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Pre-COSEWIC review of southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) conservation units, Part I: Background

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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

A majority of Chinook Salmon populations (*Oncorhynchus tshawytscha*) from southern British Columbia (entering the ocean south of Cape Caution) have experienced repeated years of low spawner escapements. There is also a high degree of uncertainty surrounding the longer term trends in abundance and productivity of all populations of southern British Columbia Chinook Salmon. These populations are currently being assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Concurrently, Fisheries and Oceans Canada (DFO) is undertaking several initiatives to assess the current status of these populations and to guide implementation of Canada's Policy for Conservation of Wild Pacific Salmon (also called the Wild Salmon Policy, WSP) for southern BC Chinook Salmon.

As the primary generator and archivist of information related to southern BC Chinook Salmon, and in order to fulfill the data needs of the ongoing initiatives, DFO is responsible for reviewing available data and information held by the department and providing it to COSEWIC prior to their assessment.

Following the initial Canadian Science Advisory Secretariat review in March 2013, and owing partly to the large volume of data and information to be covered by this report, the original terms of reference were split into two research documents, with the second part (primarily focusing on the data analyses) undergoing additional review in November 2013.

Part 1 (Background) addresses general discussions of designatable units, life history characteristics, key habitat requirements, identification of threats to habitat, whether the species has a residence (as defined by SARA) and identification of other threats and limiting factors that could impact the species' risk of extinction.

Part 2 (Data, Analysis and Synthesis) focuses on the data sources and methods used to assemble and prepare time series of escapement data, and presents other data relevant to the quantitative assessment of COSEWIC criteria of abundance and distribution for southern BC Chinook Salmon conservation units.

1 INTRODUCTION

Several Chinook Salmon populations (*Oncorhynchus tshawytscha*) from southern British Columbia (entering the ocean south of Cape Caution) have experienced repeated years of low spawner escapements. There is also a high degree of uncertainty surrounding the longer term trends in the abundance and productivity of all populations of southern British Columbia Chinook Salmon. Given their importance to natural ecosystems, First Nations culture and the recreational and commercial fishing sectors, there is keen interest from all stakeholders to try to better understand these uncertainties and improve productivity of these populations wherever possible. In order to address these issues, several parallel initiatives have been undertaken in recent years.

In 2011, the Southern British Columbia Chinook Strategic Planning Initiative (SBC CK SPI) was launched to begin the process of developing plans and policies to better understand and manage Chinook populations in southern British Columbia. This cross-sectoral steering committee consists of representatives from Fisheries and Oceans Canada (DFO), First Nations, recreational and commercial fishing sectors, the Province of British Columbia and non-government agencies. As part of the Initiative, a Technical Working Group (SBC-TWG) was formed to assemble and review available information on southern BC Chinook from all sources, both within and outside DFO. This information is to be compiled into Conservation Unit profiles within the framework of Canada's Policy for Conservation of Wild Pacific Salmon, also called the Wild Salmon Policy (WSP) (DFO 2005).

Additionally, under the auspices of the Species at Risk Act (SARA), the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is undertaking an independent status assessment of southern BC Chinook Salmon. As a primary generator and archivist of data related to southern BC Chinook Salmon, DFO is responsible for compiling and reviewing information held by the department prior to making it available to COSEWIC, in the form of a pre-COSEWIC review.

Following recommendations from the Canadian Science Advisory Secretariat – Pacific region (CSAP) Salmon Subcommittee, the original draft of this pre-COSEWIC review was divided into two volumes. Part 1 (this document) provides background information on species organization, life history, habitat requirements and threats that could affect the extinction risk for the species. Part 2 focuses on the data sources and methods used to assemble and prepare time series of escapement data, and presents other data relevant to the quantitative assessment of COSEWIC criteria of abundance and distribution for southern BC Chinook Salmon conservation units.

There are standardized objectives for a pre-COSEWIC review. Specifically, this document will address the following objectives:

1. Review designatable units, including discussion of morphology, meristics, genetics and distribution.
2. Discuss general life history characteristics, including growth parameters, mortality rates, recruitment rates, fecundity, generation time, early life history patterns and enhancement.
3. Provide a general description of the species habitat and threats to that habitat.
4. Discuss whether the species has a residence, as defined under SARA.
5. Identify other threats and/or limiting factors that could be relevant to the risk of extinction of the species.

1.1. SPECIES CLASSIFICATION AND DESCRIPTION

Chinook Salmon are one of seven anadromous and semelparous species of Pacific salmon native to North America (Healey 1991). Other common names for this species include spring salmon, king salmon, tyee, and quinnat (Scott and Crossman 1973).

Chinook Salmon populations are unique in the large degree of variability they exhibit, including a large range of life history behaviours at all life stages and variable life spans (ranging from 2 to 7 years or more). Morphologically, Chinook can be identified by black pigmented gums on the lower jaw, and a large number of pyloric caeca (Hart 1973; Healey 1991; Phillips 1977), variable flesh colour (from white through various shades of pink to red). Further, adult Chinook Salmon can grow to be the largest among all of the Pacific salmon species (upwards of 45 kg) (Healey 1991). Juvenile Chinook Salmon are primarily distinguished by dark, wide parr marks that extend below the lateral line along with distinctly shaped anal and adipose fins (Hart 1973; Phillips 1977). More detailed descriptions of Chinook Salmon at all life stages can be found in Healey (1991), Scott and Crossman (1973) and Quinn (2005).

For the purposes of this research document, southern British Columbia Chinook Salmon include all Chinook Salmon spawning in British Columbia waters that enter the ocean at any point south of Cape Caution (51° 09' 49" N). Collectively, the populations comprising southern BC Chinook Salmon exhibit almost the full range of characteristics and behaviours known to the species.

2 REVIEW OF DESIGNATABLE UNITS: WSP CONSERVATION UNITS

In 2005, DFO published *Canada’s Policy for Conservation of Wild Pacific Salmon* (DFO 2005), often referred to as the Wild Salmon Policy (WSP). This policy identified a goal of “restoring and maintaining healthy and diverse salmon populations and their habitat”. In order to identify and protect that diversity, the WSP directed DFO to assemble groups of salmon into Conservation Units (CUs), such that a given CU would contain fish that were similar with respect to genetics, behaviour and distribution. Each CU was also expected to be “sufficiently isolated from other groups that, if extirpated, is very unlikely to re-colonize naturally within an acceptable timeframe” (DFO 2005).

Holtby and Ciruna (2007) established that diversity of Pacific salmon can be characterized using three “pillars” of information: life history, ecology (ecotype) and genetics, and that there is high concordance for CU identification among the three information sources. As an example, life history characteristics such as smolt age or mature spawner age-at-return are phenotypically apparent, and represent intraspecific adaptation to the local environment, which in turn can be both genetically and environmentally determined.

2.1 ECOTYPOLOGY

Environmental typology (or “ecotypology”) can be used to describe species assemblages or populations that are co-adapted to particular habitats. Using a number of specific habitat criteria, Holtby and Ciruna (2007) defined several Freshwater Adaptive Zones (FAZ) and Marine Adaptive Zones (MAZ) that, when combined, classified and categorized the adaptive environments encountered by Pacific salmon throughout their full life history. The combined zones were defined as Joint Adaptive Zones (JAZ). The working hypothesis of Holtby and Ciruna’s work (2007) proposed that Pacific salmon populations found within each JAZ would more likely be ecologically interchangeable than populations from different adaptive zones. This information provided the initial delineation of possible conservation units for all Pacific salmon in British Columbia (Holtby and Ciruna 2007). In all, 17 JAZs exist among the 35 southern BC Chinook Salmon CUs.

2.2 GENETICS

Chinook Salmon populations have often been characterized as either “stream-type” or “ocean-type” life histories (Gilbert 1912, 1922) that were once thought to represent distinct genetic lineages or “races” (Healey 1983, 1991). It is now recognized, however, that this strict attribution of life history type to distinct genetic lineages is oversimplified and has been confounded by parallel evolution and/or phenotypic plasticity (Brannon *et al*. 2004; Waples *et al.* 2004; Beacham *et al.* 2006). Genetic indications of the ancient lineages that likely arose from isolation in glacial refugia have apparently been diminished by subsequent contact and mixing, contemporary patterns of gene flow, and more recent divergence of life history types due to selection and enhancement or transplantation, which has resulted in the current pattern of basin/sub-basin population structure (Moran *et al.* 2013).

This regional geographic pattern of basin/sub-basin structure forms the overarching basis of Chinook Salmon Conservation Unit classification under the WSP. However, additional subdivision of the regional genetic groups into less genetically distinctive CUs often resulted from recognition of life history and ecotype complexity (Holtby and Ciruna 2007). Thus, levels of intra- and inter-CU genetic diversity, as measured by microsatellite loci, have not been standardized. For southern BC Chinook Salmon, the 35 CUs (excluding three additional CUs which represent regionally-based cross-CU transfers of fish) group into 12 genetically-based regions (Table 1). The regional groupings constitute “high confidence” assignment/reporting regions for the genetic stock identification (GSI) methods currently used for fisheries management, research, and conservation applications (Parken *et al.* 2008; Winther and Beacham 2009; Tucker *et al.* 2011). Two of these reporting regions, Boundary Bay (CK-01) and Okanagan (CK-02) consist largely of fish straying into BC from more numerically abundant enhanced Chinook Salmon populations belonging to Evolutionary Significant Units or ESUs defined by the United States (Puget Sound and Upper Columbia River, respectively).

Regional isolation-by-distance genetic structure in southern BC Chinook Salmon largely reflects contemporary straying patterns among populations, as evidenced by recoveries of coded wire tagged (CWT) fish in watersheds other than the one of origin. For southern BC Chinook Salmon populations that have hatchery, ‘stray’ CWT recoveries, these generally occur within 80 km of the source population (Candy and Beacham 2000). Although there are some exceptions (e.g., some enhancement programs on Vancouver Island—see discussion below), the predominant use of local fish in hatchery stock development, and restricted transplantation of fish between hatcheries, has resulted in limited disruption of regional stock structure among CUs.

An exception may be the low level of genetic diversity within and among the fall Chinook Salmon CUs of southeastern Vancouver Island, which likely—at least partially—reflects the wide-scale hatchery production and an associated (historically) high level of within-region transplantation. On the west coast of Vancouver Island, there is little evidence that the initial development of large hatchery populations was associated with transplantation. More recently however, low abundances of wild fish have coincided with ongoing hatchery production at high levels, leading to concerns about the impact of hatchery strays on regional (inter- and intra-CU) population structure and local adaption (Riddell *et al.* 2013). Exacerbating the concern are hatchery practices which may increase the stray rates of hatchery fish between river systems within CUs and possibly between CUs (e.g., the use of net-pen rearing for the final phase of growth before release of smolts, or the collection of broodstock from sites near the marine/freshwater interface, which can include maturing non-local fish still migrating to the stream of origin). Such practices have been used at sites around Vancouver Island but their influence can be tempered by other factors, such as the geographic isolation of the spawning site (which will decrease the likelihood of observing migrating strays in the system).

Currently, complete allelic frequencies are available for 121 southern BC Chinook Salmon populations/collection sites representing 33 CUs (Table 2). Individual genotypes with more than four missing loci were screened out of the dataset. Missing from the analysis are Boundary Bay (CK-01), Okanagan (CK-02), East Vancouver Island – Goldstream (CK-21), Nanaimo River – Spring (CK-23), and Southern BC – Miscellaneous (CK-9005). Both CK-01 and CK-02 are genetically similar to Washington State populations so are not considered in context of the remaining BC populations. There are no representative genetic samples from CK-21, CK-23 or CK-9005. Also, genetically similar collections that are characterized by supplementation (CK-9006, CK-9007 and CK-9008) were combined with the source population (Harrison River, CK-03) for analysis, but kept separate on the tree diagram, since each collection has been heavily influenced by transfers of juveniles from the Harrison River (CK-03).

Genetic distances between populations of southern BC Chinook Salmon were determined using pairwise Cavalli-Sforza and Edwards' (CSE) cord distances (Cavalli-Sforza and Edwards 1967) from 15 microsatellite markers and visualized using a Neighbor-joining (Saitou and Nei 1987) clustering algorithm (Figure 1). The populations by CU are colour-coded by regional grouping using the colour key in Table 1. Values at major tree nodes indicate the number of "consensus trees" or identical tree structures occurring to the right of the node produced by bootstrapping across loci for each population by recalculating pairwise distances for 1000 trees (Felsenstein 1985).

In order to assess the extent of genetic divergence at different levels of geographic hierarchy, the overall molecular variance was partitioned into components corresponding to the population divergence within and among the 30 CUs and 121 populations by an analysis of molecular variance (AMOVA) model (Excoffier *et al.* 1992). This analysis demonstrated weak structuring among the 30 CUs (0.50%, $P = 0.645$). The variance among populations within CUs was limited but highly significant (4.27%, $P < 0.001$), whereas most of the variation occurred within the 121 populations (95.23%, $P < 0.001$). See Table 3 for a summary of these results.

Genetic distance (F_{ST}) between CUs was determined by combining genotypic data for all populations within CUs (Table 4) then using ARLEQUIN version 3.5.1.2 (Excoffier and Lischer 2010) to calculate F_{ST} and p-values for these estimates using a permutation algorithm. Pairwise comparisons were significantly different ($P < 0.001$) between all CUs except the following:

- Mid Fraser River – Spring (CK-10) and Mid Fraser River – Summer (CK-11);
- Fraser Canyon (CK-08) and Mid Fraser River - Summer (CK-11);
- South Thompson – Shuswap River (CK-15) and South Thompson – Bessette River (CK-16);
- Upper Adams River (CK-82) and the three South Thompson CUs (CK-14 to CK-16);
- Cowichan River – Fall (CK-22) and East Vancouver Island – Fall (CK-25);
- Cowichan River – Fall (CK-22) and Qualicum/Puntledge River – Fall (CK-27);
- Cowichan River – Fall (CK-22) and Southern Mainland – Southern Fjords (CK-28); and
- Cowichan River – Fall (CK-22) and East Vancouver Island – Summer (CK-83).

2.3 REVIEW OF WSP CONSERVATION UNITS

When the initial CU list was established (Holtby and Ciruna 2007), it was recognized that the list would be refined as new information, analyses and data became available (DFO 2009). In light of this, and in preparation for this report, the SBC-TWG reviewed the southern BC Chinook CUs using the most recent version of Holtby and Ciruna's list (version 3) as a starting point (Blair Holtby, 2012, DFO, Nanaimo. BC, pers. comm.). Recent information from a variety of sources was used in the re-analysis, including recent salmon spawner enumeration surveys, Pacific Salmon Commission Chinook Technical Committee reports, genetic studies, enhancement records, ageing records, the Mark-Recapture Program (MRP) coded wire tag (CWT) dataset, Aboriginal Traditional Knowledge (ATK), Local Ecological Knowledge (LEK) and the Fisheries Information Summary System (FISS) (DFO 2013b). Table 5 summarizes the current list of southern BC Chinook Salmon CUs.

The SBC-TWG review (DFO 2013b, Table 5) resulted in several relatively minor restructurings of the CUs originally proposed by Holtby and Ciruna (version 3). Two pairs of CUs were combined: the East Vancouver Island-Puntledge Summers and East Vancouver Island-Nanaimo Summer CUs were similar in genetics, adult run timing and distribution so were merged into a single CU, called the East Vancouver Island—summer timing. The second pair was the Port San Juan and Southwest Vancouver Island (SWVI) CUs. The Port San Juan CU was comprised of Gordon and San Juan Rivers and their tributaries. These were originally distinguished from the SWVI CU by perceived earlier adult run timing. Upon further investigation, the run timing difference was an artefact of the escapement reporting form, and recent data confirmed both CUs exhibit a single adult run timing. Thus, these two CUs were merged and the designation of Southwest Vancouver Island was retained for the new CU. Additionally, several individual census sites were moved among CUs, or deleted if there was no evidence of Chinook Salmon ever spawning at the site. (Note that although the term “census site” is used here and would normally indicate complete enumeration of a population, this is rarely possible in rivers where Chinook Salmon are found.) Additionally, information from ATK and LEK sources was collected opportunistically from local experts in select areas for this report through the members of the SBC-TWG.

The updated CU definitions for southern BC Chinook are illustrated in Figure 2 (ocean-type CUs) and Figure 3 (stream-type CUs).

2.4 CODED WIRE TAG DATA

In many cases—owing to financial and material constraints—sufficient information has not been (and cannot be) collected on an annual basis to fully monitor all 35 conservation units of southern BC Chinook Salmon. For this reason, a subset of indicator stocks has been established and—through an extensive coded wire tag (CWT) program—are used to provide data that informs the estimation of annual production for many populations (and conservation units) of southern BC Chinook Salmon. Although select results from the CWT program will be reported here, the specifics of the CWT program will be discussed fully in the second part of this report series.

3 LIFE HISTORY CHARACTERISTICS

Chinook Salmon are unique among species of Pacific salmon in the broad range of diverse life history strategies exhibited at all life stages. This includes variation in juvenile freshwater rearing strategy, length of freshwater, estuarine and ocean residence, ocean distribution, age-at-maturity, and timing of spawning migration. Among the populations of southern BC Chinook Salmon, almost all possible variations of this diversity are observed (Table 5).

3.1 JUVENILE LIFE HISTORY

Juvenile life history strategy identifies the amount of time salmon fry rear in freshwater before beginning their seaward migration. At least three juvenile life histories have been identified for Chinook Salmon (Healey 1983), but two are predominant. Ocean-type Chinook Salmon have a limited juvenile freshwater rearing phase that lasts from 60 to 150 days, whereas stream-type

Chinook Salmon have an extended freshwater rearing phase that lasts from one to two years (Gilbert 1912). In the third strategy, newly emerged fry begin their seaward migration immediately (and are called immediate migrants). Ocean-type Chinook Salmon typically originate from coastal streams south of 56°N on the North American coast, whereas stream-types are commonly from more northerly and inland headwater streams of North America (Healey 1991). Among the southern British Columbia Chinook Salmon populations, ocean-type Chinook Salmon generally dominate most of the coastal systems, whereas stream-type Chinook Salmon are generally from interior river systems or northern coastal systems with shorter growing seasons—though exceptions do exist (see Figure 2 and Figure 3 for the distribution of ocean- and stream-type Chinook Salmon populations in southern BC, respectively).

Ocean-type and stream-type lineages were once thought to have evolved from different racial origins within Chinook Salmon (Healey 1991). It is now widely recognized that this pattern of strict segregation of life-history types with distinct genetic linage is subsequently confounded by parallel evolution and phenotypic plasticity (Beacham et al. 2006, Moran et al. 2013). Furthermore, there have been many local adaptations resulting in several atypical migration timing and freshwater rearing strategies (Healey 1991; Waples et al. 2004). Waples et al. (2004) noted that within the Columbia River, a number of life-history types behave essentially as two different species with little evidence of gene flow, despite co-migrating through large areas of riverine and ocean habitat, and in some cases, spawning in adjacent areas of the same river system. Similar situations also exist within the Thompson River basin of the Fraser River (Candy et al. 2002; Richard Bailey DFO, Kamloops, BC, unpubl. data). It has been postulated (see Waples et al. 2004; Healey 1991; McPhail and Lindsey 1986) that the two lineages may have arisen from different glacial refugia (‘Beringia’ in the north and ‘Cascadia-Columbia’ in the south), with Beringia populations—having recolonized southward post-glacially—represented by contemporary populations in the Yukon and the northern Gulf coast of southeast Alaska (Moran et al. 2013). Beacham et al. (2006) hypothesised that Chinook might have had multiple southern refugia along coastal British Columbia. It is known that a refuge for plants and animals persisted at least as far north as the Alexander Archipelago in southeast Alaska which served as a centre of biotic dispersal upon regional deglaciation (Carrara *et al.* 2007; Heaton *et al.* 1996).

3.2 ADULT RETURN MIGRATION TIMING

Chinook populations also exhibit a wide range of adult return migration timing (defined as the peak timing of adult re-entry into freshwater). It is important to note that adult return timing is not synonymous with spawn timing as it can precede actual spawning activity by weeks, or even months, for some populations (e.g. there are spring runs that enter the Fraser River in April but do not initiate spawning until August, and summer runs entering in July that do not spawn until October). Waples *et al.* (2004) provided standardized adult run timing definitions (Table 6) that are used to classify southern British Columbia Chinook Salmon (Parken *et al.* 2008). Adult run timing for southern BC Chinook Salmon is summarized by CU in Table 5. Note that there are no known winter runs of Chinook Salmon among the southern BC Chinook CUs. Note that recent research suggests future characterizations should classify adult return timing by location in order to fully capture the evolutionary lineage of the population (Moran *et al.* 2013).

3.3 GROWTH PARAMETERS

3.3.1 Age at maturity and maximum age

As with many other characteristics of Chinook Salmon, age-at-maturity (also called “generation time”) is highly complex with as many as 16 known possible age classes (Table 7). For most Chinook Salmon, sexual maturation can occur anytime between the second and sixth year, with the most common age at maturity varying among populations. Within a population, a range of age classes will be present in any given return year, although one age class is usually dominant. Generally, females have an older average age at maturity than males (Quinn 2005; Healey 1991). There is also a (sometimes significant) component of some populations that matures precociously during their second year (for ocean-type) or third year (for stream-type); these are generally male (called “jacks”). However, some populations also have a very rare female component in this age category (called “jills”). Precocious parr (maturing in their first and second year, for ocean- and stream-type Chinook, respectively) have also been observed in some populations. Several studies have shown that genetics and environmental factors can contribute to variation in maturation rates over time (Quinn 2005). The oldest known age of maturity for Chinook is seven years (Healey 1986). Finally, it must be highlighted that the age composition of spawners does not reflect the overall maturation rate of the population due to removals of (generally) older fish through selective processes such as predation and fishing activities (Quinn 2005), as well as fishing removals on immature fish which reduce the probability of fish surviving to mature at older ages (Ricker 1980; Riddell 1986). The average expected generation time for southern BC Chinook Salmon is summarized by CU in Table 5.

3.3.1.1 Age classification nomenclature

The nomenclature used in this document to define Chinook Salmon age classes follows Koo (1962). It has a standard format (X.Y), where X represents the number of winters in fresh water, and Y represents the number of winters in the ocean. For example, an ocean-type Chinook will emerge from the gravel in March, and migrate to sea as an age 0.0 smolt. If this salmon returns in September of the same year, it will still be age 0.0. If it resides in the ocean for another year prior to returning, it will be age 0.1. Similarly, if it remains in the ocean for 3.5 years after smolting, it will be an age 0.3 adult.

3.3.2 Length at age

Table 7 reports ranges of fork lengths at maturity (in mm) for all of the combinations of juvenile and adult life histories possible for Chinook Salmon. At a given age, males are generally larger than females (Quinn 2005; Healey 1991), although exceptions to this generality have also been noted (Westrheim 1998).

In the Cowichan and Nanaimo rivers, seaward migrating juvenile Chinook Salmon fry were estimated to have fork lengths from 35-40 mm in March through late April, while smolt migrants were roughly 60-70 mm when intercepted in late May (Healey 1991). Table 8 summarizes release fork lengths and weights of CWT-associated releases of Chinook salmon as fry, smolts (age-0) and yearling (age-1) juvenile stages (where available). It is unclear how representative these results are for other wild or hatchery populations of southern BC Chinook Salmon, particularly since the rearing and growing environment for hatchery salmon is far more controlled than in the wild environment.

For juvenile Chinook Salmon during their first year at sea, general fork length categories to differentiate stream and ocean-type life histories have been established through juvenile salmon trawl surveys conducted off the West Coast of Vancouver Island and throughout northern BC and southeast Alaska (Fisher *et al.* 2007; Tucker *et al.* 2011, 2012; Table 9).

Table 10 summarizes average fork lengths and standard deviations by age and CU, derived from coded wire tag recoveries in fisheries from 1967-2012. More information on the coded wire tag data program can be found in the second volume of this report.

3.4 FECUNDITY

In general, fecundity for Chinook Salmon can range from 2,600 to 12,000 eggs (Table 7). Comprehensive and CU-specific measures of fecundity for southern BC Chinook populations are currently not available, though studies in select watersheds have been conducted in the past (as an example, see Rosberg and Aitken 1981)). Healey (1991) noted that body size is not a reliable indicator of fecundity for Chinook Salmon (unlike other fishes), but fecundity is generally believed to increase with increasing latitude of spawning site. Table 7 provides general ranges of fecundity for Chinook Salmon observed at differing ages of maturity.

3.5 GENERATION TIME

Chinook Salmon display a wide range of maturation schedules, varying from 2 to 6 years (see Table 7). Although there is usually a dominant age at maturation (or “generation time”) within each CU, typically three or more ages of maturing Chinook can return to a given site in any given year. Each southern BC Chinook CU has had an average generation time assigned to it, based on the most frequently observed age of return, or as estimated by run reconstruction techniques for CUs with associated coded wire tagged cohorts (Table 5). More detail about the methods used for these run reconstruction calculations are provided in the second volume of this report.

3.6 SURVIVAL AND RECRUITMENT RATES

3.6.1 Freshwater survival

The survival of Chinook Salmon eggs from spawning to emergence varies widely between systems and years and is influenced by stream flow, water temperature, dissolved oxygen, gravel composition and spawner density. Studies suggest that the survival of Chinook eggs to emergence is relatively high compared to other salmon species, but is likely offset by comparably lower marine survival (Bradford 1995). The same study estimated freshwater (egg-smolt) survival of stream-type Chinook Salmon at 6.4% and ocean-type Chinook Salmon at 8.6%, but noted that the difference between them was not statistically significant (based on data from 8 populations, 4 ocean-type and 4 stream-type). At this time, data on egg-smolt survival is not available for southern BC Chinook Salmon at the CU-specific level.

3.6.2 Early marine survival

The early marine rearing period for Chinook Salmon, and all Pacific salmon, has been well-documented as a critical phase in their life history (Pearcy 1992; Bradford 1995; Fisher and Pearcy 1995; Orsi *et al.* 2000; Beamish *et al.* 2004, 2008, 2012; MacFarlane 2010; Tomaro *et al.* 2012). Variability of life history types, age at ocean entry, and ocean entry timing, as well as the lack of fishery-based data for juvenile salmon, complicates the ability to discern effects of critical factors influencing the survival of Chinook Salmon during the early marine period (i.e. the first days and weeks following saltwater entry and smoltification). Trudel and Hertz (2013) provide a meta-analytic summary of many factors thought to affect early marine survival of Pacific salmon in general, including climate, migration patterns, growth and bioenergetics and pathogens and disease.

3.6.2.1 Strait of Georgia

The decline in observed abundance of juvenile ocean-type and stream-type Chinook Salmon in the Strait of Georgia in June and July is likely a result of mortality within the Strait and migration out of the Strait. An acoustic tag study of juvenile Chinook Salmon in 2007 and 2008 detected very few tagged fish leaving the Strait of Georgia, suggesting that mortality within the Strait is considerable (Neville *et al.* 2010). Beamish *et al.* (2011b) also suggest that high levels of mortality occur within the Strait of Georgia based on a study measuring the early marine survival of marked (i.e., hatchery) and unmarked (i.e. wild and unmarked hatchery) Cowichan River Chinook Salmon. They estimated over 95% mortality for marked fish and 70-92% mortality for unmarked fish between ocean entry and September. Surveys on the west coast of Vancouver Island (WCVI) in summer, fall and winter indicate that although very small numbers of ocean-type Chinook Salmon may move directly out of the Strait of Georgia in the summer and fall, larger numbers of these fish do not occur off WCVI until the winter months (Trudel *et al.* 2009; Tucker *et al.* 2011, 2012). The factors regulating this early marine mortality have not been determined, however results indicate that brood year strength for many Chinook Salmon populations entering the marine environment in the Strait of Georgia may be largely determined there.

3.6.2.2 West Coast Vancouver Island

Mortality rates have not been quantified for the early marine residence of naturally spawned west coast Vancouver Island Chinook, though the overall marine survival of Robertson Creek Chinook Salmon appears to be related to the availability of energy-rich prey such as northern copepods (Trudel *et al.* 2012b). During winter, mortality rates for Marble River Chinook Salmon range from 60% to 90% depending on the year (Trudel *et al.* 2012b). The factors contributing to this mortality are currently unknown, but do not appear to be related to size, growth, or energy accumulation (Middleton 2011; Trudel *et al.* 2012b).

3.6.3 Marine survival

Direct estimates of marine survival rates for naturally-spawning southern BC Chinook Salmon populations do not exist at present. However, based on fecundity and freshwater survival data, a species average of 1-2% survival has been estimated for these populations (Bradford 1995).

For hatchery Chinook Salmon, direct estimates of annual marine survival are obtained from CWTs (Figure 6). Further discussion of the Chinook CWT sampling program is included in the second volume of this report. Note that the applicability of these estimates to marine survival rates for wild Chinook is not known with certainty.

Potential factors influencing CU- or population-specific marine survival of juvenile Chinook salmon have been the focus of recent research (Tucker *et al.* 2012; Vélez-Espino *et al.* 2012) but remain poorly understood at this level of resolution. Similarly, the effects of changing environmental conditions on survival are recognized but not well understood (Quinn 2005). Recent results suggest that early marine migration patterns may be population-specific (which may or may not align completely by CU), and invariant to changes in ocean conditions (Tucker *et al.* 2012). Thus marine survival is expected to be influenced by the ocean conditions encountered by each population during their ocean migration. In particular, sea surface temperature has been shown to inversely affect Chinook Salmon survival rates—i.e., increasing sea surface temperature is associated with decreasing marine survival (Sharma *et al.* 2013).

3.6.4 Recruitment rates

Recruitment rates of juveniles to an age where they can be intercepted in fisheries are estimated based on CWTs recovered in coast-wide fisheries. These are reported annually by the Pacific Salmon Commission Chinook Technical Committee for aggregates of southern British Columbia Chinook populations rather than at the CU-specific level (CTC 2012). For southern BC Chinook Salmon, recruitment to the fishable biomass occurs at age 2. Detailed summaries of recruitment rates are provided in second part of this report series.

3.7 OCEAN DISTRIBUTION

3.7.1 Juvenile Chinook Salmon

Numerous studies examining the distribution, diet, and growth of juvenile southern BC Chinook Salmon during their first ocean year have been conducted over the past four decades, primarily in the nearshore and estuarine regions of the south coast of British Columbia using beach seines, purse seines, and rope trawls (Beamish *et al.* 1976, 2000, 2003; Healey *et al.* 1977; Healey 1978, 1980a, 1980b, 1983, 1991; Levy and Northcote 1981, 1982; Levy *et al.* 1979). The availability of coded wire tag recoveries and DNA analyses in recent years has resulted in more detailed analyses of stock-specific information on their marine distribution beyond the first few weeks and months in the ocean (Trudel *et al.* 2009; Beamish *et al.* 2011a, 2011b; Tucker *et al.* 2011, 2012; Weitkamp 2010; CTC 2013).

3.7.1.1 Strait of Georgia

As previously noted, juvenile Chinook Salmon from the Fraser River, southern BC mainland and east coast of Vancouver Island all begin their marine residence as smolts in the Strait of Georgia, an area that has been identified as an important rearing habitat for all species of juvenile Pacific salmon (Healey 1978, 1980a, 1980b, 1991; Argue *et al.* 1986; Beamish *et al.* 2000, 2008, 2010; Chittenden *et al.* 2009; Beamish 2012). Ocean-type Chinook smolts generally migrate downstream the earliest in the year (March-May) and remain in the nearshore and estuarine regions of the strait the longest (Levy *et al.* 1979; Healey 1980a, 1991; Levy and Northcote 1981, 1982). Exceptions to this generality are known to exist (i.e. ocean-type Chinook have been observed in Shuswap Lake in July) (Brown and Winchell 2004). These are referred to as late entry ocean-type Chinook Salmon and are generally specific to the Thompson River. In general, ocean-type smolts leave the nearshore areas and migrate to more open marine waters of the strait in May or June or as late-ocean migrants in July or August (Barraclough and Phillips 1978; Healey 1980a, 1991; Healey and Groot 1987; Beamish *et al.* 2003). In contrast, stream-type smolts generally enter marine waters later (April or May), are larger at ocean entry and do not remain in the nearshore regions—moving immediately into the deeper areas of the strait (Healey 1980a, 1991). There is an indication that with longer ocean residence, there is increased movement of larger or faster growing fish (of both juvenile rearing types) into deeper water.

Recent research indicates that some Strait of Georgia Chinook stocks may have specific and refined distributions during their early marine period. For example, Cowichan River Chinook Salmon rear primarily in the Gulf Islands area of the Strait of Georgia (Beamish *et al.* 2011a, 2011b). Catches of this stock remain high in this region from May through to September. Additionally, this stock is rarely caught in other areas of the Strait of Georgia (based on DNA analyses).

Prior to the use of genetic stock identification (GSI) techniques, it was thought that juvenile stream-type Chinook Salmon remained in the Strait of Georgia until about July (Healey 1980a) and then emigrated in September and October through Juan de Fuca Strait (Barraclough and Phillips 1978). There was also a general perception that ocean-type Chinook Salmon remained and reared in the Strait of Georgia through to November (Healey 1980a; Healey and Groot 1987). Recent GSI of juvenile Chinook Salmon has indicated that their distribution is more complex than previously believed, and is not only related to life-history, but also to ocean entry timing and stock of origin (Beamish *et al.* 2011a). Juvenile Chinook Salmon are found throughout the Strait of Georgia from the surface to 60m depth from June through to November. Overall, Beamish *et al.* (2011a) concluded that both ocean-type and stream-type life history could spend approximately 3-5 months in the Strait of Georgia. However, juvenile Fraser River stream-type Chinook Salmon have been caught in small numbers on the west coast of Vancouver Island and farther north in summer and fall of their first year, indicating that some fish leave the strait early (Tucker *et al.* 2011, 2012). In June and July, there is a mixture of ocean-type and stream-type Chinook Salmon in the Strait of Georgia. The abundance of the specific stocks identified in early-summer surveys decline dramatically by September, although reduced numbers of the same stock groupings remain in this area throughout the fall. In September, the total abundance of juvenile Chinook Salmon can be similar or even greater than in July. However, juvenile Chinook Salmon caught in the Strait of Georgia in September are primarily late-ocean entry Chinook Salmon from the Thompson River. This stock does not enter the offshore waters of the Strait of Georgia until late July/early August and remain the dominant stock group through to November when numbers of all Chinook Salmon decline (Beamish *et al.* 2010, 2011a).

Late-ocean entry ocean-type Chinook Salmon from the South Thompson region are observed in west coast Vancouver Island (WCVI) trawl surveys in the fall and remain in the region through the winter months (Tucker *et al.* 2011). These fish then disperse further north as they get older (Tucker *et al.* 2011; CTC 2012). In contrast, Lower Fraser River ocean-type Chinook Salmon appear to migrate off the west coast of Vancouver Island later than South Thompson Chinook, and are rarely found north of Vancouver Island (Tucker *et al.* 2011; CTC 2012).

3.7.1.2 West Coast of Vancouver Island

On the west coast of Vancouver Island, Chinook Salmon smolts (predominantly ocean-type) migrate to sea in May or June (Healey 1991) and remain on the west coast of Vancouver Island for nearly a year before migrating north along the continental shelf (Trudel *et al.* 2009; Tucker *et al.* 2011, 2012). In the fall and winter of their first year at sea, most stocks are distributed along the coast from their point of ocean entry to Quatsino Sound. For example, Robertson Creek Chinook Salmon are found from Barkley Sound to Quatsino Sound, whereas Marble River Chinook are distributed exclusively within Quatsino Sound during their first year at sea (Trudel *et al.* 2012a). Juvenile Chinook Salmon are primarily distributed on the shelf and inlets of WCVI within the 200m depth contour. The marine distribution of juvenile WCVI Chinook Salmon is similar for wild and hatchery fish (Tucker *et al.* 2011) and has been stable over the last decade despite considerable fluctuation in ocean conditions during that time, with strong El Niños and La Niñas events (Tucker *et al.* 2012).

3.7.2 Immature Adult Chinook Salmon

Ocean distributions of southern BC Chinook Salmon can be derived from DNA analyses and CWT recoveries in ocean fisheries. Southern BC Chinook Salmon are known to exhibit one of three general patterns of ocean distribution: locally-distributed, far-north migrating and offshore. Table 11 summarizes the ocean distribution patterns for the 11 southern BC Chinook CWT indicator stocks. Local migrants do not engage in long-distance ocean migrations and are typically caught in the coastal waters off Washington and British Columbia. Far-north migrants are typically caught in northern BC and Alaska fisheries. Offshore migrants do not spend time in nearshore coastal waters and so are harvested almost entirely in nearshore or terminal locations in BC when they return to spawn.

Adults and sub-adults are caught as far north as Cook Inlet in Alaska, with the majority of the recoveries occurring in Southeast Alaska and the west coast of Vancouver Island (Weitkamp 2010, CTC 2012).

3.8 ENHANCEMENT

In British Columbia, Chinook Salmon have been the subject of directed enhancement activity for over 30 years. Although the role that enhanced stocks of Chinook will play in future Wild Salmon Policy assessments remains unclear, levels of enhancement must be included among the relevant factors affecting population structure of southern BC Chinook.

In BC (and elsewhere), enhancement programs have been developed to support stocks of Chinook Salmon. Within DFO, the Salmonid Enhancement Program (SEP) is responsible for fish production, habitat restoration and community stewardship activities intended to support Chinook Salmon stocks in southern British Columbia. The program was initiated in 1977, and in southern BC is currently enhancing Chinook at 14 DFO operated facilities, 11 Community Economic Development Program (CEDP) hatcheries, and 25 volunteer-supported Public Involvement Projects (PIP) (Table 10). The majority of these sites are found in the Vancouver Island and southern mainland CUs, with the remainder in the Fraser River CUs (Figure 4).

3.8.1 Fish production

Production of Chinook at SEP facilities directly supports the delivery of several departmental priorities, which include:

- Harvest – enhancement for fisheries that are reliant on enhanced production, and would disappear or become severely constrained in the absence of enhancement. This includes harvest opportunities for First Nations, recreational, or commercial fisheries. When the objective is to provide a targeted-fishery opportunity, production targets may be set to consider both natural spawning and harvest requirements.
- Assessment – fish produced for marking where stock assessment information contributes to Pacific region assessment priorities, such as the Pacific Salmon Treaty. The information may also contribute to assessment as defined under the regional stock assessment framework, Area stock assessment priorities and regional SEP assessment priorities i.e. those produced for program performance measurement. Fish produced for assessment generally address other objectives as well but, in a few instances, fish are produced solely for marking for assessment purposes.
- Conservation – enhancement of a stock at high risk of extirpation or extinction, or a vulnerable stock that has been identified as a regional priority (e.g. subpopulations which have an approved conservation/recovery strategy). This includes re-establishing locally extinct subpopulations according to transplant guidelines (Fedorenko and Shepard 1986) and rebuilding subpopulations at high risk of extirpation.
- Rebuilding – enhancement of a stock that is below apparent carrying capacity. This includes rebuilding depleted subpopulations and mitigating for habitat loss.
- Stewardship and Education – small numbers of fish produced to provide a stewardship or educational opportunity. Production for these purposes is assessed based on contribution to stewardship and educational goals and not on production levels or contribution to harvest or escapement.

Production planning occurs annually as part of the Integrated Fisheries Management Planning process. Internal priorities from all DFO sectors, including Fisheries Management, Science Stock Assessment and SEP are brought forward and integrated with partner and stakeholder priorities in the development of a comprehensive production plan. The annual SEP production plan identifies production targets by species, stock, release site and release strategy in order to meet specific production objectives. Production targets are calculated using current bio-standard survival rates by species and release stage, and are set at a level intended to produce a number of returning adult salmon that will support harvest, conservation or assessment goals.

In 2012, the SEP Production Plan for Southern BC Chinook included a total production target of nearly 40 million Chinook Salmon juveniles. Total Chinook Salmon production in 2011 (the most recent year with complete production data available) was approximately 34 million Chinook juveniles.

Since 1995, there has been active enhancement in 23 of the 35 CUs in Southern BC, while the remaining 12 CUs have had no directed enhancement. Over this period, mean annual production has been 49.3 million juvenile Chinook Salmon, although this has decreased during the most recent generation (2007-2011) to 39.7 million per year. Direct estimates of enhanced production as a percentage of total CU production cannot be calculated because the wild component is unknown; however, the relative scale of enhancement by CU over the past 3 generations is summarized in Table 13.

3.8.2 Release strategies

SEP has developed several options for releasing Chinook Salmon progeny from hatcheries into the natural environment. Each strategy has advantages and disadvantages and is selected to best meet the enhancement objective as per the production planning framework. The release strategies are shown in Table 14, in order from earliest life history stage to the oldest stage. The information in this table has been adapted from the Hatchery Scientific Review Group (HSRG 2004), California Hatchery Scientific Review Group (California HSRG 2012) and Morley *et al.* (1996).

3.8.3 Assessment and monitoring

As part of ongoing program development and monitoring, SEP employs many program- and project-level tools to guide operations and planning. At the program level, several integrated planning tools guide management and decision-making, including *A Biological Risk Management Framework for Enhancing Salmon in the Pacific Region* (DFO 2013a), and *SEP Production Planning: A Framework* (DFO 2012). These tools will be integrated into a long-term planning process that will focus on program-level strategic management as well as directing annual program and project planning. This will ensure that enhanced salmon production objectives of the Department and stakeholders are being met.

At the operational level, Fish Health Management Plans (FHMPs) have been implemented at all DFO-operated hatcheries. These plans were summarized in a technical report commissioned by the Cohen Commission of Inquiry into the Decline of Sockeye Salmon (Stephen *et al.* 2011). In addition to the FHMPs, SEP implements operational guidelines as per the *Operational Guidelines for Salmon Enhancement Hatcheries*[1], which provides guidance at the operational level to ensure that genetic, disease and ecological risks of enhancement are minimized and managed appropriately. Hatchery operations are evaluated as a component of periodic program review processes, such as the *2004/5 SEP Facility Operations Review (FORT)*[2].

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[1] DFO. 2005. Operational Guidelines for Pacific Salmon Hatcheries. (*Draft*). Fisheries and Oceans Canada, Salmonid Enhancement Program. Pacific Region, Vancouver, B.C.

[2] DFO. 2005. Evaluation of Hatchery Practices in the Salmonid Enhancement Program (SEP) based on System-Wide Recommendations from the Hatchery Reform Project for Puget Sound and Coastal

4 HABITAT REQUIREMENTS

The productivity of Pacific salmon is closely linked to the availability of suitable freshwater, estuarine and marine habitat. This requirement is complicated by the range of life history and rearing strategies exhibited by southern BC Chinook Salmon. As an example, high quality freshwater habitats in the watersheds of the Fraser River are necessary for spawning, incubation and rearing at all times of the year due to the co-occurrence of ocean-type, stream-type and immediate-migrant Chinook in different parts of the system. Estuary, nearshore and open ocean environments are also vital for rearing juvenile and adult Chinook Salmon and the survival rates experienced in these habitats can greatly influence adult return run sizes. In particular, Higgs *et al.* (1995) provides a concise summary of Chinook Salmon life history and the natural diets at each life stage and habitat.

4.1 FRESHWATER HABITAT

In general, spawning occurs from near tidal influence to over 3,000 kilometers upstream. Ocean-type Chinook Salmon return to spawn during the summer and fall after spending between two and five years in the ocean and tend to select spawning sites in the lower or middle reaches of rivers. With shorter upriver migrations, coastal ocean-type Chinook Salmon can delay river entry until after peak flows and take advantage of a longer ocean feeding period. Stream-type Chinook Salmon typically return to freshwater during the spring and summer after between one and four years in the ocean. Since stream-type Chinook Salmon generally undertake longer return migrations to spawn in headwater tributaries, their early entry to freshwater permits them to take advantage of high spring and summer flows to reach these more remote areas.

In general, most individual spawning subpopulations are relatively small (in British Columbia, 80% of surveyed streams average fewer than one thousand spawners). In general, Chinook Salmon from northern latitudes and higher elevations (and generally stream-type) tend to spawn earlier with peak spawning times ranging from July to September. In comparison, Chinook from southern latitudes and lower elevations (generally ocean-type) may spawn as late as January. Within a given river system, populations with differing life histories may co-exist, with each spawning at a different time and in specific reaches of the river (Parken *et al.* 2008).

Chinook Salmon require spawning sites within the stream or river where water velocity, depth and gravel size are optimal for the incubation of developing eggs, though considerable variation has been observed in the characteristics of spawning beds chosen by Chinook (Healey 1991). Generalized requirements for Chinook are a gravel area that is $16m^2$ (stream-type) to $24m^2$ (ocean-type) per spawning pair (Burner 1951) based on a spawning pair using and defending an area equal to about four times the redd area. However, gravel requirements per spawning pair can be much greater than reported by Burner (e.g. up to 40 m^2, Chapman *et al.* 1986). For specific examples from southern BC Chinook Salmon populations, average redd size for stream-type Chinook was 9.1-10 m^2 in the Nechako River (Nielson and Banford 1983) and 8.7 m in the Nicola River (n=124, CV=24%; Chuck Parken, DFO, Kamloops, BC, unpub. data).

Once spawning has occurred, and under ideal conditions, Chinook Salmon eggs incubate for roughly 1 to 4 months (Weatherley and Gill 1995). The length of time ultimately required for incubation is strongly dependent on water temperature. Successful incubation also requires stable flow rates that are adequate to supply required levels of oxygen, but not high enough to

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Washington (*Draft*). Fisheries and Oceans Canada, Oceans, Habitat and Enhancement Branch, Pacific Region, Vancouver, B.C.

cause gravel movement or streambed scour which could expose eggs to predators or dislodge them from the redd. The stream substrate must be small enough to be moved by the fish and large enough to allow good intra-gravel water flow to the incubating eggs and developing alevins. Since Chinook eggs are the largest of all the Pacific salmon and therefore have a small surface-to-volume ratio, good sub-gravel flow is vital to egg survival (Raleigh *et al.* 1986). In one reported case, 87% of Chinook fry emerged successfully when gravel was large and sub-gravel flows were adequate (greater than 0.03 cm/s percolation rate) (Shelton 1955).

Upon hatching, juvenile Chinook Salmon (called alevins) remain under the gravel, moving within the spaces between gravel particles. Larger gravel particles allow the alevins to move further distances. The newly hatched salmon alevins have an attached yolk sac that provides their required nutrition during this period. In the spring, toward the end of incubation, the alevins move up through the gravel to emerge as fry. This process generally occurs at night, helping to minimize predation and generally coincides with the complete absorption of the yolk sac.

In general, while migrations are influenced by water flow, the movement of fry in rivers and streams is an active behaviour. For Chinook spawning in upstream areas, this migration serves as a dispersal mechanism that distributes fry among suitable rearing habitats. Chinook fry are most often found where substrate size is small, velocity relatively low and depth shallow. They seem to prefer main river channels and are not often found in off-channel habitat. Brown (2002) provides a comprehensive review of the freshwater rearing habitat required for Chinook salmon, in both coastal and interior British Columbia watersheds.

Ocean-type Chinook from the South Thompson River demonstrate wide variations in the duration of freshwater residence, ranging from those that migrate to the estuarine environment immediately upon emergence to those that reside in freshwater well in excess of 100 days. The timing of emergence and subsequent length of freshwater residence determine the timing of entry into the marine environment. For example, ocean-type Chinook from the South Thompson emerge around the time of the spring freshet, and the newly emerged fry move into recently flooded river margins and other ephemeral habitats away from the main flow for a period of time. As they feed and grow, they move back on-channel and distribute downstream, arriving in the Fraser River estuary by late July or August.

For stream-type Chinook, freshwater rearing may occur throughout the river system from headwater tributaries downstream to the lower extent of large river systems, and multiple strategies may influence the distribution of fry and parr annually (Richard Bailey, DFO, Kamloops, BC, unpubl. data; Bradford and Taylor 1997). For example, in the Interior Fraser and Thompson Rivers, there are three main strategies of juvenile distribution:

1. remain in the natal stream from emergence until smolting;
2. remain in the natal stream through the first summer after emergence and then migrate into a larger mainstem river such as the Thompson or Fraser where they overwinter and smolt; or
3. leave the natal stream shortly after emergence and move (actively and passively) downstream into larger rivers, to overwinter in the Lower Fraser River.

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

In most cases, smolting occurs within one year of freshwater rearing. However, in less productive environments, juveniles may remain resident for two or even three years before migration to the marine environment.

4.2 ESTUARINE HABITAT

Coastal estuaries are important as they provide an environmental transition zone, extensive opportunities for feeding and growth, and refuge from predators. As environmental transition zones, brackish estuaries allow Chinook juveniles the opportunity to acclimate from freshwater to saltwater (smoltification) and between waters of differing temperatures. They provide substantial opportunities for feeding, and typically have higher food productivities than adjacent ocean or freshwater areas. Estuaries may thus offer the opportunity for enhanced growth and therefore, larger size at ocean entry which is known to correlate with higher marine survival. One final role of estuaries is to provide refuge from predators (Healey 1991; Allen and Hassler 1986). The higher turbidity often associated with estuarine areas limits the ability of visual predators to key on salmon juveniles. Also, the extensive aquatic vegetation associated with estuaries provides important structural cover.

In general, upon reaching the estuary, ocean-type Chinook smolts remain for varying periods ranging from a few weeks to several months. Due to their more prolonged estuary residence period, estuarine habitat is particularly important for ocean-type Chinook (Quinn 2005). Many studies have documented the estuarine use and behaviour of ocean-type Chinook Salmon (e.g. Healey 1980b; Sibert and Kask 1978). As they continue to grow, ocean-type Chinook smolts begin to disperse throughout the nearby coastal areas, preferring sheltered surface waters during early marine residence.

Conversely, stream-type Chinook smolts are generally thought to spend less time in the estuary of their home rivers, reducing the impact of estuarine habitat on their overall survival. There are not obvious reasons for this, though it is suspected to be related to diet preferences and migratory behaviour (Healey 1991). In most cases, they concentrate in the outer delta areas and residence times tend to be relatively short. Stream-type Chinook smolts are the first to disperse seaward from their home estuary.

For further information, Healey (1991) provides a detailed overview of the utilization of estuarine habitat by Chinook Salmon. Rempel *et al.* (2012) provide a current and comprehensive summary of suitable juvenile Chook Salmon habitat specific to the Lower Fraser River. Other estuary-specific reports pertaining to a variety of years also exist (for example, see Healey *et al.* 1980b, Korman *et al.* 1997 or Sibert 1975).

4.3 MARINE HABITAT

Chinook Salmon require productive nearshore marine habitats and survival during the period of early ocean residence can greatly influence total production. Chinook Salmon generally remain in sheltered, near shore environments for varying periods depending on factors such as food availability, competition, predation and environmental conditions. Coastal areas provide a rich habitat with opportunities for feeding and growth, which are important since survival in the ocean is size dependent with larger fish surviving at much higher rates (Quinn 2005). Throughout this period, kelp and other shoreline vegetation provide an important refuge from predators as well as a productive environment for insects and plankton, both major dietary components for juvenile Chinook (Healey 1991; Williams 1989). Therefore, the health of coastal ocean ecosystems plays a key role in the production of Chinook Salmon stocks.

Ocean-type Chinook Salmon dominate in coastal waters where they remain for most of their life at sea. Data suggests that in general, ocean-type Chinook do not disperse more than about

1,000 km from their home rivers (Healey 1991). As a result, any factors that impact the productivity of coastal regions also have an impact on ocean-type Chinook Salmon. Primary prey items consumed during the early marine phase include various zooplankton species as well as adult and larval insects. The variety of food items consumed varies over time and location but fish (primarily herring and sandlance) dominate the diet with crab larvae, squid and large zooplankton also contributing.

Stream-type Chinook comprise the majority of Chinook Salmon intercepted on the high seas, regardless of latitude. In general, stream-type Chinook Salmon are thought to disperse widely throughout the North Pacific where they feed mainly on small fish (primarily herring and sandlance), with crab larvae, squid and large zooplankton also contributing to their diet (Healey 1991).

5 HABITAT THREATS

The productivity of southern BC Chinook Salmon is affected by threats and limiting factors that are encountered at each stage in their life history. Limiting factors are natural occurrences such as predation or food restrictions, whereas threats are direct human impacts or habitat pressures exacerbated by human activities such as environmental pollution, forestry practices or urbanization.

5.1 FRESHWATER HABITAT THREATS

Strategy 2 of the WSP (DFO 2005) requires an objective approach to assess and monitor the status of habitats required by Pacific salmon. In response to this strategy, Stalberg *et al.* (2009) examined physical requirements for all species of salmon and developed indicators to assess the pressure and state indicators, and proposed a suite of metrics and benchmarks to monitor these indicators.

5.1.1 Identifying general freshwater habitat threats

In preparation for developing the assessment metrics, a list of habitat pressures, or threats, was developed pertaining to the freshwater stages of Pacific salmon life histories. Each habitat pressure was then associated with a pressure or state indicator to provide a means of measuring and monitoring the impact of each habitat pressure. Pressure indicators are natural processes or human activities that can directly or indirectly induce qualitative or quantitative changes in environmental conditions (Stalberg *et al.* 2009). For the purposes of WSP Strategy 2, the pressure indicators identified are limited specifically to human-induced changes to fish habitat. State indicators are physical, chemical, or biological attributes measured to characterize environmental condition (Stalberg *et al.* 2009). For the purposes of WSP Strategy 2, the state indicators identified are restricted to physical or chemical attributes that characterize fish habitat. Pressure and State Indicators were categorized into three broad freshwater habitats that are important to salmon: Stream, Lake and Estuary. Refer to Table 15 for the list of freshwater habitat threats (Stalberg *et al.* 2009). From this list, 25 indicators were selected, with suggested metrics and benchmarks identified for each (Stalberg *et al.* 2009). Subsequently, Porter *et al.*[3] used a subset of 19 indicators appropriate for southern BC Chinook Conservation Units and

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[3] Porter, M., Casley, S., Pickard, D., Nelitz, M. and Ochoski, N. 2013. Southern Chinook Conservation Units: Habitat Indicators Report Cards. Report prepared by ESSA Technologies Ltd. for Fisheries and Oceans Canada. Unpublished report.

populated the metrics and benchmarks for each CU. The results of this analysis will be included in the appendices in the second part of this report series.

5.1.2 Identifying localized freshwater habitat threats

The habitat assessment work described here is limited to the use of pressure indicators that are appropriate for broad synoptic-style assessment of habitat. Finer scale state and quantity indicators and localized habitat pressures that are CU- or stream-based should also be used in the overall assessment of habitat. For example, transient features such as debris jams or rock/mud slides that block upstream migration can limit adult access to spawning areas and thus negatively impact production. Also, if adverse conditions such as high water temperature or extreme flows (high or low) are encountered when spawners attempt to return to their natal river or stream, fish will often mill about in the vicinity of the river mouth for long periods, waiting for conditions to improve. This delay in river entry can have a detrimental effect on survival and on spawning success as fish are exposed to additional predation and, since feeding has stopped in preparation for spawning, vital energy reserves are used up before spawning can occur (Bell 1973, 1986; McCullough 1999). Pressures such as these require local familiarity, are specific to each CU and should be monitored through communication with local First Nations, NGOs, Municipalities and Regional Districts. A process to accumulate this information was initiated in 2012 and results will be stored in the Conservation Unit Profile documents maintained by DFO. To the greatest extent available, CU-specific habitat threat information will be presented in the second volume of this document series.

Water quality (e.g. suitable flow rate, temperature, contaminant load) in the freshwater environment is a key aspect of productivity for all Pacific salmon. Research has shown that, while Chinook Salmon eggs and alevins can withstand wide fluctuations in temperature, decreased survival and impaired development occurs at incubation temperatures outside the range of 5-15˚C (Bell 1986). Incubation temperatures outside the ideal range have been shown to cause hatching and emergent times that reduce overall fitness and survival. In addition to sufficient river flows, healthy streamside (riparian) vegetation help to moderate temperature extremes, so it is important that a buffer of natural growth remains undisturbed along the banks of salmon bearing streams. Additionally, presence of water-borne toxins such as waste water, pesticides, toxic chemicals, petroleum products and organic compounds will affect the viability of incubating Chinook Salmon eggs.

Climate change is expected to influence the availability and quality of freshwater conditions for Chinook Salmon as well, through changes in snowpack, groundwater availability, and discharge regimes—all of which can impact temperatures in-stream (Brown 2002). It is well recognized that these issues can profoundly affect the quantity, availability and quality of freshwater rearing habitats, particularly for stream-type Chinook during their longer freshwater residence. Ocean-type Chinook are also affected by these impacts with respect to access to floodplain habitats immediately post-emergence (Brown 2002).

A lack of prime spawning habitat can limit Chinook Salmon productivity as later spawners may be forced to build redds in substandard areas or on top of previously constructed redds resulting in reduced productivity rates overall. Reports indicate that when spawner densities are high or suitable spawning gravel is scarce, Chinook will spawn in areas of sand or silt that are unsuitable for successful incubation (Lisle 1989; Kondolf 2000; Reiser and White 1988). Siltation of spawning beds greatly reduces survival. This situation can occur in areas where streamside activities such as logging, road building, or agricultural practices result in high sediment runoff into the river or where high flows move sediments from upstream areas down onto spawning beds.

5.1.3 Groundwater extraction

Groundwater extraction is of particular concern to Chinook Salmon that reside in streams with “snow-dominated” hydrographs as these populations are highly dependent on ground water for much of their freshwater residence. Groundwater upwelling protects redds from anchor-ice formation, maintains suitable temperatures for late-summer rearing habitats, and moderates temperatures and water levels for returning adults (Brown 2002). In some temperature-sensitive watersheds such as the Nicola River, groundwater is the key ingredient to maintaining stream-resident salmon populations. Despite the critical dependence of stream-resident salmonids on groundwater, groundwater allocation and quantity control are still only passively managed (Douglas 2006). Further, in the arid southern interior region of British Columbia, surface water resources are fully subscribed in many rivers, yet development interests continue to promote growth of local populations. New wells continue to be drilled to access water, without consideration of the impact these activities will ultimately have on the groundwater supply to nearby rivers.

5.2 ESTUARINE HABITAT THREATS

Threats in the estuarine environment include activities that disrupt their connectivity between fresh and saltwater (particularly at low tide), alteration or removal of vital ecosystem components (such as eelgrass or kelp beds) that provide protection from predators, and overall reduction in quality and abundance of estuarine habitat. Work completed by Stalberg *et al.* (2009) includes several indicators and metrics to assess threats to southern BC Chinook in estuarine habitat (Table 15). Results of a CU-specific assessment completed by Porter *et al.*[4] based on these indicators will be included in the appendices in the second part of this report series.

5.3 MARINE HABITAT THREATS

While stock-specific migration patterns and other aspects of the marine ecology of Pacific salmon generally remain poorly understood (Trudel and Hertz 2013), conditions experienced during ocean residence are recognized as an important limiting factor to overall Pacific salmon productivity. Recent research has indicated that ocean migration patterns appear to be population-specific and invariant to ocean conditions (Tucker *et al.* 2012), despite observed influences of some ocean conditions on salmon survival (Vélez-Espino *et al.* 2012). Thus, determining population-specific migration patterns and monitoring relevant ocean conditions at appropriate spatial scales may help to resolve some of the existing uncertainty in marine survival rates of Pacific salmon populations.

5.3.1 Climate change and ocean conditions

In the marine environment, rising sea surface temperatures as a result of human-induced climate change pose a number of challenges to all species of Pacific salmon, in both direct and indirect ways (Richter and Kolmes 2005). A synthesis of current ocean conditions has been produced annually by the Canadian Science Advisory Secretariat since 2006. In the most recent report, Irvine and Crawford (2012) summarize recent observations of Pacific Ocean conditions (oxygen, salinity, temperature), and their potential effects on phyto and zooplankton,

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[4] Porter, M., Casley, S., Pickard, D., Nelitz, M. and Ochoski, N. 2013. Southern Chinook Conservation Units: Habitat Indicators Report Cards. Report prepared by ESSA Technologies Ltd. for Fisheries and Oceans Canada. Unpublished report.

invertebrate, piscine, and avian populations. Ongoing monitoring of changing ocean conditions and the resulting effects on food web dynamics and Pacific salmon condition will be key to assessing the overall impacts of climate change into the future. For example, cooler waters favour the growth of lipid rich 'northern' species of copepods, which constitute an important component of Pacific salmon diets. Climate change is expected to raise sea surface temperatures, potentially limiting future abundance and distribution of this key prey item.

Changes to other aspects of ocean condition (e.g. salinity, acidity, timing of the onset of primary production) also have the potential to impact marine survival of Pacific salmon. These are areas of keen research interest at present and it is hoped more specific data and information can be included in future updates of this report.

6 OTHER THREATS AND LIMITING FACTORS

COSEWIC's guidelines on threats and limiting factors requires that justification be provided for any threat that is identified, including the imminence and potential harm to the population or subpopulations within a DU. In addition, the uncertainty of the threat must also be described to the greatest extent possible. Only threats that are anthropogenic in nature or natural processes that are exacerbated by human activity should be considered. Threats and limiting factors that should not be included are those arising from natural mortality or threats that are hypothetical (no matter how possible or plausible).

6.1 AQUATIC INVASIVE SPECIES

Aquatic invasive species have the potential to alter natural biodiversity and stress or eliminate native species, including salmonids, through predation, alteration of food web dynamics and/or competition for food resources. They have been described as one of the most prevalent threats for Canadian at-risk freshwater fish species (Dextrase and Mandrak 2006). All Chinook Salmon rear in freshwater before migrating downstream to the ocean. Invasive species are a threat to these salmonids, while rearing in interior waters or while migrating downstream.

Thirteen alien freshwater fish species have established populations within the Fraser River drainage and there is always the concern that a new species may become established that impacts native salmonids. Brown trout (*Salmo trutta)*, a predator of juvenile salmon, were introduced to the Cowichan River more than 80 years ago. The majority of the species currently occupying habitats within the lower mainland appear to pose little to no risk to migrating salmonids. However, three spiny rayed fish: Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*M. dolomieu*), and Yellow Perch (*Perca flavescens*), are considered a threat to Fraser River Chinook Salmon. A risk assessment completed in 2009 indicated the risk that these invasive fin fish represented to native species was high (DFO 2010b). Their British Columbia distribution was described by Runciman and Leaf (2009).

Largemouth Bass is a voracious piscivore that will consume salmonid juveniles (Brown *et al.* 2009b). To date they have not become established in the interior Fraser basin, but they now inhabit the mouths of tributary streams, backwaters, and sloughs throughout the lower Fraser River. A fish-wheel operating in the main Fraser River above Misson B.C. in 2009-10 caught 32 Largemouth Bass (G. Cronkite, DFO, Nanaimo, BC, pers. comm.), so they are known to utilize the main river. Although the number of bass residing within the lower Fraser River is unknown, the species is well established and appears to be thriving. Largemouth Bass have the potential to consume large numbers of juvenile Chinook as they migrate to sea, thus impacting productivity of interior Fraser River Chinook CUs. Largemouth Bass have also been formally identified as a threat to native fish species (DFO 2011).

Smallmouth Bass reside in the littoral zone of lakes and slower moving rivers (Brown *et al.* 2009c). They are also piscivorous and can have a significant impact on native communities through predation on small-bodied fish, and are considered to be a threat to native species (Tovey *et al.* 2008; DFO 2010c). There is considerable literature that demonstrates that Smallmouth Bass prey on juvenile Chinook although the ultimate effect on salmonid abundance varies (Brown *et al.* 2009c; Counihan *et al.* 2012). In 2006, Smallmouth Bass were found in Beaver Creek, a tributary of the Quesnel River (L.-M. Herborg, Province of British Columbia, Victoria, B.C., pers. comm.). The Province of BC has initiated and maintains an active control program since 2007 (L.-M. Herborg, Province of British Columbia, Victoria, B.C., pers. comm.); however, it is likely Smallmouth Bass will eventually move downstream into the Quesnel River. They will ultimately reduce Chinook productivity in the Quesnel drainage through predation and may put at risk Fraser Chinook in that system (Tovey *et al.* 2008; DFO 2010c).

Yellow Perch is a highly adaptable species that can utilize a wide range of habitats (Brown et al 2009a). They are considered to be lacustrine-limnetic although in larger lakes, they utilize the littoral zone. Perch juveniles tend to bottom-feed, and larger perch will consume fish eggs and fish (Brown *et al.* 2009a). When introduced into small lakes, Yellow Perch can have severe impacts on native fish species, largely as a result of competition for food (Bradford *et al.* 2008; Brown *et al.* 2009a). Its impact in larger lakes may be less severe, though less information is available. Competition and predation will occur where habitat utilization overlaps, especially lake edge habitat. Spiny ray species (i.e. Yellow Perch) have the potential to dominate fish assemblages, through both predation and interspecies competition (Brown *et al.* 2009a). Yellow Perch were found in small lakes bordering Shuswap and Adams Lake in 1996 (Runciman and Leaf 2009). Nine small interior lakes were rotenone treated from 2008-10 to eradicate the dense populations of Yellow Perch that had developed (L.-M. Herborg, Province of British Columbia, Victoria, B.C., pers. comm.). Yellow Perch were captured in Adams Lake in 2008 and spring 2009, during a spiny ray fish inventory program (Lynda Ritchie, DFO, Kamloops, B.C., pers. comm.). The likely source of introduction was from an established population in Forest Lake which is connected to Adams Lake via Sinmax Creek. Another population of Yellow Perch was found in Rosemond Lake which is directly connected to Mara Lake that drains into Shuswap Lake in January 2013 (Andrew Klassen, Province of British Columbia, Victoria, B.C., pers. comm.). There is high risk regarding the possible spread in range and potential of these introduced fish to impact native fish populations, including interior Chinook Salmon within the Thompson River system (DFO 2010b). Once these invasive species redistribute and enter into larger water bodies such as Shuswap Lake, they put all fish species at risk and are very difficult to eliminate. Although they may not cause extinction, they will alter natural patterns of species diversity and reduce native fish productivity.

6.2 MARINE MAMMAL PREDATION

Of the 31 species of marine mammals that occur in waters off the Pacific coast of Canada, seven are known to prey on salmonids. Although rates of predation specifically on Chinook Salmon are in many cases unknown, in some cases marine mammal predation may play a significant role in mortality rates for certain Chinook stocks. These predator/prey relationships are part of the natural processes in the Chinook life cycle however there are several instances that have an anthropogenic connection which will be described below.

6.2.1 Seals

6.2.1.1 Recreational fishing

For several decades in the 1940s to 1960s the Harbour Seal (*Phoca vitulina*) population was deliberately culled as a control measure to protect salmon. Since the cull ended in the late

1960s, the Harbour Seal abundance along the Pacific coast has increased dramatically. In the Strait of Georgia, abundance increased at 11.5% per year after the mid-1970s before stabilizing in the mid-1990s at about 40,000 animals. This trend is typical of the BC coast generally, with current total abundance estimated at 105,000 animals (Olesiuk 2010). Extensive scat collections during the 1980s indicated that Harbour Seals in the Strait of Georgia consumed a wide variety of prey species but their diet was dominated by herring and hake. Overall, salmonids represented only about 4% of their diet with salmonid consumption concentrated on pre-spawning adult salmon in estuaries and rivers (Olesiuk 1993).

Seal predation on Chinook is a natural process however the seals have learned to follow recreational vessels and seem to recognize when a fish has been hooked. From a seal's point of view, they may not preferentially select Chinook Salmon, but rather, opportunistically target recreational fishers' activities. From the fishers' point of view, if they are allowed a daily limit of two Chinook, any fish taken by seals are not considered catch and 'don't count' toward their daily limit so they continue fishing, effectively increasing the number of Chinook Salmon removed from the population.

The number of salmon lost to seals per recreational vessel, by geographic area varied considerably over the time period 2000 to 2011. In areas outside of the Strait of Georgia the loss rate is estimated to be around 0 to 0.02 salmon per boat; in the Strait of Georgia, the loss rate averaged around 0.045 salmon per boat until 2009 when it decreased by over half to around 0.01 salmon lost per boat and has averaged less than 0.02 since. This abrupt change in loss rate coincides with increased incidence of transient Killer Whales (*Orcincus orca*) in the Strait of Georgia (Graeme Ellis, DFO, Nanaimo, B.C., pers. comm.). The hypothesis from this observation is that the seals were unable to freely follow recreational vessels due to the presence of predators. Table 16 shows the annual estimated number of salmon lost to seals from recreational fishing effort.

6.2.1.2 Log Booms

Up to 300 Harbour Seals have been seen in Cowichan Bay using log booms as surrogate haul out habitat. Local observers note that the log booms not only provide refuge from Transient Killer Whales, but also attract inbound migrating Chinook adults using the booms as cover—giving the seals additional hunting advantage. This situation is exacerbated by low water flow conditions during the upstream migration period, forcing Chinook Salmon adults to remain in Cowichan Bay until rain storm events result in higher river water levels. This low water situation exposes the Chinook Salmon to predation from the seals for a longer period.

6.2.1.3 Freshwater predation

Seal predation in freshwater can potentially be a major source of mortality of returning adult Chinook in cases where run size is small and habitat modification increases vulnerability to predation (e.g., Puntledge River). Juvenile salmon, including Chinook Salmon, are also preyed upon by Harbour Seals. Predation on juveniles can occur in marine areas as well as in rivers. Predation rates on downstream migrating juveniles can be significant in areas that are artificially illuminated at night such as bridge crossings (e.g., Puntledge River, Bigg *et al.* 1990; Olesiuk *et al.* 1996). The constrained nature of a river can increase vulnerability to highly mobile and agile predators such as seals. The extent of predation on juvenile Chinook Salmon by Harbour Seals in natural settings is unknown. Anecdotal information indicates harbour seals have colonized in Harrison Lake and been observed above Hells Gate in the Fraser River, so although currently not well quantified, their impact on Chinook Salmon populations should not be underestimated at this time.

6.2.2 Killer whales

Three distinct ecotypes of Killer Whales (*Orcinus orca*) exist in coastal waters of the NE Pacific. Of these, only the resident Killer Whales, which currently total approximately 350 animals in BC waters, are known to consume salmon. This ecotype can be considered a salmonid specialist, and groups of resident Killer Whales congregate during summer and fall in specific areas to intercept salmon migrating to natal spawning rivers. Although these congregations are spatially and temporally correlated with the abundance of migrating pink and sockeye salmon, extensive field studies of foraging behaviour of resident Killer Whales using identification of prey fragments recovered from predation events and genetic prey identification from scat samples indicate that forage selectively for Chinook Salmon and, to a lesser extent, chum salmon (Ford and Ellis 2006; Hanson *et al.* 2010). The whales appear to target larger, older fish (most being 4 or more years of age). Chinook Salmon appear to be very important to these predators – survival rates of resident Killer Whales dropped significantly during a 5-year period of low Chinook Salmon abundance off the west coast during the late 1990s (Ford *et al.* 2010).

The resident Killer Whale was designated as Endangered by COSEWIC in 2001 and subsequently listed under the Species at Risk Act (SARA), Schedule 1, as Endangered. This designation was followed by a Recovery Strategy document in 2011, which included measures required to protect and recover the species. The recovery strategy includes a section on Critical Habitat which includes the Strait of Juan de Fuca and Strait of Georgia south of the Fraser River and specifically mentions that the presence of this species in this area coincides with salmon. The relationship of the resident Killer Whale with Chinook Salmon would suggest that this prey species should be included as part of the Critical Habitat in the SARA Recovery Plan.

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

Genetic stock identification of Chinook Salmon consumed by resident Killer Whales has been conducted for prey taken in many locations off the BC coast mostly during field sampling in 2002-2009. A wide variety of stocks are represented in these samples. South Thompson Chinook Salmon was the single most important stock, with that and other stocks in the Fraser River system comprising 58% of samples overall. As would be expected, the proportion of Fraser River Chinook Salmon stocks in the sample increased as distance from the Fraser River mouth decreased. These stocks comprised 64% of Chinook Salmon consumed in Johnstone Strait and 75% of Chinook Salmon consumed off southwestern Vancouver Island and in the Strait of Georgia. Also significant in samples from these areas were stocks from both the west and east coasts of Vancouver Island.

6.3 AVIAN PREDATION

Avian predation, a natural process, from species including common mergansers *Mergus merganser*, great blue herons *Ardea herodias*, bald eagles *Haliaeetus leucocephalus,* and belted kingfishers *Megaceryle alcyon* is depensatory on salmonids, including Chinook Salmon, during their seaward migration (Wood 1987a). Depensatory implies that the mortality rate on salmonids increases as salmon abundance decreases. Avian predation of Chinook Salmon also occurs in estuaries by species such as Bonaparte's Gulls *Larus Philadelphia,* Caspian terns

Hydroprogne caspia and double-breasted cormorants *Phalacrocorax auritus* (Mace 1983; Sebring *et al.* 2013). Ocean-type Chinook Salmon populations are vulnerable for a shorter period of time in freshwater to avian predators than stream-type populations. For ocean-type populations in coastal BC, the largest impact from avian predators occurs during the seaward migration with maximum mortality rates reported to be between 8% (Wood 1987a) and 12% (Mace 1983). Stream-type populations spend at least one year rearing in freshwater, while ocean-type populations in the interior Fraser River spend up to 5 months in freshwater before arriving in the Fraser River estuary. This extended period of freshwater residence increases the vulnerability of stream-type Chinook Salmon populations to avian predators. Although we were unable to find a direct assessment of avian predation rates on stream-type Chinook Salmon, Wood (1987b) reported that high mortality rates for Coho Salmon which have a one year stream residence (24-65% of smolt production; Wood 1987b).

6.4 ENHANCEMENT

A number of southern BC Chinook Salmon populations, particularly those from the coastal areas of Vancouver Island and the lower Fraser River, have been supplemented routinely over many years since the beginning of the Salmonid Enhancement Program (MacKinlay *et al.* 2004). The risks of enhancement to wild salmon populations cited in the literature include undesirable genetic effects, disease implications, ecological interactions, as well as impacts on harvest and marine carrying capacity (Gardner *et al.* 2004; HSRG 2004). DFO's Salmon Enhancement Program provides an extensive review of the risks associated with enhancement in their biological risk management framework (DFO 2013a). A brief overview of the issues is provided here. A CU-level summary of enhancement activity within each CU is presented in Table 17. A full description of the method used to define levels of enhancement is included in the second part of this document series.

6.4.1 Genetic Risks

Genetic risks associated with salmon enhancement fall into three general categories: inbreeding depression (including loss of genetic diversity), domestication selection (changes to population genetics through selectivity—or lack of representativeness—during broodstock selection), and outbreeding depression (including reduced fitness, and associated lower relative reproductive success, in the natural environment, through fish straying or cross-breeding). Most of these risks are of highest concern when hatchery productivity outweighs productivity in the associated natural spawning environment.

There are uncertainties about the interrelationships between, and the relative effects of, genetic and environmental factors on fitness. There are also uncertainties about the optimal balance between increased number of spawners and possible decreases in reproductive fitness (i.e. what should the maximum target enhanced contribution be for conservation-based enhancement?). There is some evidence that hatchery populations have experienced a decrease in age at maturation over time (Figure 5). The linear regression lines in Figure 5 indicate a decreasing trend in age at maturation for over half of the southern BC CWT indicator stocks (i.e., p-values are less than 0.05 for 7 out of the 11 stocks).

It should be noted that, due to the integrated approach to hatchery brood stock in British Columbia, a watershed containing both hatchery- and natural-spawned Chinook Salmon does not contain two populations, but rather, has one genetic population with two expressions of the phenotype (with potential for differences in size, smoltification readiness, nutrition or disease status). Hatchery-origin Chinook Salmon could be considered to be well-adapted for rearing in a hatchery environment, whereas natural-origin Chinook Salmon could be considered well-adapted for rearing in the natural environment (R. Withler, DFO, Nanaimo, B.C., pers. comm.).

6.4.2 Disease Risks

The risk of disease resulting from interactions between fish and a pathogen is increased when individuals are exposed to physical, chemical or biological pressures that may compromise their resistance, but little evidence currently exists to support the risk of routine transmissions from hatchery to wild populations, although some risk likely exists (HSRG 2004). A contained population that has become diseased may present a potential risk to wild fish present in the system receiving water from an infected site because it may amplify a normally present pathogen (Brannon *et al.* 1999). Studies under consideration relate to addressing uncertainties around the effectiveness of targeted disease screening and vaccination programs on juvenile to adult survival rates. If deemed effective, adult production could then be maintained with reduced juvenile input. In the meantime, most disease risks can be mitigated by appropriate disinfection and housekeeping measures.

6.4.3 Ecological Interaction Risks

Ecological interaction risks associated with enhancement not previously covered include freshwater carrying capacity, competition and predation.

Risks associated with carrying capacity in the freshwater environment are most likely to occur when juvenile enhanced salmon are released and remain resident within the watershed, either by design (as part of an enhancement strategy) or as an unintentional outcome of a strategy and result in hatchery fish displacing wild resident juveniles. Research documenting effects of hatchery fish on the freshwater carrying capacity of salmon streams is largely lacking (Brannon *et al.* 1999), particularly for southern BC Chinook Salmon, but evidence suggests that large releases of hatchery pre-smolts, particularly at inappropriate times and sizes, can result in significant competition with wild salmon for food and cover (Brannon *et al.* 1999). Risks to wild salmon during the juvenile migration phase most likely manifest as competition and predation (DFO 2013a).

Similar to carrying capacity, the risks of competition are elevated when enhanced fish are released or migrate at a time or in a condition that extends their time in the freshwater environment (Flagg and Nash 1999). Size differences created by hatchery rearing conditions (e.g. warmer water and higher feed levels) may result in hatchery smolts that are larger than wild smolts, and better able to compete for space or food (DFO 2013a).

Risks associated with predation come from a number of sources. Hatchery smolts may consume wild juveniles (Gardner *et al.* 2004), when a sufficient size differential exists. Hatchery releases may attract predators to the detriment of local wild populations. Hatchery fish may also become prey of wild fish and predatory birds, in part due to less experience in predator avoidance (Flagg and Nash 1999). These relationships are often dependent on existing environmental conditions (e.g. low prey abundance).

Uncertainties exist regarding changes to intrinsic carrying capacity under differing environmental conditions and whether hatchery programs may be contributing to density-dependent effects and predation-competition interactions in freshwater environments during the juvenile and adult spawning phases (DFO 2013a).

6.4.4 Harvest Risks

An inherent challenge in fisheries management is the harvest of co-migrating mixtures of strong and weak salmon populations, whether wild or enhanced. In such fisheries, there are risks of overfishing reproductively weaker or lower-numbered wild salmon populations that are mixed with stronger or larger-numbered wild or enhanced populations (DFO 2013a). The production of large numbers of hatchery-origin Chinook Salmon also creates an expectation of successful fishing opportunities, particularly in marine waters. This expectation can lead to higher fishing pressure on all populations present, including lower productivity wild-origin Chinook Salmon.

6.4.5 Marine Carrying Capacity

Enhanced releases from British Columbia account for a small portion of the total number of Chinook Salmon released to the Pacific Ocean each year and are not expected to have a significant influence on the offshore marine environment (Ruggerone *et al.* 2010; Trudel and Hertz 2013). With respect to the near-shore environment, Georgia Strait is influenced by hatchery releases and wild salmon from both Canada and the United States, at levels that fluctuate significantly from year to year. Ongoing work, and studies such as those by Beamish *et al.* (2007, 2008, and 2011b) and the Georgia Strait Ecosystem Initiative will inform future analysis (DFO 2013a).

6.4.6 Enhancement and the Wild Salmon Policy

The WSP defines a wild salmon as one that has “spent their entire life cycle in the wild and originate from parents that were also produced by natural spawning and continuously lived in the wild” (DFO 2005). It also confirms enhancement as a strategy for rebuilding depleted populations. It is difficult to operationalize the WSP’s definition of a wild salmon, but it can be surmised that a population that has received annual supplementation of hatchery-origin Chinook for a number of years may actually contain very few “wild” fish (particularly if first generation hatchery fish comprise a high proportion—typically anything greater than 30%—of the return). If a WSP conservation unit must be comprised exclusively of “wild” Chinook, then by this definition, several southern BC Chinook CUs likely contain very few wild Chinook Salmon. Additional work is presently ongoing to address the implications of enhancement on future policy and WSP assessments of southern BC Chinook Salmon (R. Withler, DFO, Nanaimo, B.C., pers. comm.).

6.5 FISHERIES IMPACTS

Southern BC Chinook Salmon are substantial contributors to ocean troll and sport fisheries, as well as substantial terminal sport, First Nations and commercial fisheries from Georgia Strait and west coast Vancouver Island to Alaska. Reduced marine survival in the 1980s and subsequent management actions throughout the1990s to conserve at-risk populations resulted in coast-wide reductions in fishing effort and landed catches observed over time. Figure 7 illustrates the combined landed catch of Chinook Salmon from all regions over the period from 1975 to 2011. Under the 1985 Pacific Salmon Treaty, Canada and the U.S. committed to halting the decline of Chinook Salmon escapements. In 1997 and 1998, Canadian ocean fisheries were dramatically reduced to lesson impacts on Interior Fraser River Coho Salmon, further altering marine catch distributions and lowering ocean catches of Fraser River Chinook.

Samples of CWTs recovered in fishery catches can be used to determine ocean distribution at all ages vulnerable to fishing gear (usually by two years of age for ocean-type and three years of age for stream-type Chinook). Figure 8 illustrates proportional differences in fishery impacts by gear type for each of the southern BC Chinook CWT indicator stocks. When escapement samples are also available, quantitative analyses such as cohort analysis procedures can be applied to estimate exploitation rates by stock, brood, age and fishery. The same data can also be used to generate annual exploitation rates for pre-terminal and total fisheries for each of the southern BC Chinook CWT indicator stocks (Figure 9). Total fishing impacts (i.e., all human-induced fishing mortality) vary for each of the southern BC indicators according to fishery type (see Figure 10 for annual overall proportional impacts in troll, net and recreational fisheries). CU-specific CWT information can be found in the second part of this report series.

A summary of CWT releases for southern BC Chinook Salmon can be found in Table 18. Release data are from the 2000-2009 brood years while CWT recovery data are from the 12-year period 2000-2011. Under ‘Release Information’, ‘Mean CWT’ is the mean number of juveniles released per brood with a CWT and marked by removal of the adipose fin. The values included under ‘Mean Associated non-CWT’ are the mean number of untagged and unmarked fish released from the same broods and associated to the tagged and marked release. The number of contributing broods is given under ‘n Broods’. Under ‘Estimated CWT Information, ‘Mean CWT’ provides the total estimated number of CWTs represented in fishery catches and in the spawning escapement based on actual CWTs recovered in sampling programs. Mean percentages under the four right-most columns provide the proportional occurrence of the CWTs in all BC ocean fisheries (Ocean-CA), in all ocean fisheries in the U.S. (Ocean-US; which includes Alaska, Washington or Oregon), in terminal marine or freshwater fisheries for a particular stock (the terminal area is stock-specific) and in the spawning escapement. These four percentages sum to 100%. The number of years of CWT recovery (n Years) includes only those years with at least two age classes of CWT releases available for capture.

Total fishing mortality includes both ‘observed’ landed catch and an estimate of mortality incidental to fishing activity. This can be a large source of mortality for Chinook Salmon and has varied over time in relation to gear and timing and location of fisheries openings.

7 RESIDENCE AS DEFINED BY SARA

The concept of residence has previously been defined by Environment Canada (2004), and interpreted, both generally (with respect to the Species at Risk Act) by DFO (DFO 2010a) and specifically for Sockeye Salmon (de Mestral Bezanson *et al.* 2012). de Mestral Bezanson *et al.* (2012) concluded that a salmon redd meets the definition of residence because it fulfills the necessary criteria:

1. Individuals use a discrete place that is similar to a den or nest,
2. These places are occupied by the individual, and
3. These places are crucially linked to the performance of a specific function, such that if the place was not available the function could not be carried out successfully.

Further, DFO (2010a) determined that, in order to be an aquatic species residence, an individual must make an investment of energy, time, or defense in the residence, and/or invest in the protection of the place or structure. The location should contribute to the success of the life history function of the individual. The residence can be a central location within the individual’s home range with repeated returns to complete a specific life function. Finally, there should be an aspect of uniqueness associated with the residence, such that if it were damaged the individual would not be able to complete the life history function in another location without some loss of fitness.

Bearing all of these arguments in mind, it is concluded that southern BC Chinook Salmon redds can be considered a residence as defined by SARA.

8 CONCLUDING REMARKS

Repeated years of low spawner escapements for some southern BC Chinook Salmon stocks have prompted DFO and other agencies to investigate the extent and nature of these declines.

As the first in a two part series, this document addresses the general COSEWIC topics of designatable units, life history characteristics, key habitat requirements, identification of threats to habitat, whether the species has a residence (as defined by SARA) and identification of other threats and limiting factors that could impact the species' risk of extinction for southern BC Chinook Salmon. A fundamental message underlying much of this work is that the complexity of Chinook Salmon in general (and which is fully realized among the populations of southern BC Chinook Salmon) cannot be underestimated when considering their responses to environmental change and for their ongoing management.

The second part of this report series will focus on the methods used to assemble and prepare time series of escapement data, and present other data relevant to the quantitative assessment of southern BC Chinook Salmon abundance, distribution, and habitat threats. It is expected that ongoing efforts to fill knowledge gaps and provide population status information at a finer resolution (ideally, for all conservation units) should enable a more comprehensive update of this work in future years.

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11 TABLES

Table 1. CUs corresponding to regional genetic groupings of Chinook Salmon in BC and Washington state. Regional group notation: UCR-su = Upper Columbia River summers, NPS-f = North Puget Sound falls, LWFR-f = Lower Fraser River falls, LWFR-sp/su, = Lower Fraser River spring/summer, UPFR-sp = Upper Fraser River springs, MDFR-sp/su = Middle Fraser River spring/summer, South Thompson River spring/summer = SOTH-sp/su, Lower Thompson River spring = LWTH-sp, North Thompson River spring/summer = NOTH-sp/su, Southern Mainland-falls = SOMN-f, East Coast Vancouver Island summer/falls = ECVI-su/f, West Coast Vancouver Island = WCVI-f. Colours used to indicate regional groupings in this table are also used in the neighbour-joining tree in Figure 1.

Conservation Unit	Regional Genetic Group	Colour on tree
CK-01	UCR-su	Not shown
CK-02	NPS-f	Not shown
CK-03, CK-9006 to CK-9008	LWFR-f	Light green
CK-04 to CK-06 and CK-08	LWFR-sp/su	Light blue
CK-09 to CK-12	UPFR-sp/MDFR-sp/su	Green-Blue
CK-13 to CK-16, CK-07, CK-82	SOTH-sp/su	Red
CK-17	LWTH-sp	Dark Blue
CK-18, CK-19	NOTH-sp/su	Purple
CK-20, CK-34, CK-35	SOMN-f	Brown
CK-21 to CK-29, CK-83, CK-9005	ECVI-su/f	Dark green
CK-31 to CK-33	WCVI-f	Orange

Table 2. CU names, population names, and stock codes associated with 33 CUs for 121 southern British Columbia Chinook Salmon populations/sampling sites used in the genetic analysis. Note: CUs missing from this table are CK-01, CK-02, CK-21 and CK-9005.

CU	**Population Name**	**Stk_CU**	**CU**	**Population Name**	**Stk_CU**
CK-03	HARRISON RIVER	6-CK03	CK-17	SPIUS CREEK	81-CK17
CK-04	BIRKENHEAD RIVER	93-CK04	CK-17	NICOLA RIVER	42-CK17
CK-05	PITT RIVER-UPPER	272-CK05	CK-17	LOUIS CREEK	90-CK17
CK-05	BLUE CREEK	426-CK05	CK-17	DEADMAN RIVER	82-CK17
CK-06	SLOQUET CREEK	341-CK06	CK-17	COLDWATER RIVER-UPPER	223-CK17
CK-06	BIG SILVER CREEK	92-CK06	CK-17	COLDWATER RIVER	46-CK17
CK-07	MARIA SLOUGH	212-CK07	CK-17	BONAPARTE RIVER	83-CK17
CK-08	NAHATLATCH RIVER	91-CK08	CK-18	FINN CREEK	87-CK18
CK-09	PORTAGE CREEK	74-CK09	CK-18	BLUE RIVER	210-CK18
CK-10	WEST ROAD (BLACKWATER) RIVER	103-CK10	CK-19	RAFT RIVER	70-CK19
CK-10	NAZKO RIVER	349-CK10	CK-19	NORTH THOMPSON RIVER	226-CK19
CK-10	LIGHTNING CREEK	452-CK10	CK-19	LEMIEUX CREEK	211-CK19
CK-10	HORSEFLY RIVER	96-CK10	CK-19	CLEARWATER RIVER	145-CK19
CK-10	ENDAKO RIVER	104-CK10	CK-19	BARRIERE RIVER	208-CK19
CK-10	COTTONWOOD RIVER-UPPER	50-CK10	CK-20	SQUAMISH RIVER	12-CK20
CK-10	CHILCOTIN RIVER-UPPER	73-CK10	CK-20	SHOVELNOSE CREEK	123-CK20
CK-10	CHILCOTIN RIVER-LOWER	102-CK10	CK-20	MAMQUAM SPAWNING	119-CK20
CK-10	CHILAKO RIVER	206-CK10	CK-20	CHEAKAMUS RIVER	415-CK20
CK-10	CARIBOO RIVER-UPPER	254-CK10	CK-22	COWICHAN RIVER	11-CK22
CK-10	BRIDGE RIVER	45-CK10	CK-25	NANAIMO RIVER-FALL	101-CK25
CK-10	BAKER CREEK	482-CK10	CK-25	CHEMAINUS RIVER	18-CK25
CK-10	BAEZAEKO RIVER	351-CK10	CK-27	QUALICUM RIVER	2-CK27
CK-11	TASEKO RIVER	143-CK11	CK-27	PUNTLEDGE RIVER-FALL	106-CK27
CK-11	STUART RIVER	29-CK11	CK-27	LITTLE QUALICUM RIVER	97-CK27
CK-11	QUESNEL RIVER	8-CK11	CK-28	PHILLIPS RIVER	241-CK28
CK-11	NECHAKO RIVER	30-CK11	CK-29	WOSS RIVER	335-CK29
CK-11	KUZKWA RIVER	228-CK11	CK-29	QUINSAM RIVER	3-CK29
CK-11	ELKIN CREEK	71-CK11	CK-29	QUATSE RIVER	110-CK29
CK-11	CHILKO RIVER	44-CK11	CK-29	NIMPKISH RIVER	94-CK29
CK-11	CARIBOO RIVER	99-CK11	CK-31	SOMASS RIVER	1-CK31
CK-12	WILLOW RIVER	69-CK12	CK-31	TRANQUIL CREEK	111-CK31
CK-12	WALKER CREEK	233-CK12	CK-31	TOQUART RIVER	257-CK31
CK-12	TORPY RIVER	247-CK12	CK-31	THORNTON CREEK	34-CK31
CK-12	SWIFT CREEK	66-CK12	CK-31	SOOKE RIVER	405-CK31
CK-12	SLIM CREEK	67-CK12	CK-31	SARITA RIVER	107-CK31
CK-12	SALMON RIVER	38-CK12	CK-31	SAN JUAN RIVER	135-CK31
CK-12	PTARMIGAN CREEK	232-CK12	CK-31	NITINAT RIVER	9-CK31
CK-12	NEVIN CREEK	225-CK12	CK-31	NAHMINT RIVER	108-CK31
CK-12	MORKILL RIVER	246-CK12	CK-31	MOYEHA RIVER	464-CK31
CK-12	KENNETH CREEK	231-CK12	CK-31	MEGIN RIVER	459-CK31
CK-12	INDIANPOINT CREEK	68-CK12	CK-31	KENNEDY RIVER-LOWER	31-CK31
CK-12	HORSEY CREEK	63-CK12	CK-32	ZEBALLOS RIVER	315-CK32
CK-12	HOLMES RIVER	65-CK12	CK-32	TLUPANA RIVER	332-CK32
CK-12	HOLLIDAY CREEK	134-CK12	CK-32	TAHSIS RIVER	331-CK32
CK-12	GOAT RIVER	64-CK12	CK-32	SUCWOA RIVER	340-CK32
CK-12	FRASER RIVER-ABOVE TETE JAUNE CACHE	39-CK12	CK-32	KAOUK RIVER	463-CK32
CK-12	FONTONIKO CREEK	98-CK12	CK-32	GOLD RIVER	314-CK32
CK-12	BOWRON RIVER	49-CK12	CK-32	CONUMA RIVER	5-CK32
CK-12	BAD RIVER (JAMES CREEK)	350-CK12	CK-32	BURMAN RIVER	242-CK32
CK-13	SOUTH THOMPSON RIVER	85-CK13	CK-33	MARBLE RIVER	72-CK33

CU	Population Name	Stk_CU	CU	Population Name	Stk_CU
CK-13	LOWER THOMPSON RIVER	137-CK13	CK-33	CAYEGHLE SYSTEM	330-CK33
CK-13	LITTLE RIVER	95-CK13	CK-34	HOMATHKO RIVER	177-CK34
CK-13	ADAMS RIVER	84-CK13	CK-35	KLINAKLINI RIVER	147-CK35
CK-14	SEYMOUR RIVER	270-CK14	CK-35	DEVEREUX CREEK	148-CK35
CK-14	SALMON RIVER	76-CK14	CK-82	ADAMS RIVER-UPPER	195-CK82
CK-14	EAGLE RIVER	75-CK14	CK-83	PUNTLEDGE RIVER-SUMMER	105-CK83
CK-15	SHUSWAP RIVER-MIDDLE	47-CK15	CK-83	NANAIMO RIVER-SUMMER	7-CK83
CK-15	SHUSWAP RIVER-LOWER	43-CK15	CK-9006	STAVE RIVER	194-CK9006
CK-16	DUTEAU CREEK	235-CK16	CK-9007	CAPILANO RIVER	262-CK9007
CK-16	BESSETTE CREEK	183-CK16	CK-9008	CHILLIWACK/VEDDER RIVER	40-CK9008
CK-17	SPIUS CREEK-UPPER	224-CK17			

Table 3. Results from a standard Analysis of Molecular Variance (AMOVA) using 121 southern BC Chinook Salmon populations and the 30 CUs for 15 microsatellite loci. Note: CK-9006, CK-9007 and CK-9008 are combined with CK-03 as these CUs have been heavily influenced by transfers of fish from CK-03.

Source of variation	df	Sums of squares	Variance components	Percent of variation
Among CUs	29	4428.55	0.02690	0.50*
Among populations	-	-	-	-
– Within CUs	91	6590.11	0.23139	4.27***
– Within populations	40897	211023.74	5.15988	95.23***
Total	41017	222042.40	5.41817	100.0

Average over all loci: F_{ST} = 0.0477, F_{SC} = 0.0429, F_{CT} = 0.0049. * not significant, *** P<0.001

Table 4. Pairwise F_{ST} values for 30 CUs determined by 15 microsatellite markers. Non-significant p-values at the 0.05 and 0.001 levels are indicated by shading and boldface respectively. The southern BC Chinook CUs contributing to the analysis are listed in sequence along the top and left side of the matrix.

CU	CK03	CK04	CK05	CK06	CK07	CK08	CK09	CK10	CK11	CK12	CK13	CK14	CK15	CK16	CK17	CK18	CK19	CK20	CK22	CK25	CK27	CK28	CK29	CK31	CK32	CK33	CK34	CK35	CK82	CK83
CK03*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK04	0.095	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK05	0.045	0.076	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK06	0.055	0.110	0.036	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK07	0.073	0.137	0.115	0.110	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK08	0.035	0.116	0.071	0.056	0.072	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK09	0.052	0.111	0.071	0.070	0.072	0.040	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK10	0.030	0.100	0.062	0.050	0.070	0.015	0.033	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK11	0.046	0.112	0.049	0.061	0.063	***0.000***	0.030	***0.000***	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK12	0.050	0.118	0.068	0.070	0.072	0.011	0.044	0.001	0.014	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK13	0.036	0.085	0.059	0.047	0.050	0.024	0.031	0.027	0.026	0.030	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK14	0.060	0.118	0.074	0.070	0.059	0.023	0.038	0.029	0.035	0.039	0.018	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK15	0.065	0.118	0.070	0.076	0.046	0.013	0.037	0.022	0.043	0.039	0.009	0.006	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK16	0.055	0.117	0.084	0.069	0.059	0.031	0.045	0.036	0.032	0.033	0.018	0.008	***0.000***	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK17	0.052	0.132	0.088	0.089	0.080	0.034	0.066	0.026	0.036	0.037	0.049	0.050	0.052	0.050	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK18	0.059	0.127	0.091	0.073	0.083	0.033	0.053	0.035	0.014	0.036	0.048	0.040	0.031	0.054	0.054	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK19	0.046	0.112	0.063	0.061	0.069	0.014	0.039	0.012	0.010	0.025	0.031	0.030	0.032	0.036	0.037	0.019	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CK20	0.015	0.095	0.062	0.053	0.072	0.043	0.052	0.038	0.043	0.044	0.034	0.052	0.048	0.053	0.049	0.069	0.049	–	–	–	–	–	–	–	–	–	–	–	–	–
CK22	0.040	0.112	0.060	0.063	0.081	0.038	0.052	0.028	0.058	0.054	0.037	0.067	0.074	0.055	0.055	0.063	0.059	0.022	–	–	–	–	–	–	–	–	–	–	–	–
CK25	0.026	0.101	0.074	0.055	0.086	0.054	0.052	0.050	0.042	0.051	0.041	0.061	0.050	0.066	0.058	0.086	0.059	0.031	***0.000***	–	–	–	–	–	–	–	–	–	–	–
CK27	0.030	0.098	0.062	0.057	0.088	0.053	0.052	0.041	0.047	0.053	0.042	0.064	0.060	0.065	0.059	0.080	0.061	0.027	***0.000***	0.007	–	–	–	–	–	–	–	–	–	–
CK28	0.007	0.080	0.070	0.043	0.075	0.049	0.044	0.043	0.027	0.036	0.027	0.046	0.026	0.053	0.049	0.077	0.044	0.019	***0.000***	0.028	0.017	–	–	–	–	–	–	–	–	–
CK29	0.038	0.112	0.073	0.075	0.098	0.063	0.059	0.051	0.060	0.067	0.057	0.083	0.080	0.083	0.072	0.088	0.071	0.039	0.024	0.029	0.027	0.019	–	–	–	–	–	–	–	–
CK31	0.043	0.116	0.067	0.059	0.085	0.034	0.047	0.030	0.029	0.036	0.030	0.052	0.052	0.056	0.058	0.060	0.047	0.040	0.038	0.037	0.040	0.027	0.049	–	–	–	–	–	–	–
CK32	0.052	0.121	0.076	0.070	0.097	0.050	0.052	0.043	0.035	0.046	0.043	0.060	0.059	0.070	0.069	0.073	0.052	0.052	0.054	0.059	0.056	0.047	0.064	0.010	–	–	–	–	–	–
CK33	0.057	0.130	0.043	0.059	0.099	0.036	0.037	0.021	0.049	0.059	0.043	0.068	0.083	0.063	0.073	0.047	0.048	0.045	0.065	0.031	0.038	0.011	0.037	0.030	0.030	–	–	–	–	–
CK34	0.003	0.093	0.062	0.041	0.075	0.039	0.035	0.029	0.019	0.028	0.025	0.043	0.036	0.051	0.037	0.073	0.044	*0.002*	***0.000***	0.028	0.015	0.017	0.023	0.024	0.046	0.003	–	–	–	–
CK35	0.038	0.092	0.056	0.060	0.084	0.045	0.047	0.038	0.045	0.052	0.038	0.061	0.061	0.062	0.068	0.063	0.049	0.030	0.051	0.044	0.043	0.023	0.049	0.046	0.051	0.043	0.004	–	–	–
CK82	0.035	0.113	0.083	0.057	0.051	0.026	0.027	0.040	0.017	0.027	0.003	***0.000***	***0.000***	***0.000***	0.050	0.054	0.031	0.044	0.038	0.059	0.056	0.046	0.069	0.042	0.056	0.030	0.044	0.052	–	–
CK83	0.052	0.144	0.124	0.086	0.106	0.091	0.078	0.081	0.072	0.077	0.076	0.098	0.085	0.105	0.088	0.124	0.094	0.059	***0.000***	0.028	0.037	0.057	0.044	0.066	0.092	0.049	0.059	0.074	0.103	–

* CK03 combined with CK9006-CK9008

Table 5. General summary of southern BC Chinook Conservation Units.

CU Index	CU Name	CU Acronym	Juvenile Life History	Adult Run Timing	Average Generation Time	Total Census Sites*	Basis for CU†, Comments
CK-01	Okanagan_1.X‡	OK	Ocean	Summer	4	1	Life history and geography.
CK-02	Boundary Bay_FA_0.3	BB	Ocean	Fall	4	3	Life history and geography.
CK-03	Lower Fraser River_FA_0.3	LFR-fall	Ocean	Fall	4§	1	Life history and run timing.
CK-04	Lower Fraser River_SP_1.3	LFR-spring	Stream	Spring	5	3	Life history and run timing.
CK-05	Lower Fraser River-Upper Pitt_SU_1.3	LFR-UPITT	Stream	Summer	5	1	Spawn (and run?) timing.
CK-06	Lower Fraser River_SU_1.3	LFR-summer	Stream	Summer	5	8	Life history and run timing.
CK-07	Maria Slough_SU_0.3	Maria	Ocean	Summer	4	1	Geography (otherwise similar to CK-13).
CK-08	Middle Fraser River-Fraser Canyon_SP_1.3	FRCanyon	Stream	Spring	5	2	Genetics (confirmed since original designation).
CK-09	Middle Fraser River-Portage_FA_1.3	Portage	Stream	Fall	5	1	Life history and run timing.
CK-10	Middle Fraser River_SP_1.3	MFR-spring	Stream	Spring	5	24	Run timing.
CK-11	Middle Fraser River_SU_1.3	MFR-summer	Stream	Summer	5	18	Run timing.
CK-12	Upper Fraser River_SP_1.3	UFR-spring	Stream	Spring	5§	41	Run timing.

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[*] Not all census sites within a CU have sufficient data to contribute to analysis.

[†] The original basis for CU designation as summarized in Holtby & Ciruna (2007).

[‡] This CU was assessed by COSEWIC under its own process and will not be discussed in detail in this report series (Davis *et al.* 2007). General information is provided for sake of completion only.

[§] Estimated by cohort analysis of coded wire tagged fish. See second volume of this report for more information.

CU Index	CU Name	CU Acronym	Juvenile Life History	Adult Run Timing	Average Generation Time	Total Census Sites[*]	Basis for CU[†], Comments
CK-13	South Thompson_SU_0.3	STh-0.3	Ocean	Summer	4	5	Life history, age and spawning location (genetics similar to CK-07).
CK-14	South Thompson_SU_1.3	STh-1.3	Stream	Summer	5	4	Life history, age and genetics.
CK-15	Shuswap River_SU_0.3	STh-SHUR	Ocean	Summer	4[§]	3	Genetics (otherwise similar to CK-13).
CK-16	South Thompson-Bessette Creek_SU_1.2	STh-BESS	Stream	Summer	4	4	Life history and age.
CK-17	Lower Thompson_SP_1.2	LTh	Stream	Spring	4[§]	9	Genetics, run timing and age.
CK-18	North Thompson_SP_1.3	NTh-spr	Stream	Spring	5	7	Genetics, run timing and age.
CK-19	North Thompson_SU_1.3	NTh-sum	Stream	Summer	5	7	Run timing (otherwise similar to CU#18).
CK-20	Southern Mainland-Georgia Strait_FA_0.X	SMn-GStr	Ocean	Fall	4	42	Geography and comparison to coho & chum population structure.
CK-21	East Vancouver Island-Goldstream_FA_0.X	Goldstr	Ocean	Fall	3	2	Genetics.
CK-22	East Vancouver Island-Cowichan & Koksilah_FA_0.X	CWCH-KOK	Ocean	Fall	3[§]	6	Genetics and Run timing
CK-23	East Vancouver Island-Nanaimo-SP	NanR-spr	Stream	Spring	4	1	Age, genetics, run timing
CK-83	East Vancouver Island-Georgia Strait_SU_0.3	EVI-sum	Ocean	Summer	4[§]	4	Genetics and run timing, CK-24 and CK-26 merged
CK-25	East Vancouver Island-Nanaimo & Chemainus_FA_0.X	EVI-fall	Ocean	Fall	3[§]	4	Genetics and run timing
CK-27	East Vancouver Island-Qualicum & Puntledge_FA_0.X	QP-fall	Ocean	Fall	4[§]	17	Genetics and run timing

CU Index	CU Name	CU Acronym	Juvenile Life History	Adult Run Timing	Average Generation Time	Total Census Sites[*]	Basis for CU[†], Comments
CK-28	Southern Mainland-Southern Fjords_ FA_0.X	SMn-SFj	Ocean	Fall	4	25	Run timing and habitat
CK-29	East Vancouver Island-North_FA_0.X	NEVI	Ocean	Fall	4[§]	18	Run timing and habitat
CK-31	West Vancouver Island-South_FA_0.X	SWVI	Ocean	Fall	4[§]	69	Run timing and habitat, CK-30 and CK-31 merged
CK-32	West Vancouver Island-Nootka & Kyuquot_ FA_0.X	NoKy	Ocean	Fall	4	57	Run timing.
CK-33	West Vancouver Island-North_FA_0.X	NWVI	Ocean	Fall	4	17	Ecotype
CK-34	Homathko_SU_X.X	HOMATH	Stream	Summer	5	2	Genetics.
CK-35	Klinaklini_SU_1.3	KLINA	Stream	Summer	5	2	Genetics.
CK-82	Upper Adams River_ SU_1.X	UAdams	Ocean	Summer	5	1	Genetics and run timing, new CU. Does not fit with other South Thompson CUs
CK-9005	Southern BC-Miscellaneous	sBC-Misc	Ocean	Fall	3	1	Enhancement bin
CK-9006	Fraser-Cross-CU Supplementation Exclusion	FR-XCU	Ocean	Mixed	3	3	Enhancement bin
CK-9007	Southern BC-Cross-CU Supplementation Exclusion	sBC-XCU	Ocean	Mixed	4	4	Enhancement bin
CK-9008	Fraser-Harrison fall transplant_FA_0.3	Chil_trans_FA	Ocean	Fall	3[§]	1	Enhancement bin

Table 6. Adult return run timings, based on Waples et al. (2004) and Parken et al. (2008).

Adult Migration Timing	Timing Name
March – May	Spring
June	early Summer
July	mid-Summer
August	late Summer
September-November	Fall
December-February	Winter

Table 7. General variation in age at maturity, length at maturity and fecundity for Chinook Salmon. Reproduced from Healey (1986).

Juvenile Life History	Age at Maturity	Maximum Occurrence (%)	Range in Fork Length (mm)	Range in Fecundity
Ocean	0.1	50.0	280-570	-
Ocean	0.2	35.0	480-730	-
Ocean	0.3	53.0	630-880	2,648-4,462
Ocean	0.4	12.0	810-1,030	3,419-5,355
Ocean	0.5	1.0	955-1,150	4,297-5,724
Stream	1.0	1.0	102-401	4,720
Stream	1.1	19.0	358-635	-
Stream	1.2	56.0	572-909	4,018
Stream	1.3	77.0	727-1,031	5,388-9,063
Stream	1.4	60.0	828-1,010	8,716-10,094
Stream	1.5	12.0	967-1,025	8,196-12,040
Stream	2.1	~0.0	NA	-
Stream	2.2	~0.0	602	-
Stream	2.3	~0.0	749	-

Table 8. Summary of release fork lengths (mm, n=48,251) and weights (g, n=140,800) by southern BC Chinook conservation unit, based on associated CWT releases.

Conservation Unit	Fork Length (mm)			Weight (g)		
	Fry	Smolt	Yearling	Fry	Smolt	Yearling
CK-03	57.7	78.7	151.9	1.78	5.24	31.51
CK-04	NA	70.0	NA	2.89	6.16	16.02
CK-05	NA	95.7	NA	NA	8.10	NA
CK-06	NA	95.0	NA	NA	8.82	NA
CK-07	NA	83.0	NA	NA	6.24	NA
CK-10	94.0	84.4	116.0	11.10	5.91	18.50
CK-11	95.6	78.9	103.5	9.24	5.27	12.94
CK-12	59.3	81.6	100.6	2.14	6.03	12.27
CK-14	NA	NA	108.2	4.70	3.99	16.54
CK-15	65.0	81.6	NA	2.48	NA	NA
CK-17	90.0	78.6	115.6	5.34	5.86	17.43
CK-18	NA	91.9	NA	NA	7.94	NA
CK-19	NA	84.6	118.0	5.92	7.26	18.60
CK-20	67.0	87.0	NA	2.29	7.36	NA
CK-22	NA	84.5	NA	NA	5.40	NA
CK-25	NA	89.4	NA	NA	7.13	NA
CK-27	NA	81.1	172.0	2.00	6.62	117.95
CK-28	NA	NA	98.2	NA	4.88	12.10
CK-29	65.6	87.7	NA	2.50	8.03	45.00
CK-31	NA	78.9	115.4	2.71	5.90	23.56
CK-32	NA	82.4	186.0	2.75	6.22	75.00
CK-33	NA	NA	NA	NA	6.40	NA
CK-35	NA	NA	NA	2.63	4.50	NA
CK-83	57.5	82.4	NA	2.36	5.57	102.09
CK-9006	NA	85.4	NA	NA	6.48	NA
CK-9007	NA	83.9	NA	2.60	6.15	34.44
CK-9008	56.0	82.9	NA	1.80	5.58	NA

Table 9. Generic length-at-age categories established for juvenile Chinook Salmon caught during their first year at sea (based on Tucker et al. 2011).

Life History Type	West Coast Vancouver Island			Southeast Alaska/Northern BC		
	Summer	Fall	Winter	Summer	Fall	Winter
Ocean-type	< 125	< 300	125-325	-	-	-
Stream-type	125-275	-	325-400	125-275	150-350	<400mm

Table 10. Fork lengths at age (mm) for southern BC Chinook Salmon CUs, derived from fisheries coded wire tag recoveries, 1967-2012. (n=73,709)

Conservation Unit	**Average Generation Time (years)**	**Fork Length by Age (mm)**			
		Age-2	**Age-3**	**Age-4**	**Age-5**
CK-03	4	653.8	797.8	879.3	NA
CK-04	5	599.6	759.7	891.5	965.0
CK-05	5	675.2	804.4	912.0	NA
CK-06	5	645.6	804.9	888.6	NA
CK-07	4	636.3	777.0	828.0	NA
CK-10	5	665.2	738.9	846.8	NA
CK-11	5	629.7	766.9	869.7	895.2
CK-12	5	601.2	741.5	798.0	870.0
CK-14	5	628.0	750.0	835.8	850.0
CK-15	4	702.1	812.1	880.6	NA
CK-17	4	614.9	695.2	794.6	NA
CK-18	5	696.5	786.8	869.8	NA
CK-19	5	661.3	796.1	889.0	992.0
CK-20	4	687.9	848.1	930.3	NA
CK-22	3	666.2	788.0	820.9	NA
CK-25	3	674.6	819.4	902.5	NA
CK-27	4	658.3	833.2	938.6	950.0
CK-28	4	616.9	773.8	930.4	NA
CK-29	4	619.2	807.4	955.0	1001.0
CK-31	4	706.9	825.2	910.4	927.3
CK-32	4	695.7	824.1	916.5	961.9
CK-33	4	668.2	829.6	917.7	976.6
CK-35	5	459.7	683.7	839.7	NA
CK-83	4	617.4	766.3	840.2	885.0
CK-9006	3	679.7	824.3	940.0	NA
CK-9007	4	650.6	808.3	845.5	895.0
CK-9008	3	681.6	818.5	887.2	NA

Table 11. General ocean distribution strategies of immature adult southern BC Chinook Salmon CWT indicators (CWT abbreviation in parentheses).

Local Migrants	**Far-North Migrants**	**Offshore Migrants**
Cowichan-Koksilah (COW)	Southwest Vancouver Island (RBT)	Nicola River (NIC)
ECVI Nanaimo-Chemainus Fall (NAN)	Northeast Vancouver Island (QUI)	Dome Creek (DOM)
Lower Fraser Fall (white) (HAR)	Qualicum-Puntledge Falls (BQR)	-
Lower Fraser Fall (CHI)	Mid-ECVI Summers (PPS)	-
-	Shuswap River Summer (SHU)	-

Table 12. Summary of Salmon Enhancement Program facilities in southern BC. CEDP – Community Economic Development Program; PIP—Public Involvement Project.

CU Index	CU Name	DFO Hatcheries	CEDP Hatcheries	PIP Hatcheries
CK-02	Boundary Bay_FA_0.3	-	-	L Campbell R, Nicomekl R, Serpentine R
CK-9006	Fraser-Cross-CU Supplementation Exclusion	Chehalis R	-	Alouette R
CK-9008	Fraser-Harrison fall transplant_FA_0.3	Chilliwack R, Inch Cr	-	Poco Hatchery
CK-15	Shuswap River_SU_0.3	Shuswap R	-	Kingfisher Cr
CK-13	South Thompson_SU_0.3	Spius Cr	-	-
CK-20	Southern Mainland-Georgia Strait_FA_0.X	Capilano R, Tenderfoot Cr	Lang Cr, Sechelt Band, Seymour R, Sliammon R	Chapman Cr, Reed Point/Ioco, Westridge Term
CK-21	East Vancouver Island-Goldstream_FA_0.X	-	-	Goldstream R
CK-22	East Vancouver Island-Cowichan & Koksilah_FA_0.X	-	Cowichan R	-
CK-83	East Vancouver Island-Georgia Strait_SU_0.3	Puntledge R	Nanaimo R	-
CK-25	East Vancouver Island-Nanaimo& Chemainus_FA_0.X	Big Qualicum R, L Qualicum R	-	Englishman Enh, Oyster R
CK-28	Southern Mainland-Southern Fjords_ FA_0.X	-	-	Gillard Pass
CK-29	East Vancouver Island-North_FA_0.X	Quinsam R	Gwa'ni, P Hardy/ Quatse	Kokish R, Sayward F&G, Woss Comm Hatchery
CK-31	West Vancouver Island-South_FA_0.X	Nitinat R, Robertson Cr	Clayoquot, San Juan R, Thornton Cr	Esquimalt Harbour, Sooke R, Tofino
CK-32	West Vancouver Island-Nootka & Kyuquot_ FA_0.X	Conuma R	-	Nootka Sd Wtrshd Soc, Tahsis R, Zeballos R
CK-33	West Vancouver Island-North_FA_0.X	-	-	Holberg In, P Hardy/Marble

Table 13. Summary of average Chinook Salmon releases by Conservation Unit and time period. Note: 1995-2011 is roughly equivalent to three generations and 2007-2011 is roughly equivalent to one generation, assuming a 4-year average generation time. Releases are strictly limited to within-CU populations (stock population is from the same CU as the release location CU), all other cases are counted as cross-CU releases (CK-9005 to CK-9007).

CU Index	**CU Name**	**Average release (in thousands)**		**Total released (in millions)**	
		1995-2011	**2007-2011**	**1995-2011**	**2007-2011**[9]
CK-02	Boundary Bay_FA_0.3	49.6	48.1	2.2	0.82
CK-03	Lower Fraser River_FA_0.3	370.5	45.3	25.2	1.31
CK-04	Lower Fraser River_SP_1.3	40.7	-	0.5	-
CK-05	Lower Fraser River-Upper Pitt_SU_1.3	<0.1	-	<0.1	-
CK-06	Lower Fraser River_SU_1.3	342.0	436.1	7.5	2.18
CK-07	Maria Slough_SU_0.3	21.0	36.5	0.2	0.04
CK-10	Middle Fraser River_SP_1.3	9.8	-	0.1	-
CK-11	Middle Fraser River_SU_1.3	37.5	0.5	1.8	0.00
CK-12	Upper Fraser River_SP_1.3	29.9	--	1.8	-
CK-14	South Thompson_SU_1.3	55.4	61.2	1.6	0.61
CK-15	Shuswap River_SU_0.3	92.6	60.2	16.6	4.27
CK-17	Lower Thompson_SP_ 1.2	43.4	42.8	6.4	1.84
CK-20	Southern Mainland-Georgia Strait_FA_0.X	184.6	134.4	20.3	4.03
CK-21	East Vancouver Island-Goldstream_FA_0.X	51.6	85.0	1.1	0.26
CK-22	East Vancouver Island-Cowichan & Koksilah_FA_0.X	162.2	54.4	27.6	4.02
CK-83	East Vancouver Island-Georgia Strait_ SU _0.3	140.3	67.8	16.7	4.60
CK-25	East Vancouver Island-Nanaimo & Chemainus_FA_0.X	99.0	137.6	8.0	2.06
CK-27	East Vancouver Island-Qualicum & Puntledge_FA_0.X	445.7	408.1	151.6	40.81
CK-28	Southern Mainland-Southern Fjords_ FA_0.X	52.4	77.9	0.7	0.47
CK-29	East Vancouver Island-North_FA_0.X	186.8	174.8	57.7	16.26
CK-31	West Vancouver Island-South_FA_0.X	401.9	352.9	236.3	60.35
CK-32	West Vancouver Island-Nootka & Kyuquot_ FA_0.X	290.3	353.3	53.7	15.19
CK-33	West Vancouver Island-North_FA_0.X	88.6	144.6	6.5	1.59
CK-9005	Southern BC-Miscellaneous	-	-	-	-
CK-9006	Fraser-Cross-CU Supplementation Exclusion	198.4	215.2	12.9	4.30
CK-9007	Southern BC-Cross-CU Supplementation Exclusion	176.2	203.8	25.6	8.36
CK-9008	Fraser-Harrison fall transplant_FA_0.3	154.8	154.8	25.2	6.96
UNK	Unknown CU for release location	33.6	115.0	0.9	0.34
TOTAL RELEASES TO ALL CUs:		--	--	708.7	180.7

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[9] Note: The average only includes years where releases occurred, so represents the actual average release size rather than an annualized release size over the time span (17 and 4 years, respectively).

Table 14. Summary of hatchery Chinook Salmon release strategies.

Release strategy	Advantages	Disadvantages
Egg plants	• Used when surplus taken if rearing habitat is available • Lower cost	• Lower survival rates than smolt or fed fry • Vulnerable to extreme weather events
Unfed Fry (incubator boxes)	• Slower early growth may produce more natural age class structure • Less domestication • More exposure to competition and predation to allow natural selection • Lower cost	• Lower survival rates than smolt or fed fry • Vulnerable to extreme weather events
Fed Fry	• Slower early growth may produce more natural age class structure • Less domestication • More exposure to competition and predation to allow natural selection • Lower cost • May facilitate homing	• Lower survival rate than smolt • Forced release • May displace or out-compete wild fry • More exposure to competition and predation • Requires available rearing habitat
Smolt 0+	• Highest survival rates for production of ocean type Chinook • Used for assessment as indicator of wild production (must be over 2g in body weight to tag and mark) • Often a volitional release • Most cost effective strategy • May be accelerated to produce a larger smolt with improved survival rate	• Large size at release may produce higher proportion of jacks
Smolt 1+	• Used for stream type Chinook where this is a natural life history to improve survival rate and reduce impacts on wild • Used for assessment as indicator of wild production of stream type stocks • Improved survival rate for ocean type Chinook if stock status is extremely poor	• Higher cost • Increased risk of un-natural mortality in hatchery • Increased domestication • Increased risk of stress-related disease

Release strategy	Advantages	Disadvantages
Seapen	• Minimizes competition with wild smolts in the estuary • Increases acclimation time before release, • Higher survival rate • May contribute more to harvest than river releases • May avoid predators such as birds and marine mammals at release • Offers stewardship opportunities to external partners	Higher cost • Vaccination required because smolts are reared in seawater and exposed to pathogens such as vibriosis • Infrastructure and resources required to rear at the site • Seapen site influence over homing ability of adults • Forced release
Fall, late or delayed release	• Larger size before release may improve survival rate • Reduced interaction with wild stocks	• Higher cost • Increased risk of un-natural mortality in hatchery • Increased domestication • Increased risk of stress-related disease • Immature returning adults • May residualize • May miss spring marine plankton blooms (prime food source)

Table 15. Short-list of indicators developed by the DFO Habitat Working Group.

Streams

Pressure Indicators	State Indicators
% stream length channelization/floodplain connectivity % stream length riparian zone alteration Road density % watershed area impervious surface % watershed area converted to various land uses (forestry, agriculture, urban) Wetland loss Water withdrawal as % MAD Permitted outfall discharges % lake foreshore alteration % estuary foreshore alteration	Accessible stream length/barriers Accessible off channel habitat area Channel stability measures (pool: riffle, channel width: depth ratios etc Stream discharge measures (base and peak flows) Water Quality/Water temperature (juvenile rearing, adult migration and spawning) Suspended Sediment, substrate LWD, instream cover Water chemistry (nutrients, DO, pH, conductivity, contaminants) River or stream discharge

Lakes

Pressure Indicators	State Indicators
% watershed land cover alterations % lake foreshore altered % watershed area impervious surface % riparian zone altered Road Density Recreational pressure Invasives	Accessible shore length, barriers Accessible off channel habitat area Water chemistry (nutrients, D.O., pH, conductivity, contaminants) Presence of river deltas Sediment substrate Temperature Wetland loss

Estuaries

Pressure Indicators	State Indicators
% estuary foreshore altered (*Carex*, *Typha*, riparian zone) % surface area disturbed inshore (eel grass zone) % surface area disturbed offshore (e.g. log booms) Amount of vessel traffic Invasive species	Accessible off channel habitat area Estuarine habitat area River or stream discharge Aquatic invertebrates Marine riparian vegetation Spatial distribution of wetlands, mudflat Fish Flux of detrital organic matter (CNP) between marsh and other habitats Extent of eelgrass Sediment, TSS Micro and macro algae Water chemistry: nutrients (N,P, metals), DO, pH conductivity, contaminants (PAHs, PCBs)

Table 16. Estimated number of salmon lost to seals during recreational fishing effort.

	Year											
Region	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Strait of Georgia	2,998	4,865	5,772	10,928	2,609	2,546	2,086	4,568	1,592	583	1,048	861
Juan de Fuca Strait	815	1,045	1,013	1,019	489	671	686	941	663	750	402	880
Southwest Vancouver Island	613	126	375	139	108	212	110	608	223	121	142	1,334
Northwest Vancouver Island	40	32	0	0	20	11	71	76	110	61	16	172
Johnstone Strait	75	29	7	72	31	0	0	119	104	78	46	326

Table 17. Summary of the enhancement levels of census sites within southern BC Chinook Salmon Conservation Units, 2000-2011. A dash indicates that there is no evidence of directed enhancement activity for the enhancement category from the EPAD database.

CU Index	**CU Name**	**Enhancement Level**		**Total Sites in CU**
		Unknown-Low	**Moderate-High**	
CK-02	Boundary Bay_FA_0.3	2	1	3
CK-03	Lower Fraser River_FA_0.3	1	0	1
CK-04	Lower Fraser River_SP_1.3	2	1	3
CK-05	Lower Fraser River-Upper Pitt_SU_1.3	1	0	1
CK-06	Lower Fraser River_SU_1.3	8	0	8
CK-07	Maria Slough_SU_0.3	0	1	1
CK-08	Middle Fraser River-Fraser Canyon_SP_1.3	2	0	2
CK-09	Middle Fraser River-Portage_FA_1.3	1	0	1
CK-10	Middle Fraser River_SP_1.3	24	0	24
CK-11	Middle Fraser River_SU_1.3	18	0	18
CK-12	Upper Fraser River_SP_1.3	40	1	41
CK-13	South Thompson_SU_0.3	5	0	5
CK-14	South Thompson_SU_1.3	3	1	4
CK-15	Shuswap River_SU_0.3	1	2	3
CK-16	South Thompson-Bessette Creek_SU_1.2	4	0	4
CK-17	Lower Thompson_SP_ 1.2	5	4	9
CK-18	North Thompson_SP_1.3	7	0	7
CK-19	North Thompson_SU_ 1.3	7	0	7
CK-20	Southern Mainland-Georgia Strait_FA_0.X	36	6	42
CK-21	East Vancouver Island-Goldstream_FA_0.X	1	1	2
CK-22	East Vancouver Island-Cowichan & Koksilah_FA_0.X	5	1	6
CK-23	East Vancouver Island-Nanaimo-sp	1	0	1
CK-83	East Vancouver Island-Georgia Strait_SU_0.3	2	2	4
CK-25	East Vancouver Island-Nanaimo & Chemainus_FA_0.X	2	2	4
CK-27	East Vancouver Island-Qualicum & Puntledge_FA_0.X	11	6	17
CK-28	Southern Mainland-Southern Fjords_ FA_0.X	23	2	25
CK-29	East Vancouver Island-North_FA_0.X	11	7	18
CK-31	West Vancouver Island-South_FA_0.X	54	15	69
CK-32	West Vancouver Island-Nootka & Kyuquot_ FA_0.X	48	9	57
CK-33	West Vancouver Island-North_FA_0.X	14	3	17
CK-34	Homathko_SU_X.X	2	0	2
CK-35	Klinaklini_SU_1.3	2	0	2
CK-82	Upper Adams River_ SU_1.X	1	0	1
CK-9005	Southern BC-Miscellaneous	0	1	1
CK-9006	Fraser-Cross-CU Supplementation Exclusion	0	3	3
CK-9007	Southern BC-Cross-CU Supplementation Exclusion	0	4	4
CK-9008	Fraser-Harrison fall transplant_FA_0.3	0	1	1
Total	All Conservation Units	344	74	418

Table 18. Summary of exploitation rate information for the southern BC Chinook CWT indicators.

Stock Site/Name	Stock Acronym	CU Index	CU Acronym	Run Type	Release Information			Estimated CWT Information					
					n Broods	Mean CWT	Mean Associated Non-CWT	n Years	Mean CWT	Ocean-CA	Ocean -US	Terminal	Escapement
Harrison River	HAR	CK-03	LFR-fall	Fall	9	149,096	804,461	12	1113	10.5%	20.9%	1.6%	66.9%
Chilliwack River	CHI	CK-9008	Chil-trans-FA	Fall	10	101,904	472,864	12	4153	9.2%	15.0%	7.4%	68.4%
Dome Creek	DOM	CK-12	UFR-spring	Spring	3	83,602	3,718	8	155	1.8%	23.5%	50.1%	24.6%
Lower Shuswap River	SHU	CK-15	STh-SHUR	Summer	10	186,708	370,005	12	1444	15.4%	26.8%	9.5%	48.3%
Nicola River	NIC	CK-17	LTh	Spring	9	107,174	46,275	12	1089	1.2%	6.3%	10.3%	82.3%
Cowichan River	COW	CK-22	CWCH-KOK	Fall	9	299,815	1,209,989	12	781	12.7%	48.0%	6.1%	33.2%
Puntledge River	PPS	CK-83	EVI-sum	Summer	10	115,953	508,058	12	290	15.9%	23.4%	0.0%	60.7%
Nanaimo River	NAN	CK-25	midEVI-fall	Fall	4	145,257	96,884	9	819	7.8%	33.7%	6.7%	51.8%
Big Qualicum River	BQR	CK-27	QP-fall	Fall	10	235,183	3,388,613	12	501	15.1%	26.3%	2.2%	56.4%
Quinsam River	QUI	CK-29	NEVI	Fall	10	287,024	1,842,503	12	814	22.6%	20.3%	0.1%	57.1%
Robertson Creek	RBT	CK-31	SWVI	Fall	10	256,807	6,153,023	12	2360	20.2%	16.0%	27.1%	36.7%

12 FIGURES

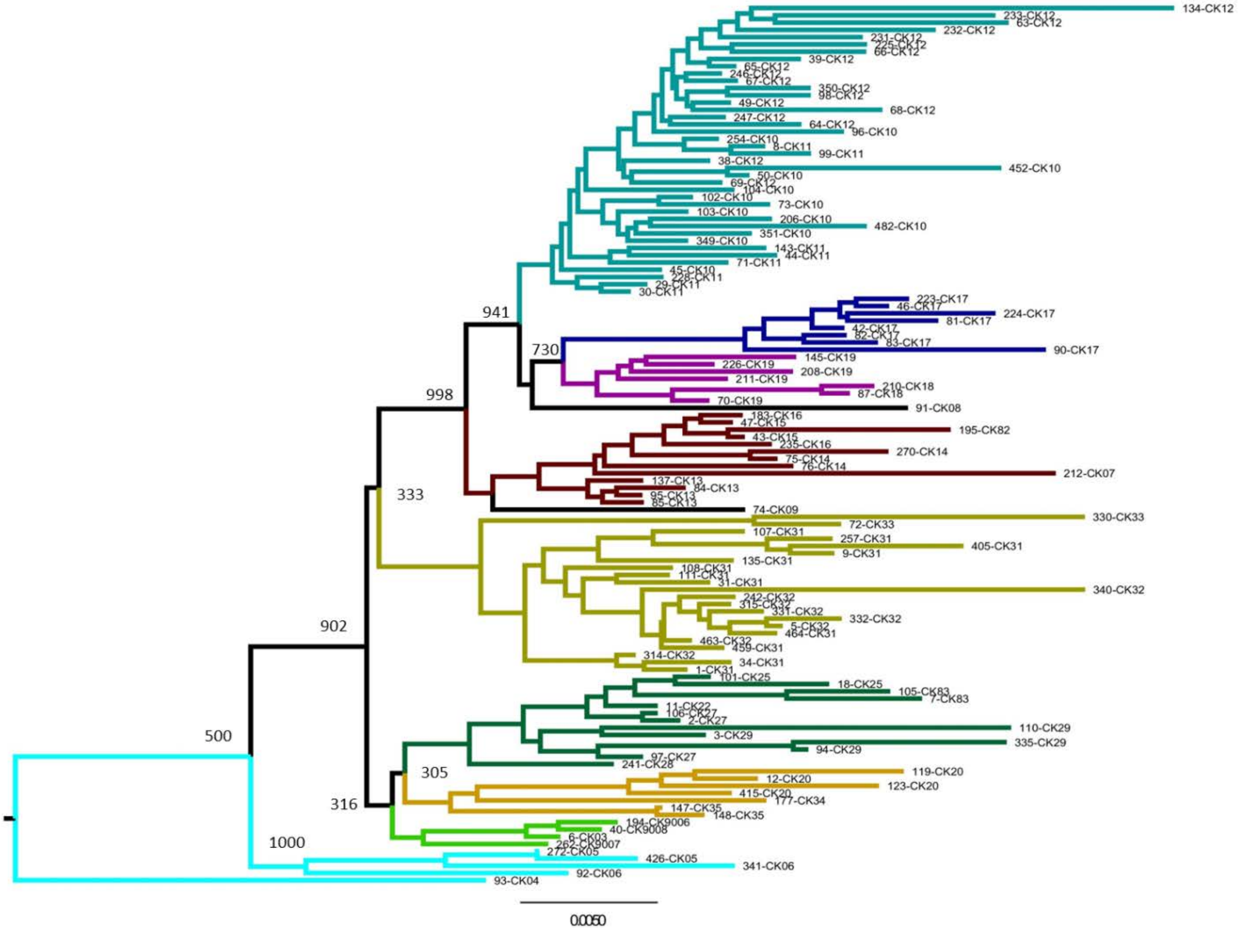

Figure 1. Neighbour-joining tree using CSE distance for southern British Columbia Chinook Salmon. Tree illustrates populations showing consensus of 1000 bootstrapped trees. Key to region group colours can be found in Table 1.

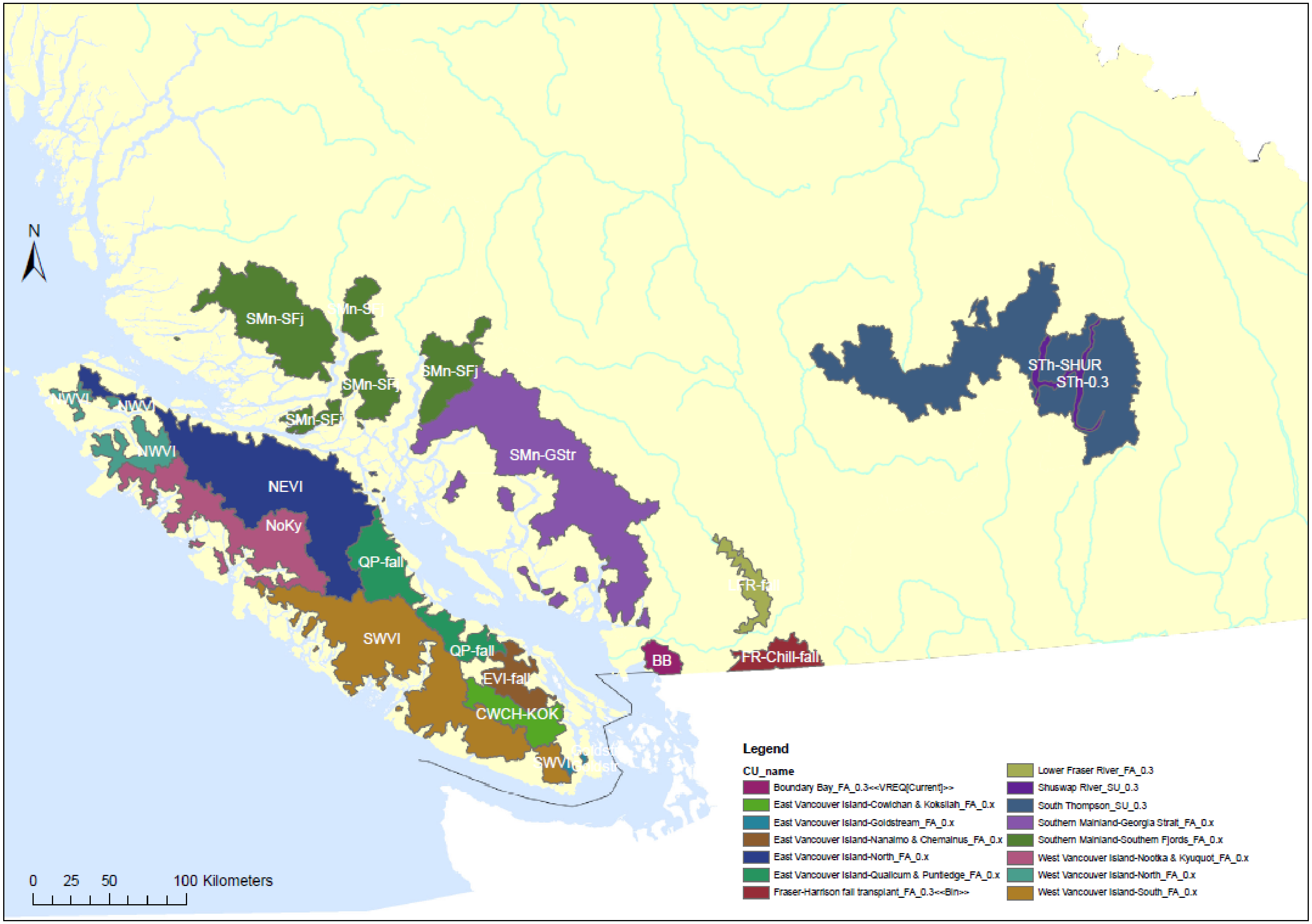

Figure 2. Distribution of ocean-type Chinook Salmon Wild Salmon Policy Conservation Units in southern British Columbia.

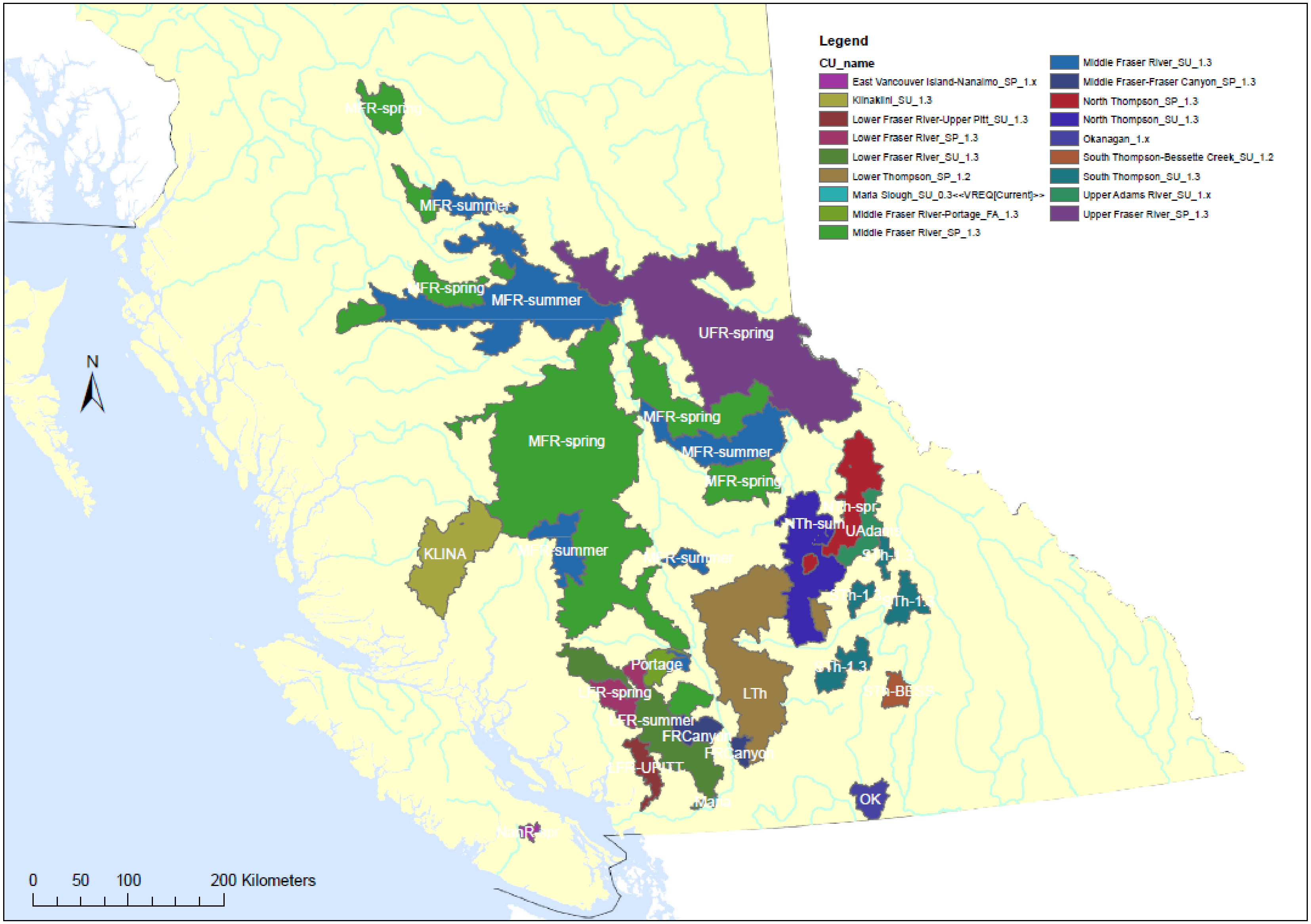

Figure 3. Distribution of stream-type Chinook Salmon Wild Salmon Policy Conservation Units in southern British Columbia.

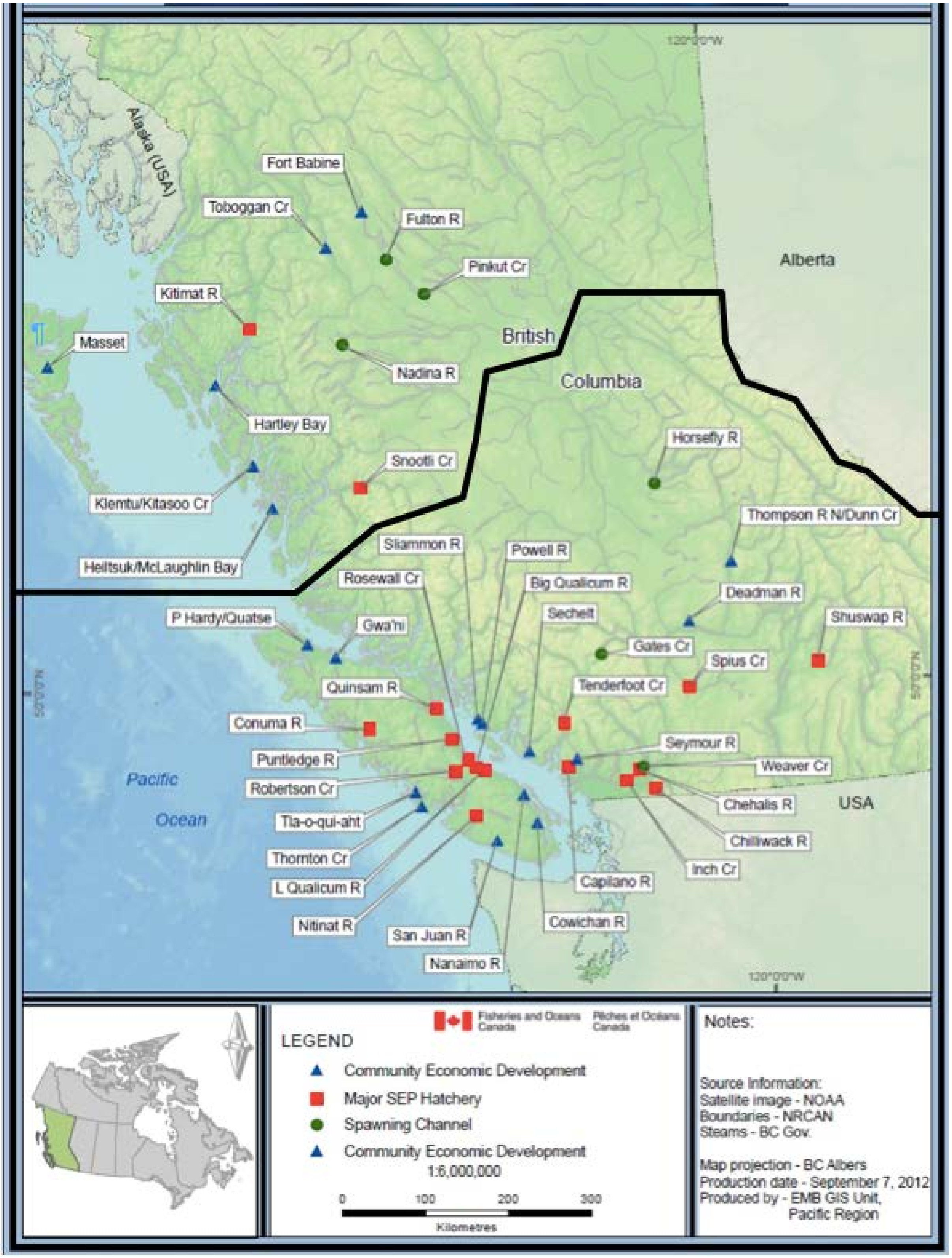

Figure 4. Map of major SEP hatcheries, spawning channels and economic development projects. All facilities located below the heavy black line are included in the southern BC Chinook region.

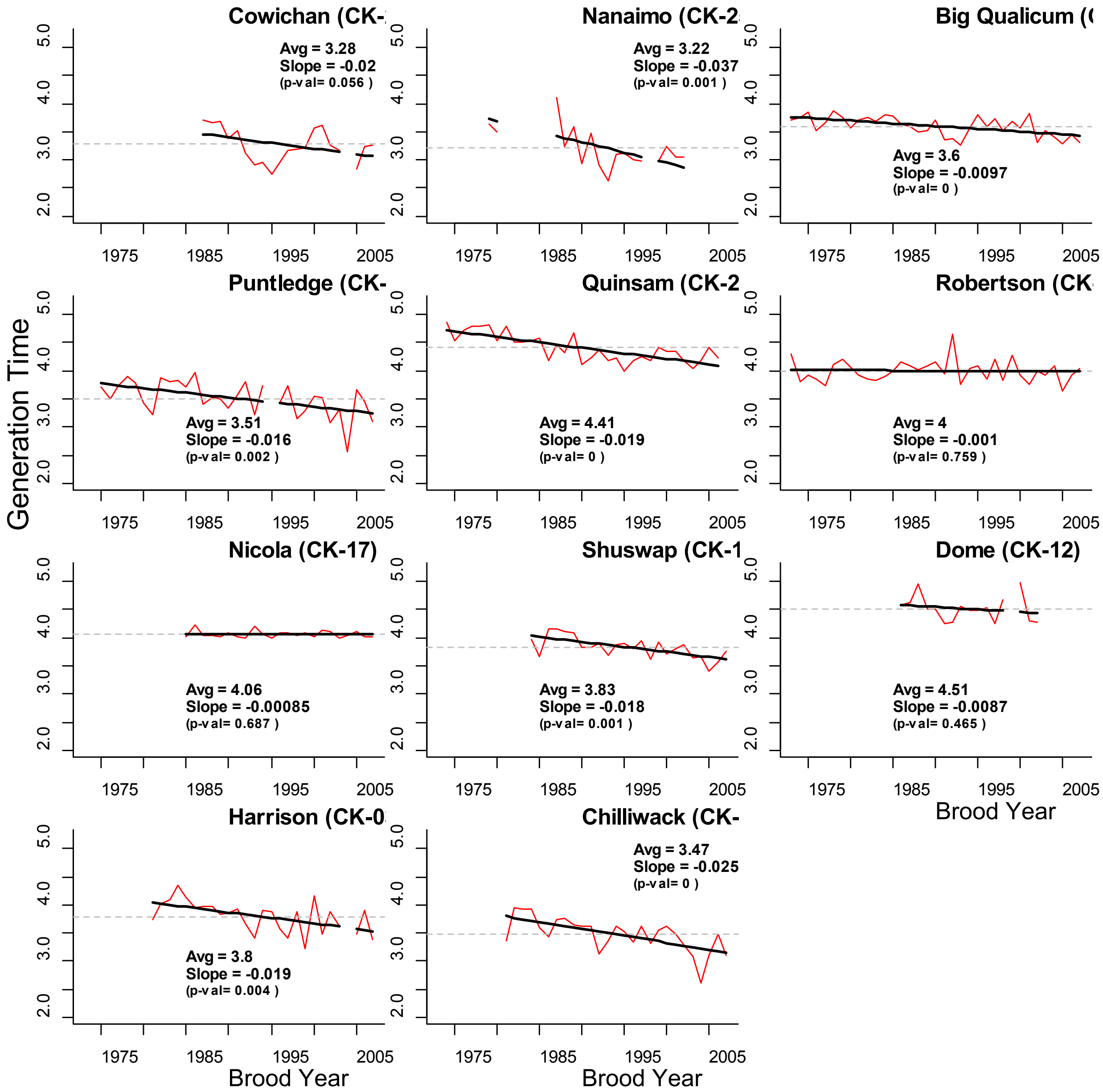

Figure 5. Average generation times for southern BC Chinook CWT indicator stocks. Additional information about the calculation of generation times from CWT recoveries can be found in the second volume of this report.

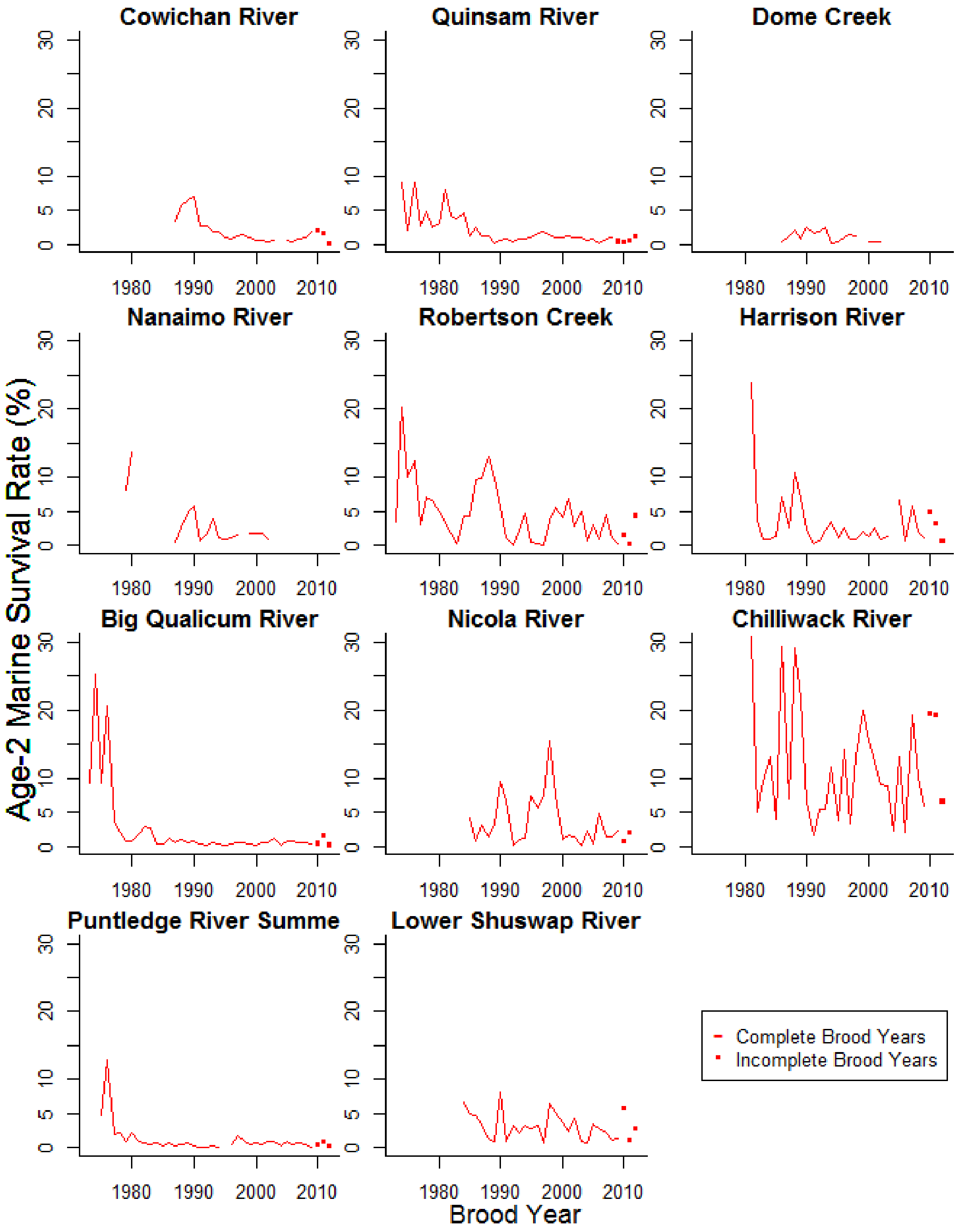

Figure 6. Smolt to Age-2 marine survival rates for southern BC Chinook CWT indicator stocks. Additional informationabout the CWT data program can be found in the second volume of this report.

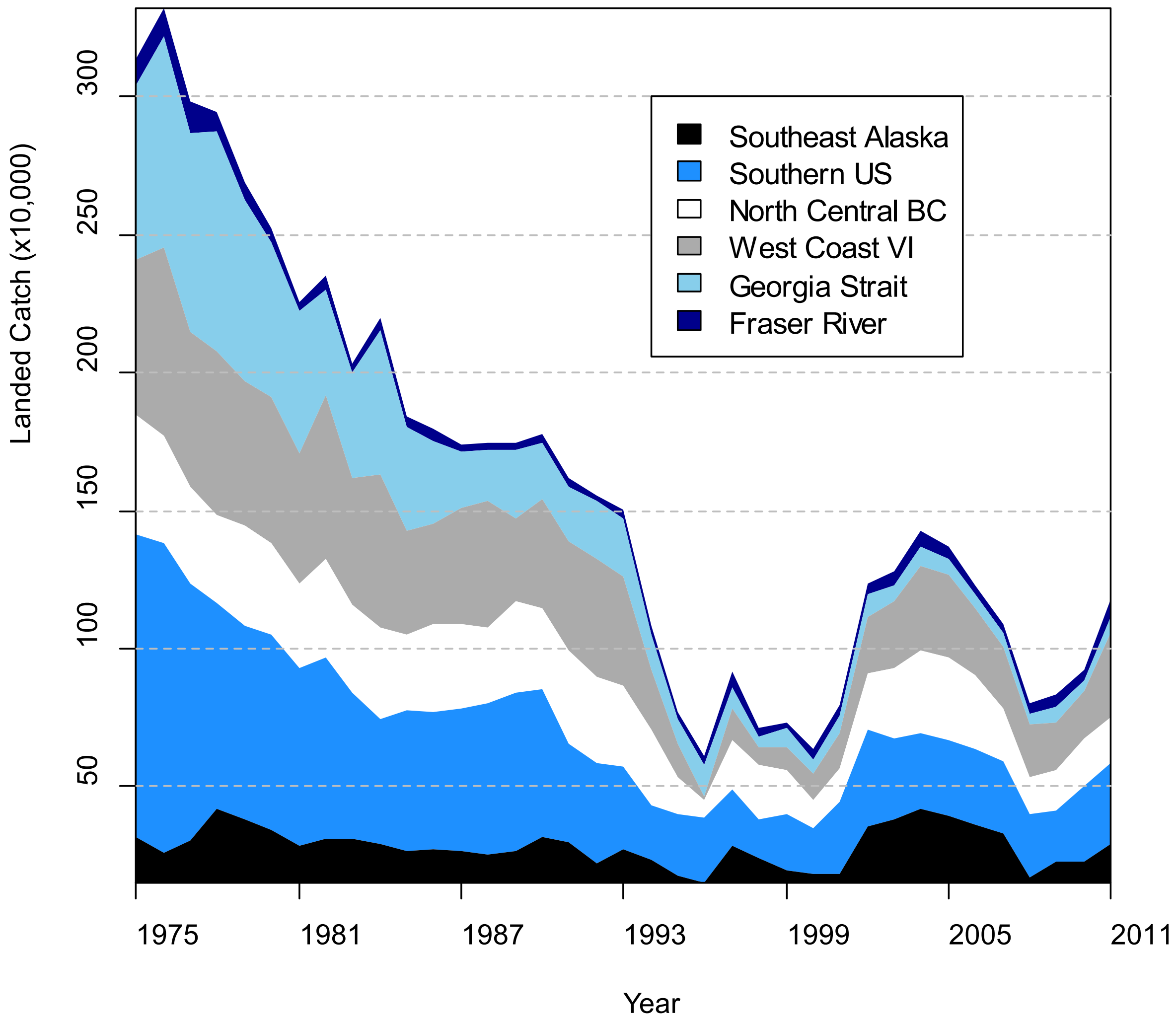

Figure 7. Observed landed catch of southern BC Chinook Salmon in all Pacific fisheries, 1975-2011.

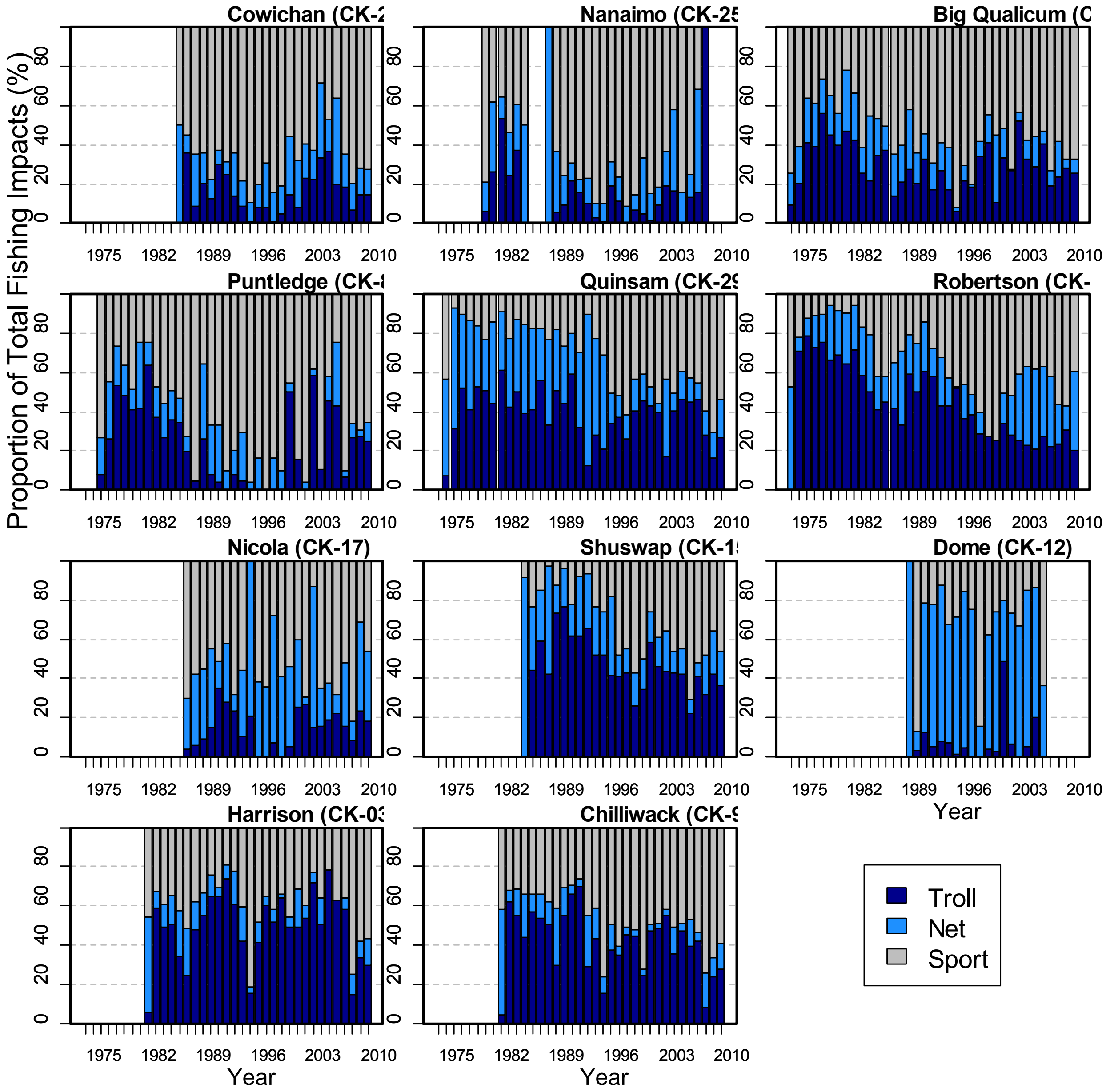

Figure 8. Fishery impacts by gear type for each southern BC Chinook Salmon CWT indicator, 1975-2011. Fishery impact assessment includes estimated landed catch mortalities and non-landed mortalities (i.e., incidental to the fishing activity)

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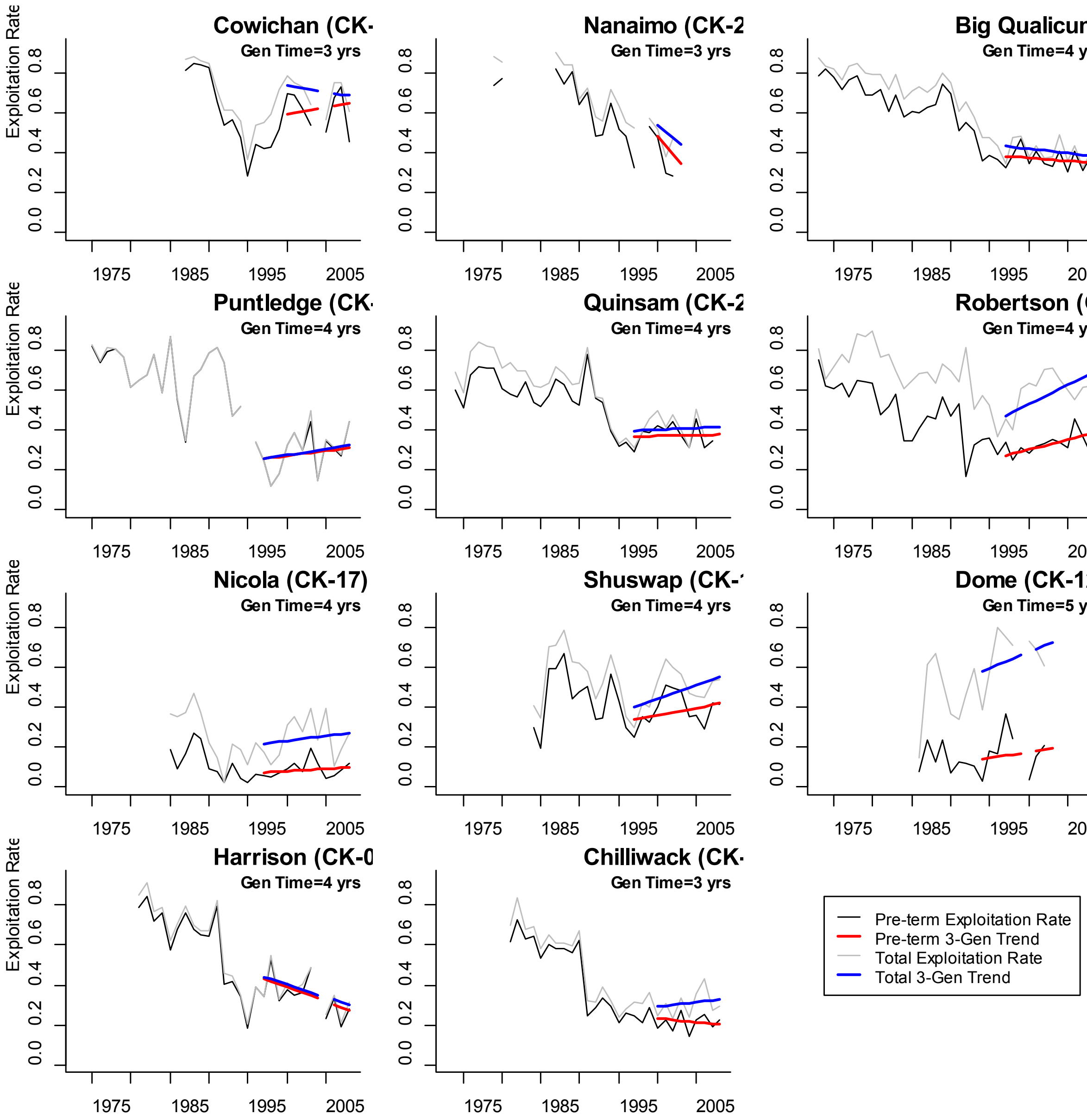

Figure 9. Annual exploitation rates and three-generation exploitation rate trends for each southern BC Chinook CWT indicator stock. For each CWT stock, both pre-terminal exploitation (black line) and total exploitation (grey line) are shown. For a given year, the difference between the two lines is the annual terminal exploitation rate. For each stock, trend lines for the most recent 3 generations are shown for pre-terminal and total exploitation (red and blue lines, respectively). Note that pre-terminal exploitation rates (and the associated 3-generation trend) exclude any exploitation that occurs near the terminal (spawning) area. Years with more than one missing age class have been excluded.

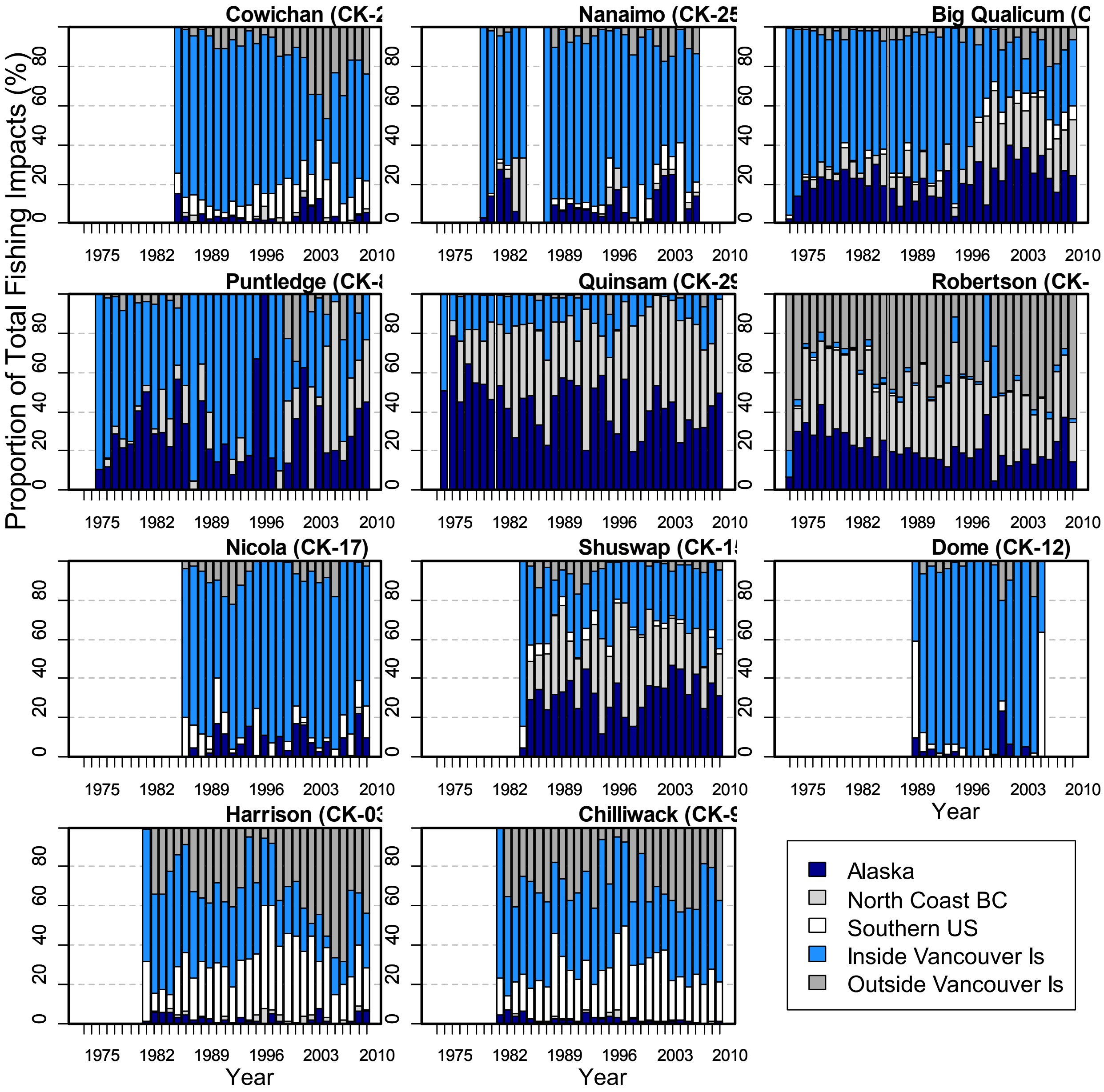

Figure 10. Fishery impacts by catch region for each southern BC Chinook Salmon CWT indicator, 1975-2011. Fishery impact assessment includes estimated landed catch mortalities and non-landed mortalities (i.e., mortalities that are incidental to the fishing activity), and is calculated here as the sum of all troll, net and sport fisheries within each region.