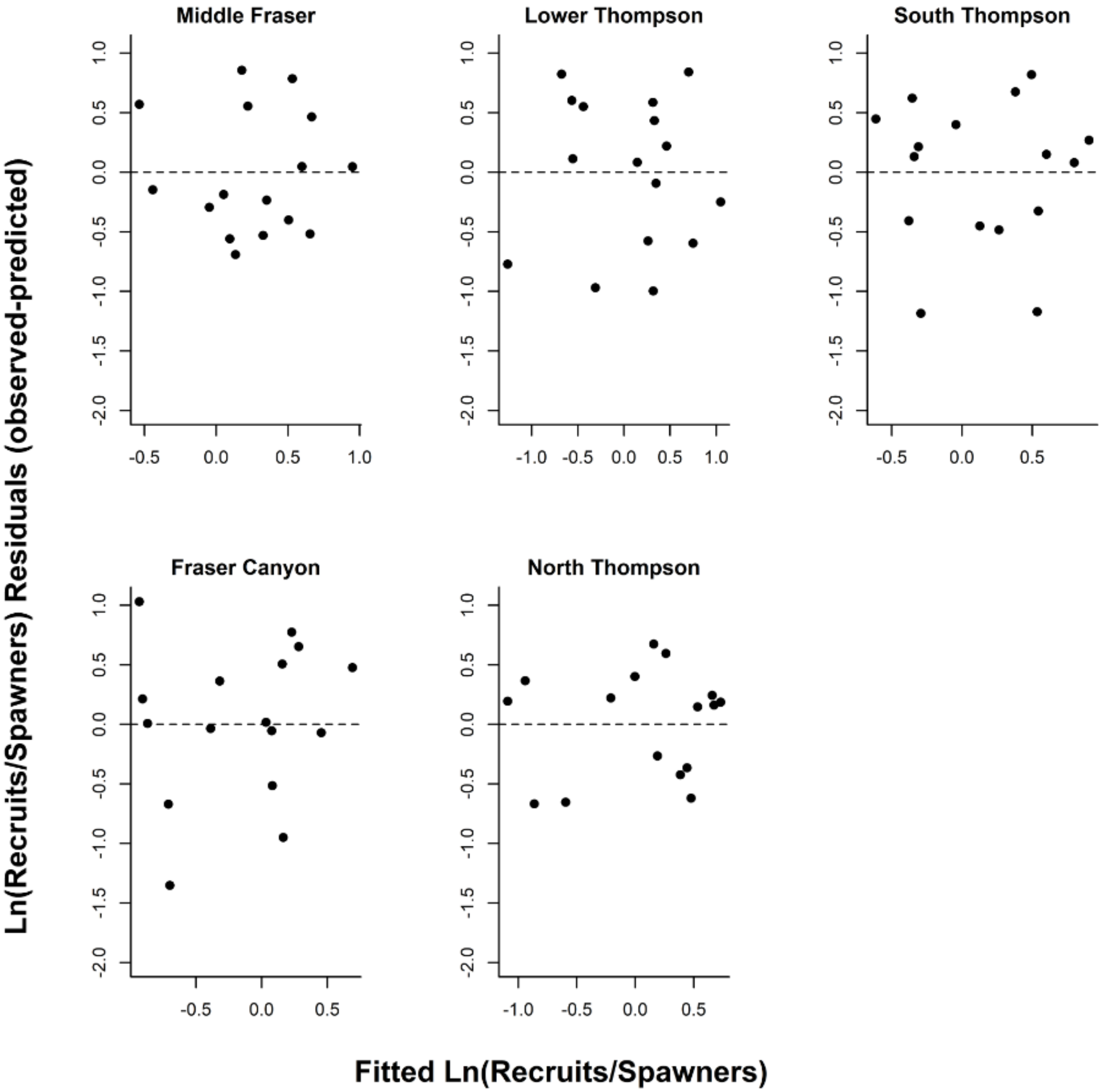

Figure 37. Median Residuals against fitted values for ***Ricker*** *model with vague priors and* ***with smolt-to-adult survival*** *covariate.*

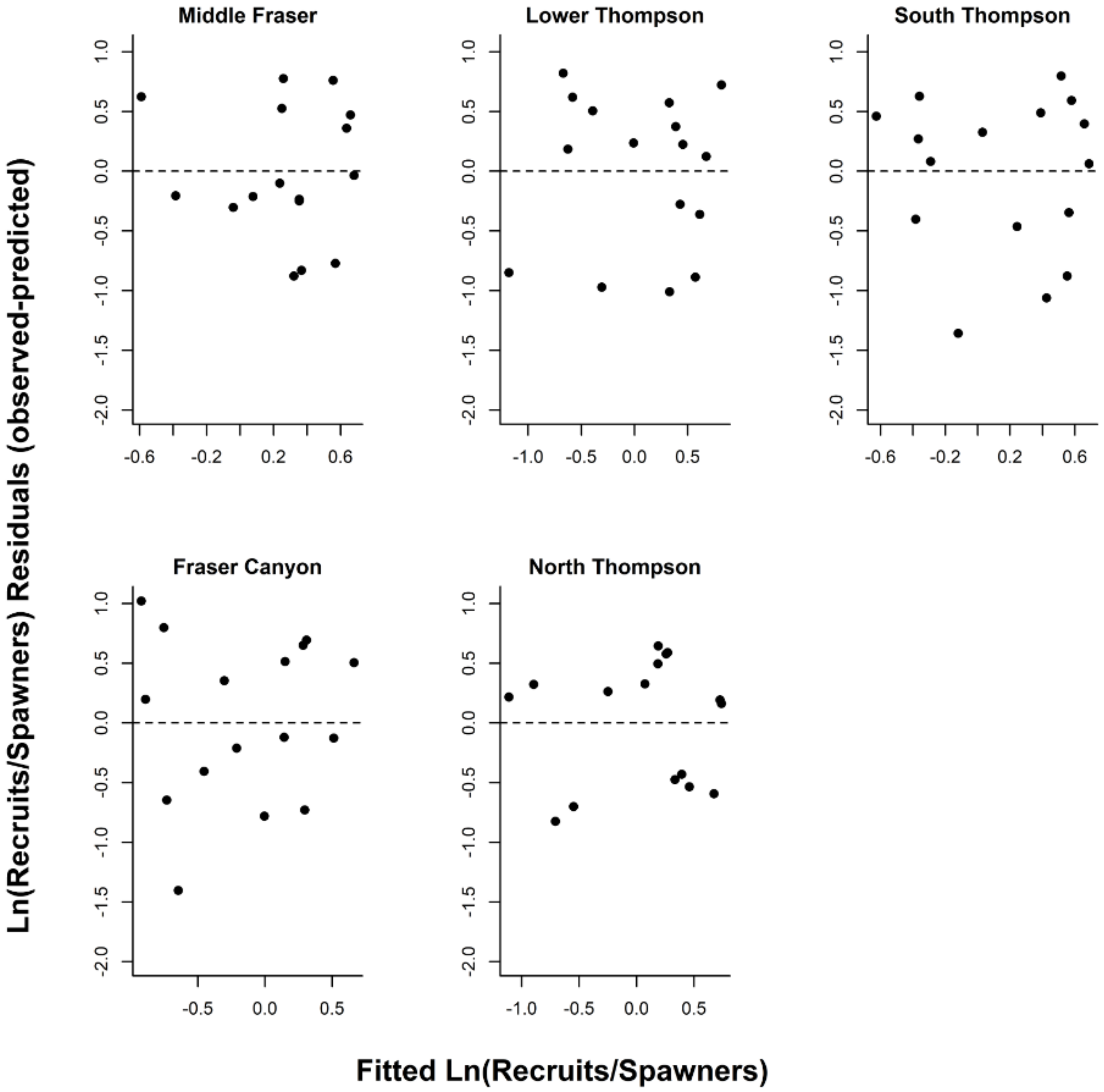

Figure 38. Median Residuals against fitted values for ***Ricker*** *model with vague priors and* ***no smolt-to-adult survival*** *covariate.*

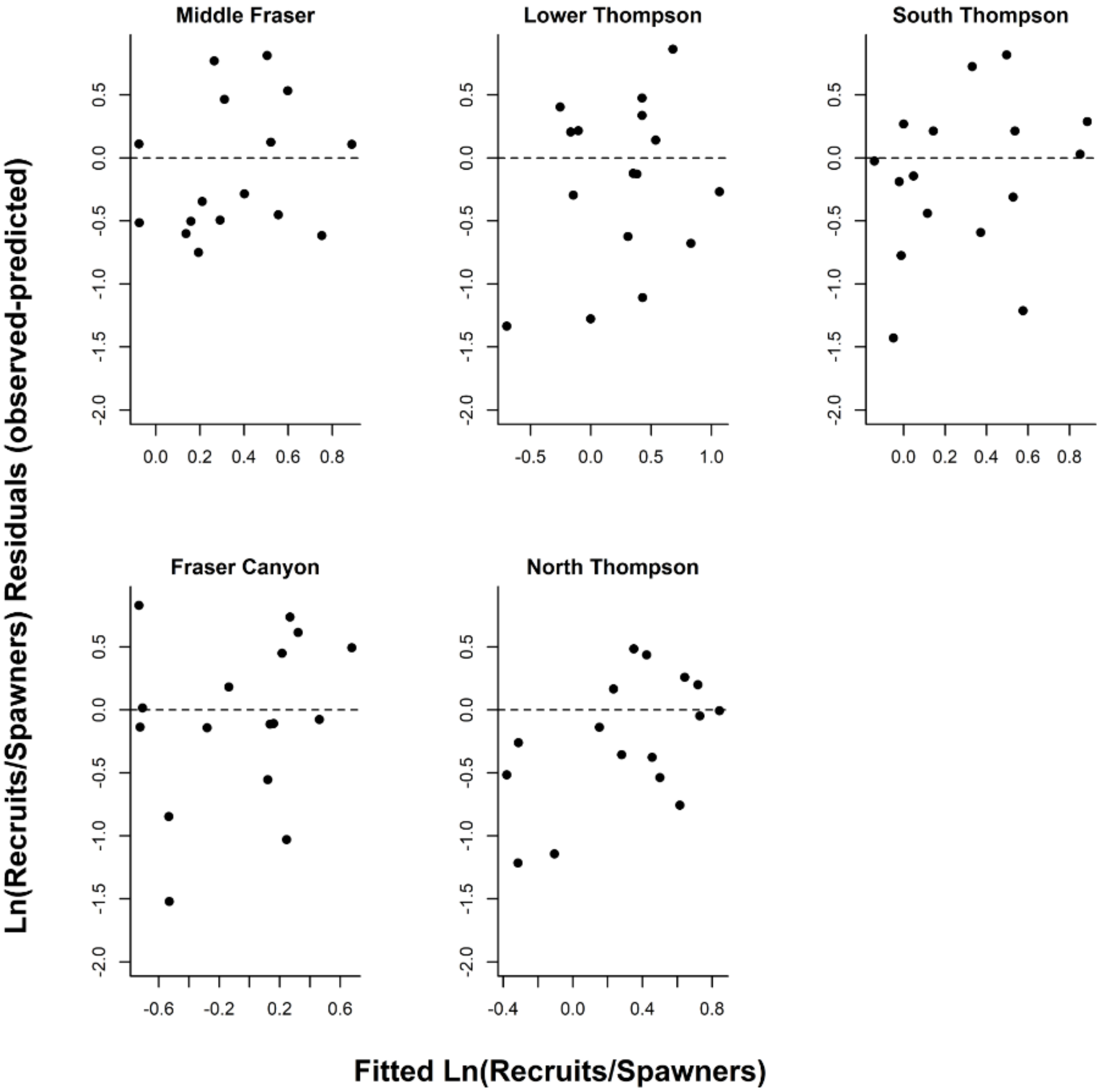

Figure 39. Median Residuals against fitted values for ***Ricker-PriorCap*** *model with informative prior on carrying capacity* ***with smolt-to-adult survival*** *covariate.*

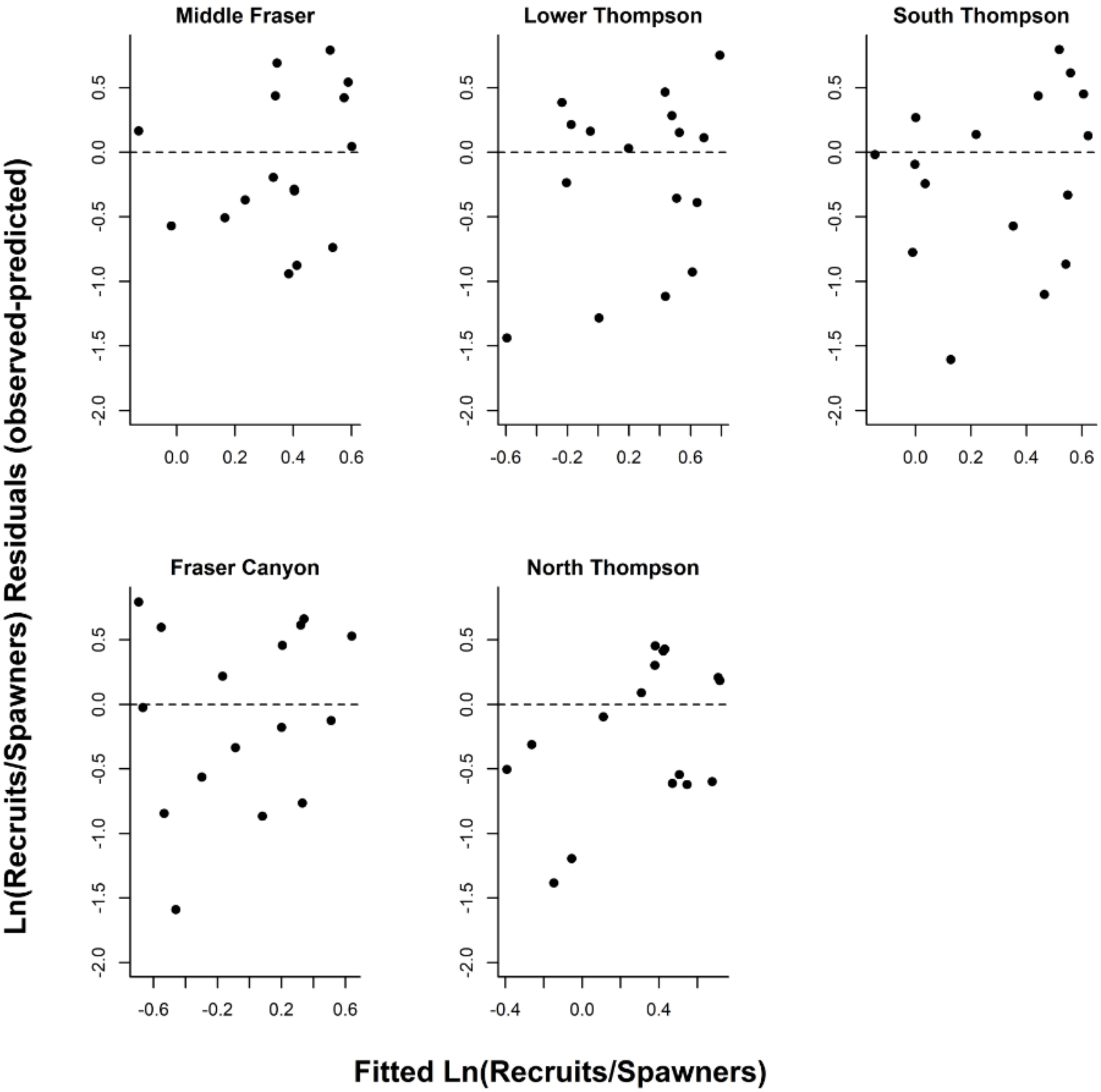

Figure 40. Median Residuals against fitted values for ***Ricker-PriorCap*** *model with informative prior on carrying capacity and* ***no smolt-to-adult survival*** *covariate.*

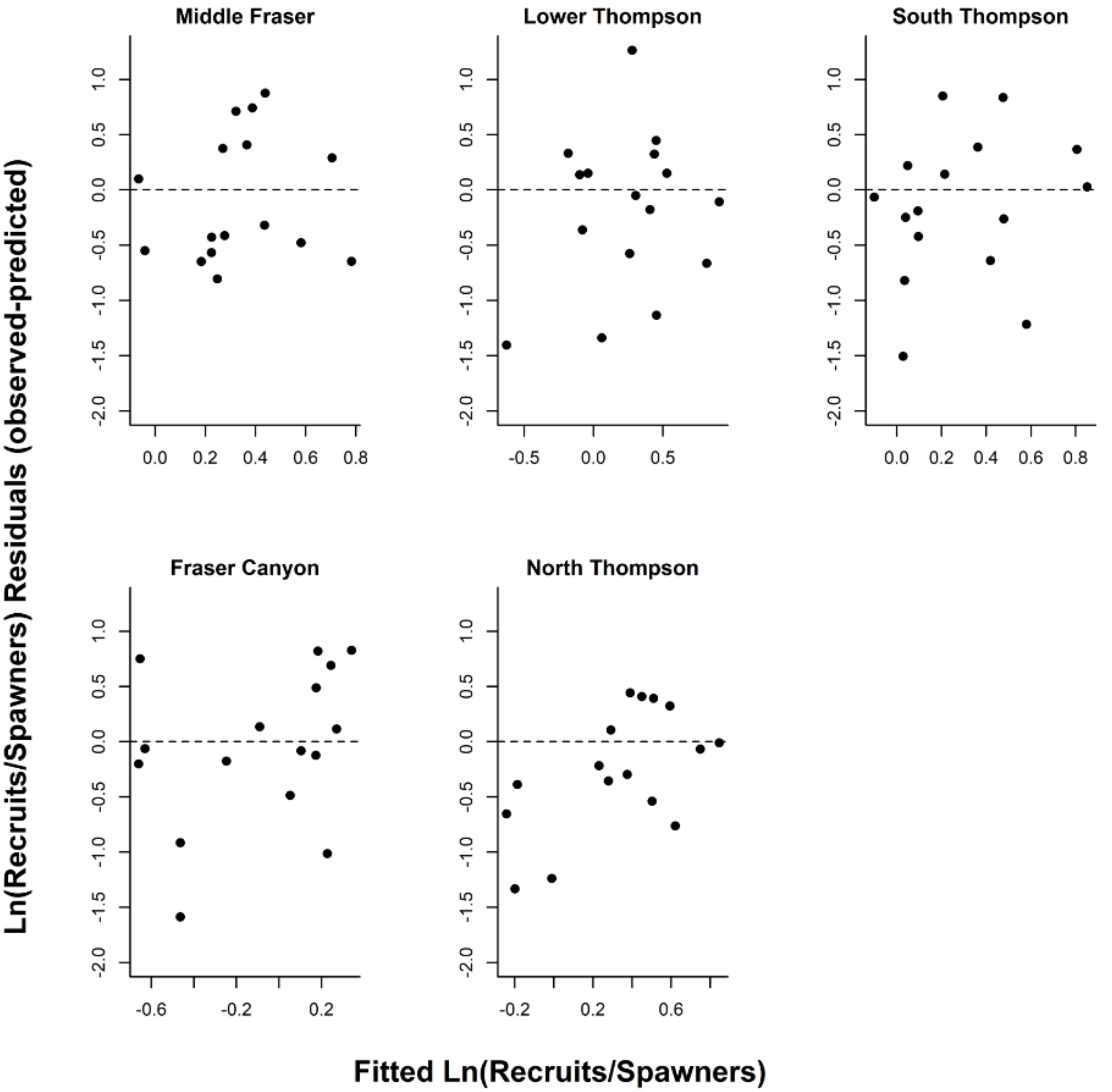

*Figure 41. Median Residuals against fitted values for **Ricker-Dep** model with informative prior on carrying capacity, assumed depensatory dynamics, and **with smolt-to-adult survival** covariate.*

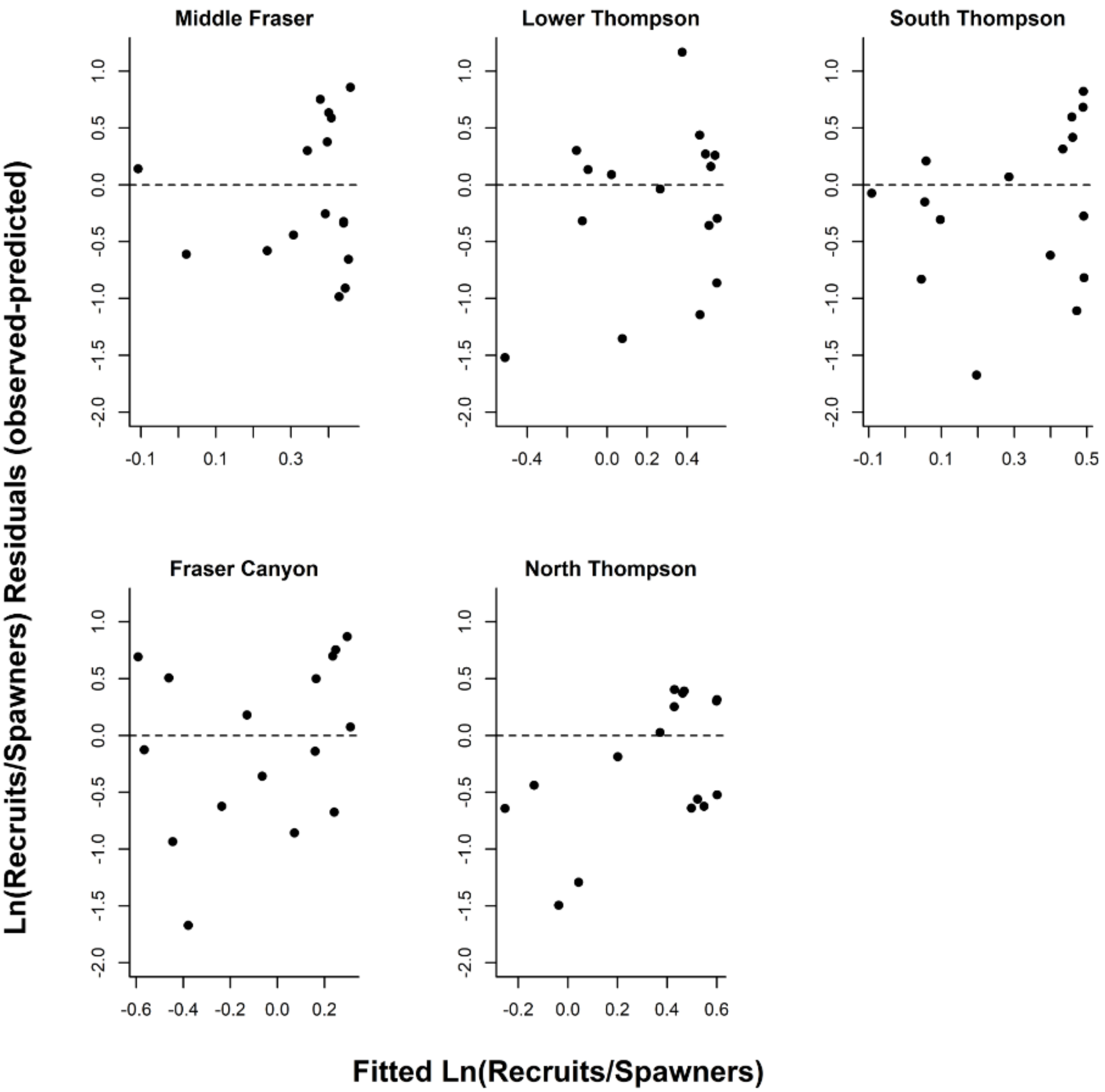

Figure 42. Median Residuals against fitted values for ***Ricker-Dep*** *model with informative prior on carrying capacity, assumed depensatory dynamics, and* ***no smolt-to-adult survival*** *covariate.*

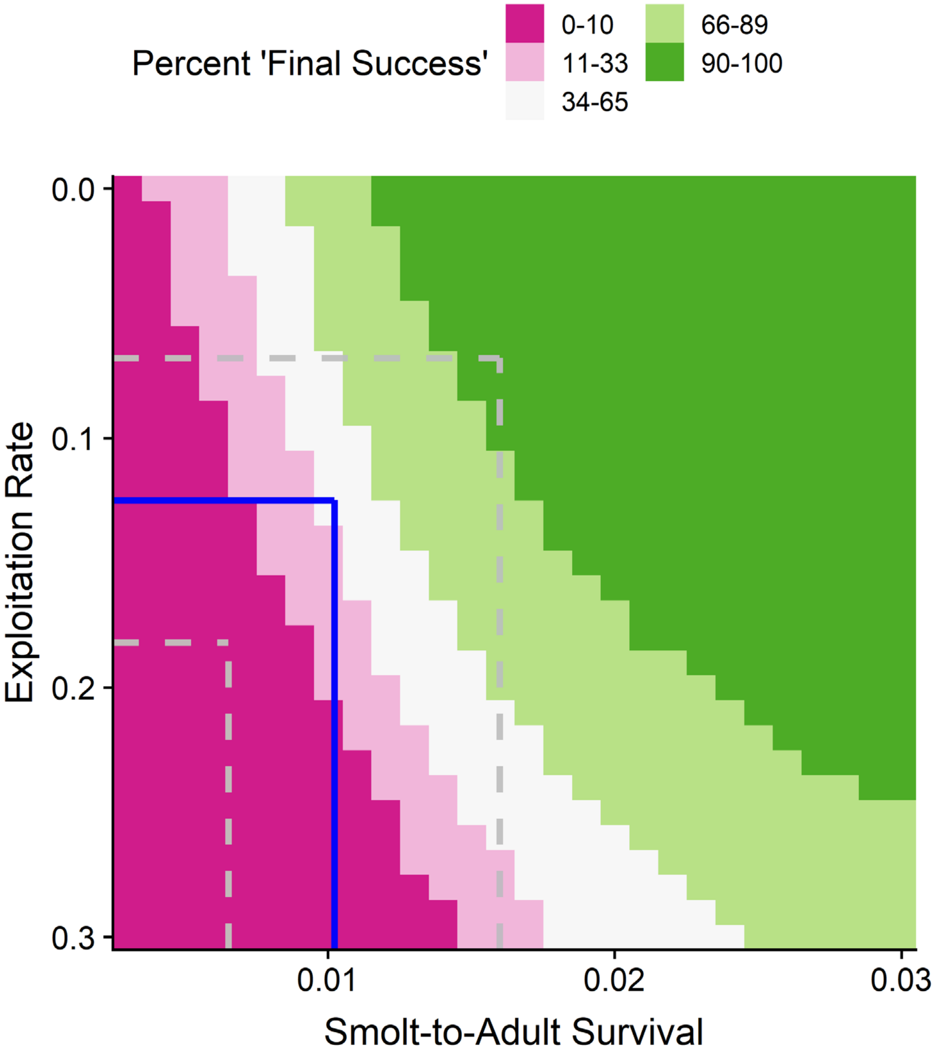

Figure 43. Proportion of Monte Carlo simulation results from the ***Ricker*** *model where the 3-year geometric mean was ≥ 35,935 ('Final Success'). The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average*

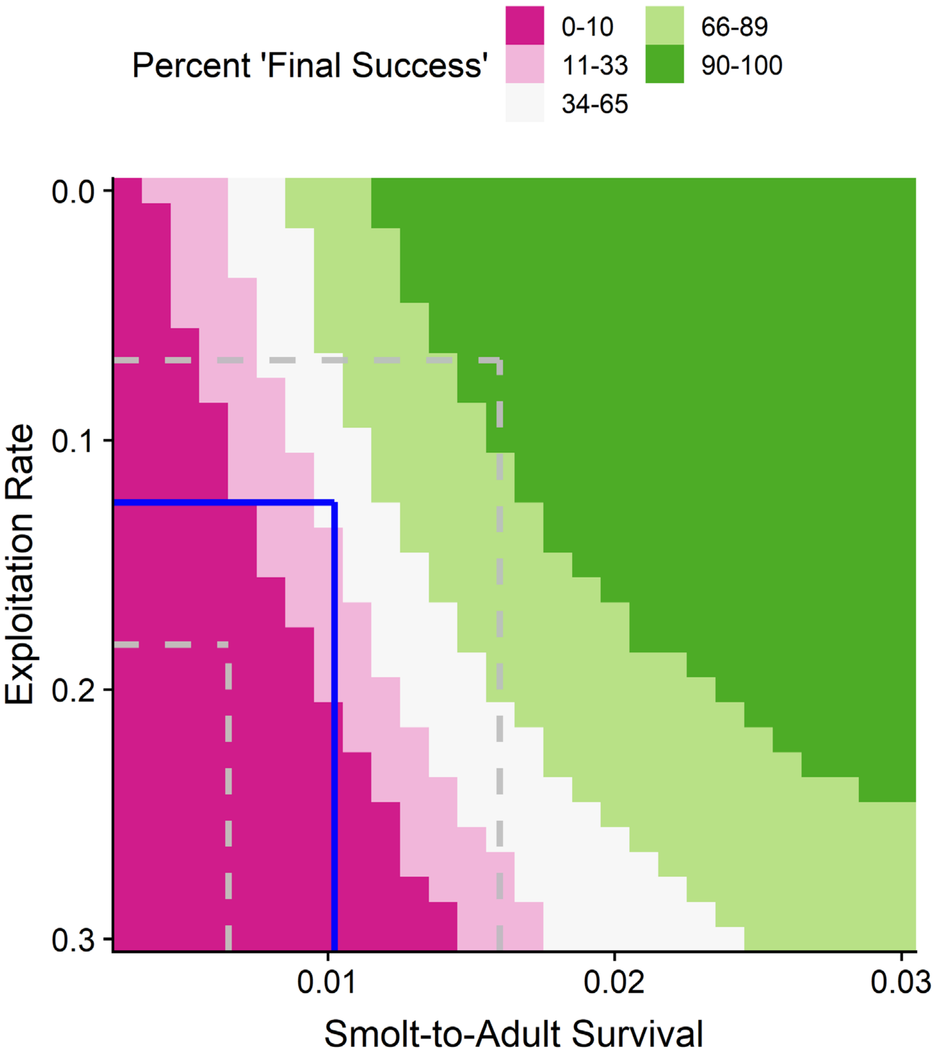

Figure 44. Proportion of Monte Carlo simulation results from the ***Ricker-PriorCap*** *model where the 3-year geometric mean was ≥ 35,935 ('Final Success'). The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average*

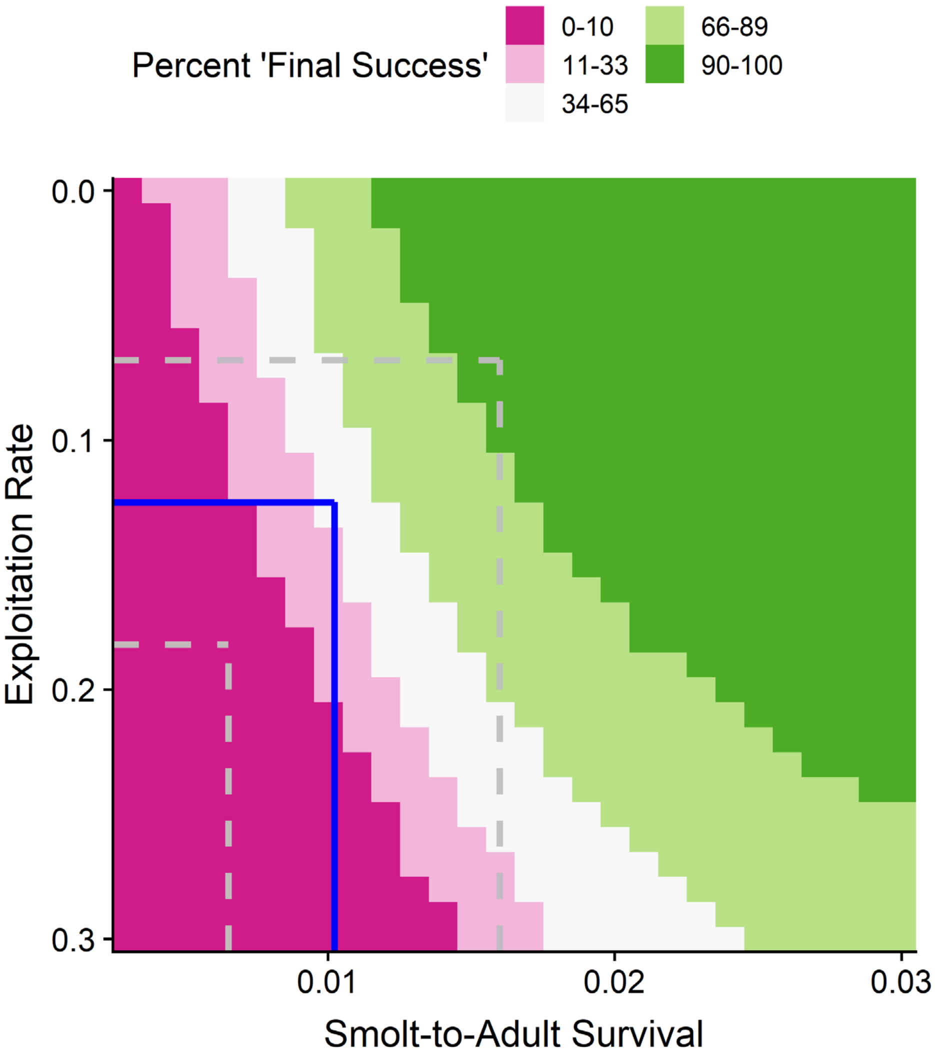

Figure 45. Proportion of Monte Carlo simulation results from the ***Ricker-Dep*** *model where the 3-year geometric mean was ≥ 35,935 ('Final Success'). The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average*

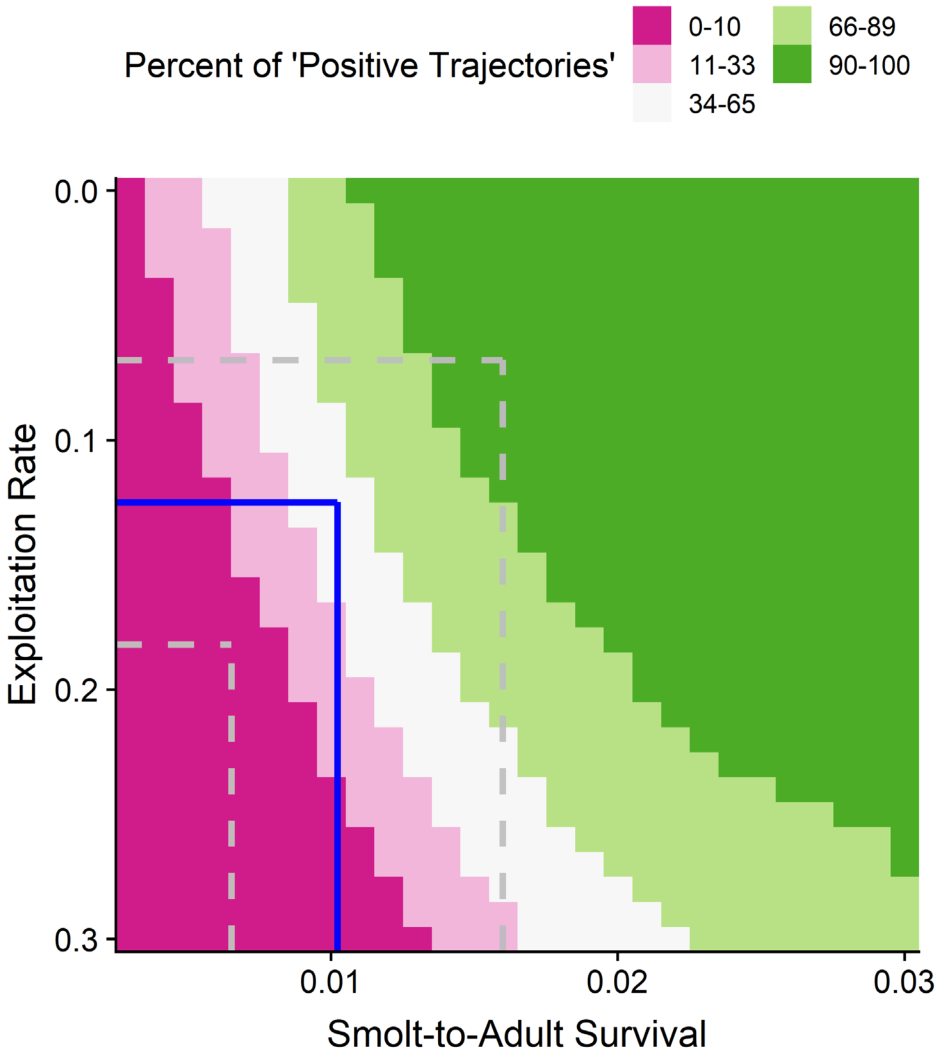

Figure 46. Proportion of Monte Carlo simulation results from the ***Ricker*** *model where the population trajectory was positive ('Positive Trajectory'). The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average*

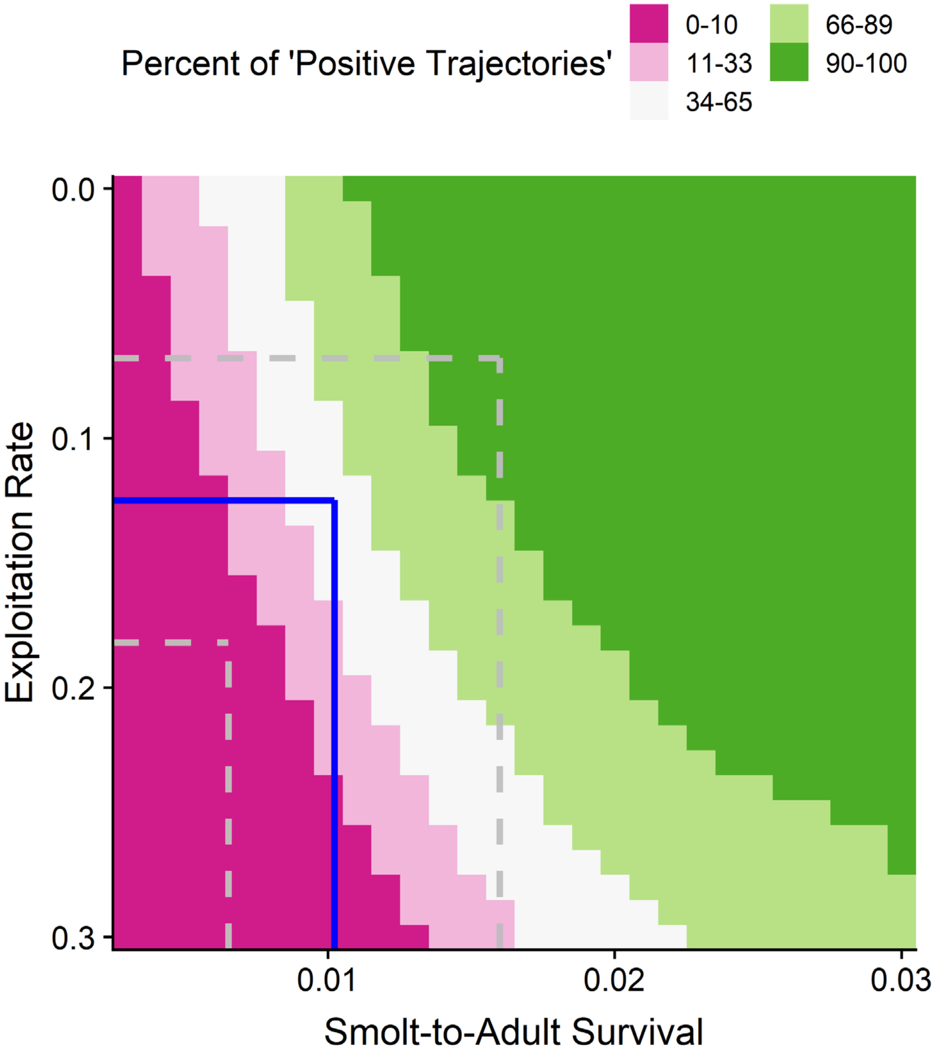

Figure 47. Proportion of Monte Carlo simulation results from the ***Ricker-PriorCap*** *model where the population trajectory was positive ('Positive Trajectory'). The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average*

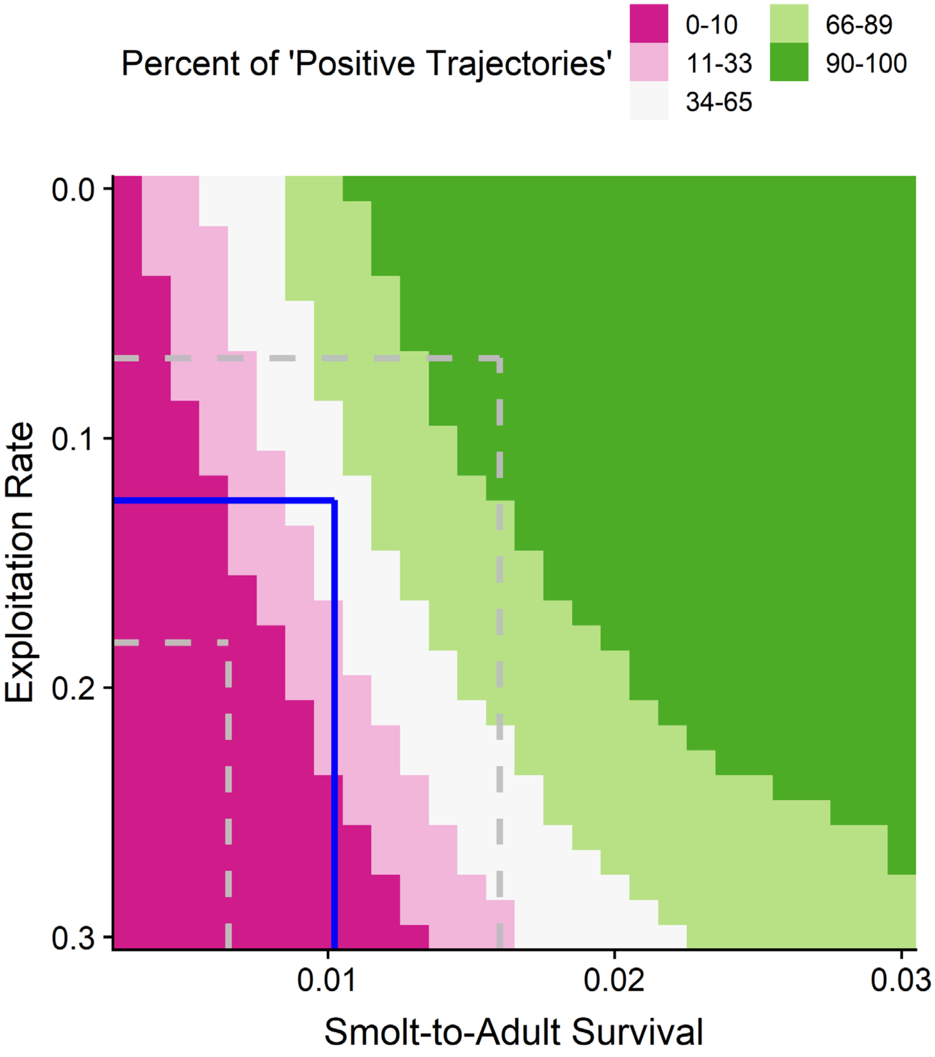

Figure 48. Proportion Monte Carlo simulation results from the Ricker-Dep model where the population trajectory was positive ('Positive Trajectory').The blue lines intersect at the current smolt-to-adult survival and exploitation rate averages. The gray dashed lines represent one standard deviation above and below each metrics average

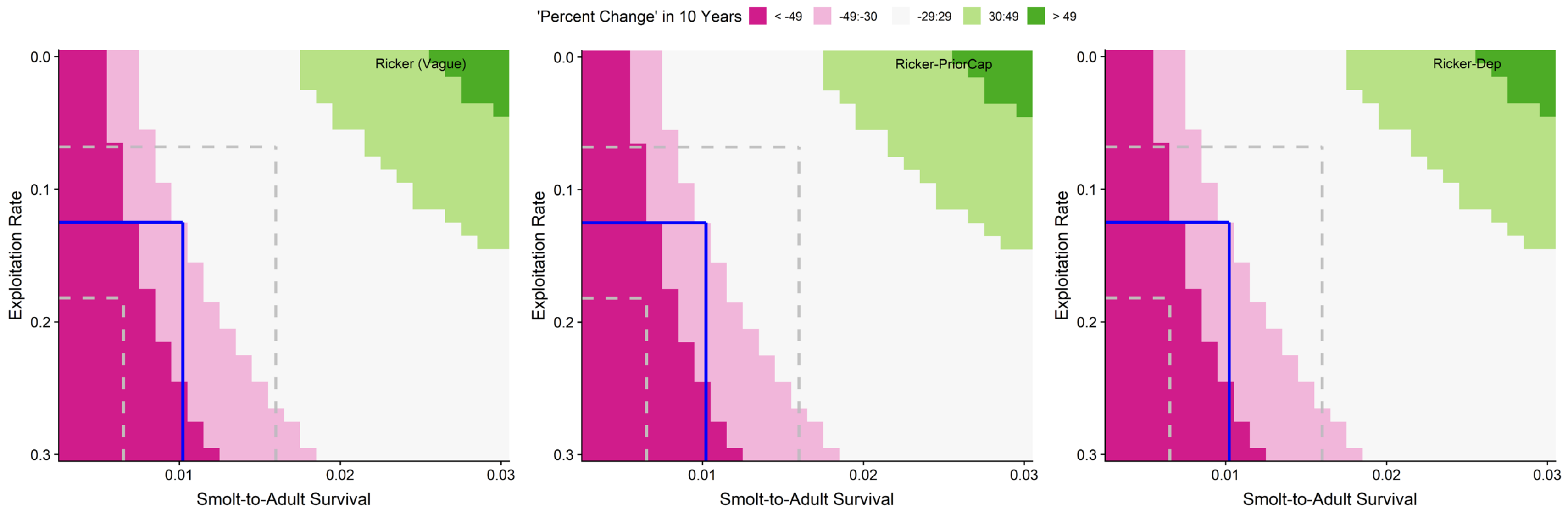

Figure 49. Ricker (left panel), Ricker-PriorCap (middle panel), and Ricker-Dep (right panel) median percent change in 10 years from simulation trials. Blue line indicates the current average of either smolt-to-adult survival or exploitation rate and the gray dashed lines are one standard deviation away from each mean. Colour scale is bound by -100 and 100, so values that were smaller or larger than these are represented by the saturated colour.