# Bridge River Project Water Use Plan

## Lower Bridge River Aquatic Monitoring

## Implementation Year 8

## Reference: BRGMON-1

***Chinook Salmon Emergence Timing and Life History Review***

**Study Period: 1996 to 2018**

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**St'at'imc Eco-Resources**

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# BRGMON-1 Lower Bridge River Aquatic Monitoring:

# Chinook Salmon Emergence Timing and Life History Review

Memo Report Prepared for:
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# 1. Introduction

## 1.1. Background

An individual's life history is defined by the events and traits that influence survival and reproduction, such as migratory timing, reproductive age, and number and size of offspring produced during reproductive events. All North American species of Pacific salmon (Chinook salmon, coho salmon, pink salmon, sockeye salmon, and chum salmon) exhibit common life history characteristics. Pacific salmon are anadromous; that is, reproduction (spawning) occurs in freshwater and, following a period of freshwater rearing, juveniles outmigrate to the marine environment where they remain through maturity. At maturity, adult salmon undertake a return migration to freshwater to spawn. Pacific salmon are also highly philopatric - most individuals return to their natal stream/lake to spawn - and semelparous, meaning that they die following a single spawning event.

Despite these generalities, within and between species, Pacific salmon exhibit highly variable life history pathways that include variation in age-at-seaward migration, length of freshwater and saltwater residency, and age-at-maturity. As early as 1912, Gilbert described two major life history variants in Chinook salmon (*Oncorhynchus tshawytscha*); "ocean/sea-type" and "stream-type". Chinook salmon are generally categorized as ocean- or stream-type based on juvenile habitat use and migration timing; that is, ocean-type juveniles outmigrate from freshwater to the ocean during their first year of life whereas stream-type juveniles rear for one or two years in freshwater prior to outmigrating to the marine environment (Gilbert 1912; Healey 1983). It is typical for stream-type Chinook salmon to predominate in populations that migrate longer distances to their spawning grounds (e.g., Upper Fraser River populations, interior Columbia River populations) and in northern rivers (Taylor 1990). In contrast, the ocean-type life history predominates in spawning populations that are geographically proximate to the marine environment (Healey 1983; Taylor 1990). Longer migratory distances also correspond with adult spawning migrations that begin earlier, in the spring or summer, with sexually mature adults arriving to the spawning grounds by late-summer/early-fall. Thus, spring/summer-runs of adult Chinook salmon spawners tend to exhibit a stream-type juvenile life history.

The stream- and ocean-type categories provide a useful starting point for understanding juvenile Chinook salmon life history variation, but more recently, there has been growing recognition of the complexity of the life history pathways expressed by the species (Figure 1.1). This complexity has far-reaching implications for understanding the temporal and spatial scale of life-history transitions and habitat use, which is critical to conservation and management planning. The known diversity of Chinook salmon juvenile life histories was recently reviewed in detail in Bourret et al. (2016) and is summarized by the schematic in Figure 1.1.

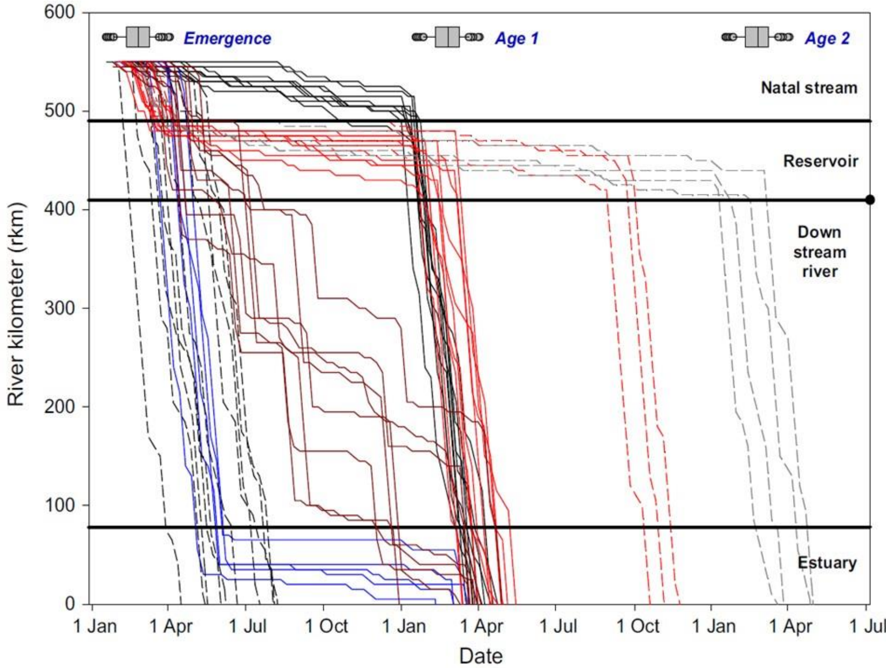


**Figure 1.1 Schematic representation of juvenile life-history pathways found in Chinook salmon (see Bourret et al. 2016). The box plots at the top of the figure depict the typical timing of juvenile Chinook salmon fry emergence, and when individuals reach "age-1" and "age-2" age classes. The hatched and solid lines show hypothetical life-history transitions of individual fish from their natal stream to downstream environments (river, reservoir, estuary), all of which may be used to some extent during juvenile rearing. The life history pathways include, from left to right: natal site rearing with rapid outmigration to the ocean as subyearling smolts (black, hatched lines); natal site rearing with rapid outmigration to the estuary as subyearlings (blue, solid lines); natal site (black, solid lines) and reservoir (red, solid lines) rearing with outmigration as yearling smolts; mixed natal site/reservoir/downstream river/estuary rearing (brown, solid lines); reservoir rearing that includes outmigration by yearling smolts (red, hatched lines) and fish that residualize in the estuary and eventually outmigrate as 1+ juveniles (grey, hatched lines).**

Theory suggests that diverse life history strategies allow individuals to "bet-hedge" in the face of variable environmental conditions i.e., they allow for flexibility in individual behavioral and morphological responses to fluctuating environments (Ellner 1997; Wilbur and Rudolf 2006). More generally, biological diversity leads to ecosystem resilience, also known as the "portfolio effect", which is analogous to a financial investment strategy that targets a diversity of asset types so as to hedge an uncertain market (Figge 2004). For instance, hundreds of spawning populations contribute to the production of sockeye salmon (*O. nerka*) in Bristol Bay, Alaska, the most valuable fishery in the United States (Schindler et al. 2010). Bristol Bay sockeye salmon exhibit diverse life history strategies, such as variable durations of freshwater and marine residency, that buffer for shifting productivity in any one spawning population (Hilborn et al. 2003; Schindler et al. 2010). Similarly, steelhead/rainbow trout (*O. mykiss*) in the Nass and Skeena rivers in northwestern British Columbia exhibit at least 36 life history pathways that are differentially expressed over time and act to stabilize the aggregate abundance of the species in any given year (Moore et al. 2014). Given the importance of life history diversity to population resiliency, fisheries managers should thus consider the full suite of phenotypes exhibited by a population in conservation planning (Watters et al. 2003).

The Chinook population in the Lower Bridge River (LBR) has been monitored as a part of a multi-year fish and aquatic monitoring program that was initiated in 1996 and has continued every year since (known as BRGMON-1 Lower Bridge River Aquatic Monitoring). The program monitors the effects of a flow release from Terzaghi Dam on salmon and steelhead production, as well as other indicators of ecosystem health (e.g., water temperature, water chemistry, periphyton accrual and diversity, benthic invertebrate abundance and diversity). The monitoring has spanned a period of years prior to the continuous flow release as well as three different flow trials (see more information about the flow trials in Section 1.2, below), which featured different flow magnitudes and hydrograph shapes.

The results from this program have characterized life history components for the freshwater life stages of Chinook in the LBR and documented trends in recruitment and juvenile abundance. Information about Chinook salmon spawner escapements and distribution has been collected under a separate program called BRGMON-3 Lower Bridge River Adult Salmon and Steelhead Enumeration. Since the first flow trial, Chinook juvenile abundance declined in the LBR and has remained consistent across the flow trials (refer to the most recent BRGMON-1 report for more details; Sneep et al. 2019). Since approx. 2005, which was five years following the start of the declines in chinook juvenile numbers, the adult escapements also dropped and have remained low.

A tremendous amount of data and information have been collected about the effects of the flow release on fish production and ecosystem health in the LBR over 24 years of monitoring. However, some uncertainty remains about the specific effects of the flow release on Chinook recruitment, survival and habitat use in the LBR, largely because some of these effects were not foreseen when the study approach and methodologies were initially conceived. This review is intended to summarize existing data to document what has been learned and provide information for making informed decisions for addressing this uncertainty going forward.

## 1.2. The Flow Trials

The BRGMON-1 program has spanned four different flow treatments to-date, including:

- **Trial 0** - Pre-Flow period from 1996 to 1999 (no continuous flow released from Terzaghi Dam so Reach 4 was dry but reaches 1, 2 and 3 were wetted by groundwater and tributary inflows);
- **Trial 1** - 3 $m^3 \cdot s^{-1}$ mean annual release (August 2000 to March 2011);
- **Trial 2** - 6 $m^3 \cdot s^{-1}$ mean annual release (April 2011 to December 2015, and January to December 2019); and
- **Trial 3** - >18 $m^3 \cdot s^{-1}$ mean annual release (January 2016 to December 2018).

Flows during the Chinook spawning and incubation periods (i.e., mid August to end of February) increased by 2–3 $m^3 \cdot s^{-1}$ from Trial 0 to Trial 1 but remained relatively consistent across trials 1 to 3 (Figure 1.2). Flow magnitudes varied during spring and summer (early March to mid August) among the trials. Peak flows were 5, 15 and 97–127 $m^3 \cdot s^{-1}$ for trials 1, 2 and 3, respectively.

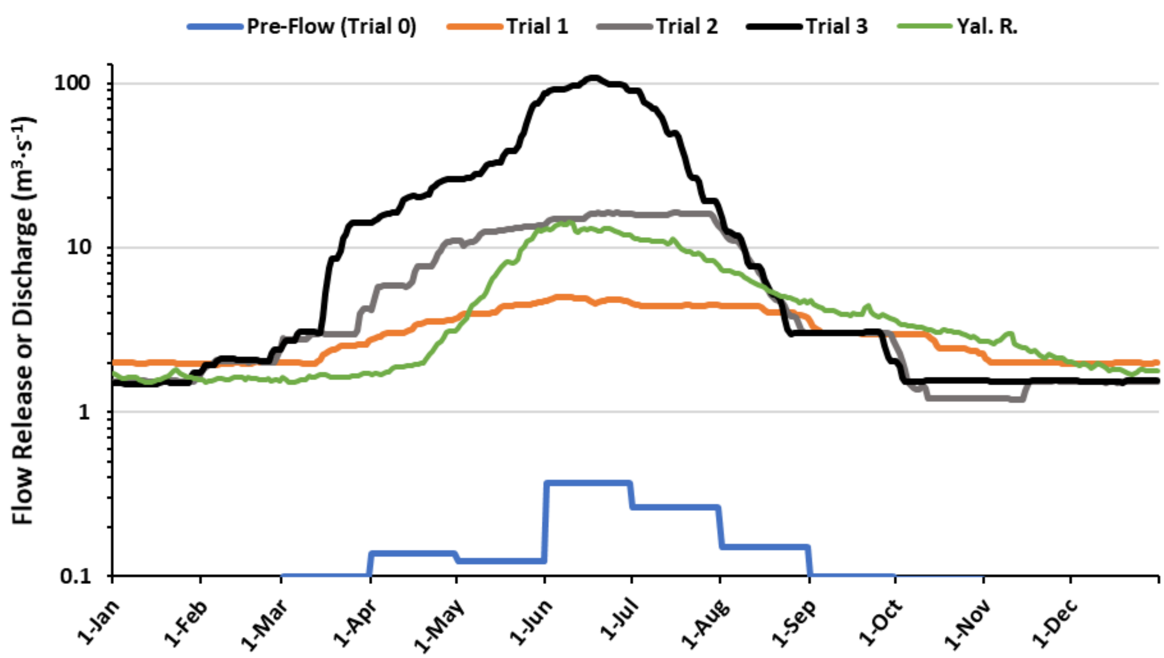


**Figure 1.2 Mean daily flow release from Terzaghi Dam among all years in each flow Trial. Mean daily flow among all years (1996 – 2018) in the Yalakom River is shown for reference. Note the log scale on the Y axis.**

## 1.3. Objectives and Management Questions

BRGMON-1 monitoring results have identified increased fall water temperatures associated with minimum flow releases under the Trial 1, Trial 2 and Trial 3 hydrographs (relative to pre-flow conditions). Based on predicted emergence timing from temperature exposures during incubation under each release strategy, coupled with the collection of recently emerged fry during late fall and early winter sampling surveys, the flow-mediated thermal regime has advanced the emergence timing of Chinook salmon fry in the LBR, and most notably in the upper portion of the study area (Sneep et al. 2019). These changes have also coincided with reduced juvenile abundance for this species. However, there is uncertainty about the extent to which early emergence has affected the survival of Chinook salmon since the observed decline in juvenile Chinook salmon abundance under flow release conditions also coincided with reduced adult returns to the Lower Bridge River and other Mid-Fraser populations. Other explanations for reduced juvenile abundance in the fall may also include life history changes (e.g., timing of outmigration) or habitat use changes (e.g., rearing in the Fraser River rather than the LBR).

In response to these uncertainties, the objectives of this review are to:

- document and summarize what is currently known about the LBR Chinook population from the results of existing monitoring for addressing flow management questions;
- review published and grey literature, and consult with regional experts, to document the array of life history strategies for other monitored Chinook populations;
- Identify where there are knowledge gaps about LBR Chinook life history; and
- Provide recommendations on future research needs to address critical data gaps.

Two management questions were established in the most current BRGMON-1 Terms of Reference (ToR; Revision 1) to address uncertainty in how Terzaghi Dam flow releases and the early emergence of Chinook salmon affect survival and early life history (BC Hydro 2018). Since these were added to the set of four management questions from the original ToR they were numbered 5 and 6. For consistency with the ToR we have maintained that numbering here, although the first four questions will not be presented or addressed in the scope of this review. The two new management questions are:

5) Do increased water temperatures and early emergence associated with Terzaghi Dam flow releases affect the survival of juvenile Chinook salmon in the Lower Bridge River?
6) What freshwater rearing habitats are used by Lower Bridge River juvenile Chinook salmon and is rearing habitat use influenced by Terzaghi Dam flow releases?

## 1.4. Study Area

The Lower Bridge River between Terzaghi Dam and the confluence with the Fraser River is approximately 41 km long and is currently the only section accessible to anadromous fish. The Lower Bridge River was divided into four reaches by Matthew and Stewart (1985); their reach break designations are defined in Table 1.1. The overall study area is illustrated in Figure 1.3.

**Table 1.1 Reach designations and descriptions for the Bridge River below Terzaghi Dam.**

| Reach | Boundary (Rkm) | | Length (km) | Description |
|---|---|---|---|---|
| | Downstream | Upstream | | |
| 1 | 0.0 | 19.0 | 19.0 | Fraser River confluence to Camoo Creek |
| 2 | 19.0 | 26.0 | 7.0 | Camoo Creek to Yalakom River confluence |
| 3 | 26.0 | 37.7 | 11.7 | Yalakom R. confl. to upper extent of groundwater inflow |
| 4 | 37.7 | 40.9 | 3.2 | Upper extent of groundwater inflow to Terzaghi Dam |

Monitoring for the Lower Bridge River Aquatic Monitoring Program (BRGMON-1) conformed to these reach break designations and has focused on the section of river between Terzaghi Dam and the bridge crossing upstream of Camoo Creek (i.e., reaches 4, 3 and 2). Monitoring in Reach 1 (i.e., the approx. 19 km section from the confluence of Camoo Creek to the Fraser River) was initiated in 2019.

Prior to initiation of the continuous flow release at the start of the flow experiment (August 2000), Reach 4 was the previously dry section immediately below the dam (length = 3.2 km). Tributary inflows to this reach are insignificant, so discharge is dominated by the release. Reach 3 was the groundwater- and tributary-fed reach extending down to the Yalakom confluence (length = 11.7 km). These inflow sources are relatively small, so discharges in this reach prior to the flow release were low (~1% of pre-regulation mean annual discharge) and release flows have dominated since the start of the flow trials. Flows in Reach 2 (length = 7.0 km) include the inflow from the Yalakom River, the most significant tributary within the study area which seasonally contributes between approximately 1 and 45 $m^3$/s at the top of Reach 2 (mean discharge = 4.3 $m^3$/s). Reach 1 receives inflow from some small tributaries (e.g., Camoo, Applesprings, Moon and Ama Creeks) but, relative to the differences among trials in the other reaches, estimated discharge rates in Reach 1 were generally similar to Reach 2.

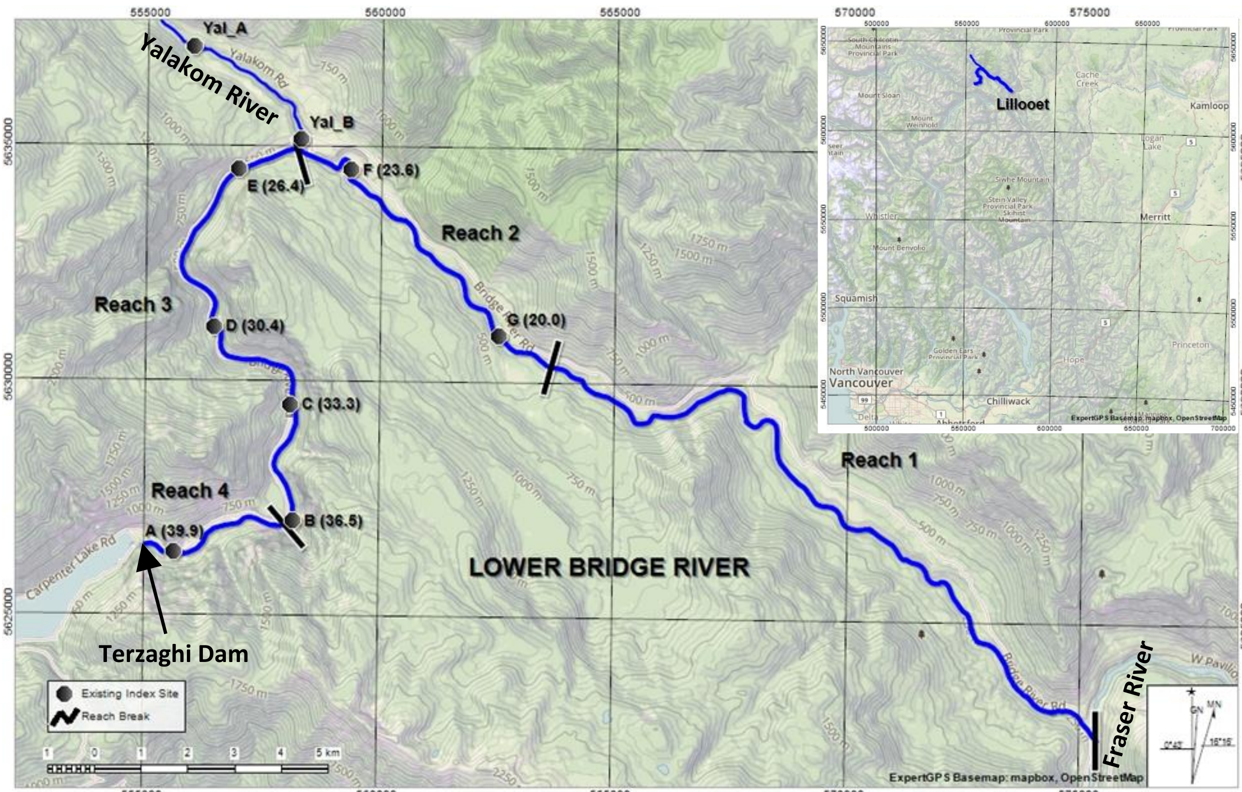


**Figure 1.3 The Lower Bridge River downstream of Terzaghi Dam near Lillooet, British Columbia. Reaches are labelled 4 through 1 with increasing distance below Terzaghi Dam. Index monitoring sites are labelled as distances upstream of the Fraser River: 39.9 km (A), 36.5 km (B), 33.3 km (C), 30.4 km (D), 26.4 km (E), 23.6 km (F) and 20.0 km (G). The inset map in the top-right corner shows the location of the sampling area within southwestern British Columbia.**

## 2. Tasks

The primary tasks for this life history review included:

1) Reviewing published and grey literature to document existing information on Chinook life history and monitored Chinook populations, particularly focussing on studies pertaining to emergence timing, rearing habitat use, and outmigration timing;
2) Consulting with regional subject-matter experts to solicit their knowledge and guidance regarding relevant literature and reports;
3) Mining existing data on LBR Chinook spawning (escapements, timing, distribution, age classes), incubation, emergence timing, rearing habitat use, juvenile abundance, and outmigration timing from the time series available in the LBR database and the BRGMON-3 data set;
4) Compiling and summarizing this information towards addressing the management questions #5 and #6 from the ToR (BC Hydro 2018), and identifying where there are remaining gaps that preclude doing so; and

5) Providing recommendations for additional monitoring to fill the identified information gaps.

# 3. Results

## 3.1. Literature Review

The purpose of this literature review is two-fold: (1) to summarize the current state of knowledge on juvenile life histories in "stream-type" populations of Chinook salmon and (2) to consider the influence of hydropower operations, and specifically temperature impacts, on juvenile life histories. Our goal is to shed light on the likely diversity of juvenile life histories exhibited by Chinook salmon in the Lower Bridge River, and better understand the potential impact of Terzaghi Dam flow releases on juvenile life history expression. It should be noted, however, that the influence of environmental variation on life history pathways in salmon is, in general, not well-understood and remains an emerging area of research (Bourret et al. 2016). Like most phenotypes, an individual's life history depends on the interaction between its genotype, condition, and environment (Evans et al. 2010; Hutchings 2011). Moreover, given patterns of genetic structuring/differentiation across salmon populations (due to homing and local adaptation processes) and the heterogenous habitats that populations encounter in space and time, the patterns/responses observed in one population to environmental variation may not be applicable to another. Below, we review literature that has described juvenile life history diversity in Chinook salmon from the Fraser and other river systems that are known to support a "stream-type" life history. Populations supporting a predominantly "ocean-type" life history were not considered as part of this review. We also summarize research findings on thermal impacts from hydropower operations on Chinook salmon life history expression, which has been examined in only a few studies.

A summary of juvenile life history diversity exhibited by "stream-type" populations of Chinook salmon, as described in the text above, is provided in Table 3.1.

### 3.1.1. Regional patterns of juvenile life history diversity

*Columbia River and U.S. Pacific Northwest*

Compared to most river systems in the Pacific Northwest, considerable salmonid life history research has occurred within the Columbia River Basin (including Snake and Willamette river subbasins) related to monitoring of hydropower system impacts on Endangered Species Act (ESA)-listed populations (n.b., all salmonid fish populations in the Columbia River are currently ESA-listed). The Columbia River is the largest river system in the Pacific Northwest and supports both spring/summer (long-distance migrants) and fall (shorter-distance migrants) runs of Chinook salmon. Spring/summer-run Chinook salmon migrate to major tributaries of the Columbia River, the Snake River and Willamette River, where they largely spawn in upstream tributaries; these populations are somewhat analogous in terms of migration distance and timing to mid- and upper-Fraser River stocks of Chinook salmon, although they have contended with up- and downstream passage through major hydropower projects and associated reservoirs on both the mainstem Columbia River (Snake Basin populations) and tributary rivers (Upper Willamette Basin populations) for decades.

Research on Snake and Upper Willamette River populations has been facilitated through the spatially and temporally widespread implementation of outmigrant trapping programs (e.g., using rotary screw traps) on both spawning tributaries and downstream migration corridors. More recently, the implementation of passive integrated transponder (PIT) tagging programs, including the operation of PIT tag arrays on numerous tributaries, and at hydropower projects, has allowed for the year-round monitoring of juvenile outmigration from tributary spawning/rearing habitats to downstream riverine and marine habitats (see https://www.ptagis.org/).

In Snake River spring/summer Chinook salmon populations in Idaho, most juveniles exhibit a "stream-type" life history, rearing in freshwater for one year prior to migrating to the ocean, although some juveniles exhibit an "ocean-type" life history (Copeland and Venditti 2009; Copeland et al. 2014). Copeland and Venditti (2009) and Copeland et al. (2014) describe four categories of juvenile Chinook salmon outmigrants from spring/summer-run spawning populations in Idaho:

(1) "fry": outmigrate from their natal tributaries soon after emergence in March. This group of fish is too small to PIT tag and thus, downstream movement and habitat use are poorly understood;

(2) "Subyearlings" (age-0 smolts): leave tributaries April-June, during spring freshet, and appear to move downstream quickly through the mainstem Salmon (major Snake River tributary) and Snake rivers;

(3) "Parr": outmigrate from spawning tributaries in the fall into the mainstem Salmon River, where they spend the winter and then continue outmigrating the following spring; and

(4) "Yearlings" (age-1 smolts): spend a full year after emergence rearing in their natal river (spawning tributary) and outmigrate as smolts in March/April (i.e., a juvenile produced during brood year 2010 would outmigrate from natal river in spring 2012); these fish quickly outmigrate through the mainstem Salmon/Snake and Columbia rivers to the marine environment.

Interestingly, conservation planning in the interior Columbia Basin has prioritized the "yearling" life history, through emphasis on natal stream habitat enhancement for juvenile rearing (Copeland and Venditti 2009). However, Copeland et al. (2014)'s research shows that adult production is largely attributable to juveniles that outmigrate from their natal tributary as subyearlings and overwinter downstream. This is in part due to subyearling smolts being more abundant, but also higher smolt-to-adult survival of subyearlings relative to yearling smolts in some systems (Copeland et al. 2014).

In the Willamette River and tributaries in Oregon, Schroeder et al. (2015) recently described at least six major life history variants among juvenile spring Chinook salmon. Following emergence, the authors categorized juveniles as either “movers” or “stayers”, with the former leaving their natal tributary shortly after emergence in December-February and the latter remaining in the natal tributary to rear for 8-16 months. “Stayers” primarily outmigrated from their natal tributary in the fall-winter following emergence and spent the winter in downstream riverine habitat until the spring. Similar to the “yearling” (age-1 smolt) life history observed in Snake Basin populations, a minority of “stayers” remained in their natal tributary for a year following emergence. “Movers” rear in habitats >140 km downstream of the natal tributary and complete outmigration to the marine environment as either subyearlings in the spring-summer (most common), as fall migrants, or yearlings the following spring (rare). While it is useful to categorize migrants into discrete life history types, an important finding of the study was that juvenile Chinook salmon outmigrate through the mainstem Willamette River all months of the year (Schroeder et al. 2015).

*Fraser River*

Compared to the Columbia River Basin, juvenile Chinook salmon life history diversity in the Fraser River is less well understood. Indeed, Bradford and Taylor (1997) note that while most mid- and upper-Fraser River Chinook salmon are “stream-type”, a holistic understanding of juvenile life history pathways is lacking for these populations.

### Upper Fraser tributaries

With support from the Fraser River Action Plan, initiated in 1991, juvenile life history research was completed in several upper Fraser River tributaries during the early-mid 1990s. Findings from these studies were published in a series of grey literature reports and a few peer-reviewed publications. At Slim Creek, a small upper Fraser tributary, Taylor et al. (1994) and Allan et al. (1995) operated rotary screw and inclined plane traps to examine juvenile outmigration timing and abundance in 1993 and 1994, respectively. Also, to examine the distribution of juvenile Chinook salmon within the mainstem Fraser River, Taylor et al. (1994) conducted a series of seine net and minnow-trap surveys on the Fraser River ~30km downstream of Slim Creek. Allen et al. (1995) conducted more extensive seine-netting surveys on the mainstem Fraser River between the Chilcotin River confluence and the town of McBride. The reports provide data summaries but no interpretation of results.

Based on this author’s (M. Evans) review of the published figures and tables, most juveniles outmigrated from Slim Creek as age-0 juveniles (fry) during spring freshet (May-early June), with a smaller number of age-1 (yearling) smolts outmigrating during early-April through May. Subyearling outmigrants were also detected during the July and August trapping sessions, but at lower abundances compared to the May-June trapping period and a small number of subyearlings continued to be detected at the traps through trap removal in mid-November (Taylor et al. 1994). Subyearling Chinook salmon were detected in the mainstem Fraser River during all months (May – October) of seine netting surveys (Taylor et al. 1994, Allen et al. 1995), suggestive of the widespread use of the mainstem Fraser River as juvenile Chinook salmon rearing habitat. A few yearling Chinook salmon were also detected by Allen et al. (1995) during seining but only during May and June, suggesting that these older juveniles use the mainstem upper and mid-Fraser as a migratory corridor rather than rearing habitat (similar to the yearling, age-1 smolt life history in Idaho's Snake Basin).

Taylor and Bradford (1996) expanded juvenile outmigration studies in 1995 to both Slim Creek and the Bowron River, albeit trapping only occurred during April through June. As in previous years, most juvenile Chinook salmon appeared to outmigrate as subyearling fry during late April through late May. A smaller number of juveniles (> an order of magnitude lower than subyearling abundances) appear to have outmigrated as age-1 yearling smolts, based on a review of the data summaries provided in the report. Patterns of outmigration were similar in the Bowron River, with most subyearling fry outmigrating in May, and a small number of yearling, age-1 smolts outmigrating during late April through mid-May.

In a common garden experiment, which controlled for differences in environmental conditions experienced following emergence, Bradford and Taylor (1997) demonstrated that some Chinook salmon fry from the upper Fraser River (Bowron River, Slim Creek, mainstem Fraser River, Dome River) moved downstream almost immediately following emergence whereas others were "stayers", i.e., individuals that remained in their natal stream. Interestingly, the proclivity towards downstream movement following emergence varied among populations, with most (80%) newly emerged fry from the Bowron and Slim populations moving downstream shortly after emergence, as was observed in previous field studies by Taylor et al. (1994), Allen et al. (1995), and Taylor and Bradford (1996). In contrast, juveniles from the Fraser and Dome river populations were more variable in their behaviour, with 40-50% of juveniles moving downstream within a few days of emergence. It was speculated that, because the Dome Creek spawning population is located in close proximity to the Fraser River, emerging fry do not need to actively migrate to reach rearing habitat in the mainstem Fraser River (Bradford and Taylor 1997).

### Nechako River

The Nechako River is a 516 km long tributary to the Fraser River (confluence located at Prince George). However, half of the Nechako River's flow was diverted through the Coast Mountain range, beginning in the 1950s, to the Kemano Project, which powers the Rio Tinto Alcan smelter in Kitimat. Baseline studies of juvenile Chinook salmon distribution and downstream migration timing within the Nechako watershed were initiated during 1980-1982 to advise fisheries management (Russell et al. 1983). In 1981, juvenile outmigration from the upper and lower watershed was monitored using multiple inclined plane traps. Overall, catches of Chinook salmon emergent fry were high in March through early May in the upper river, but declined by end of May. Outmigrating juveniles were observed in large numbers during June near Diamond Island (mid-Nechako) and during late June through August in the lower Nechako, suggestive of significant dispersal from the upper river over the summer. However, juveniles were captured in the upper Nechako during late November beach seining surveys, indicating that some fish remained in the upper river to overwinter.

The Nechako Fisheries Conservation Partnership (NFCP) was developed in the mid-1980s to guide subsequent fisheries monitoring and research in the upper Nechako watershed. The NFCP, guided by a technical review team, monitors two juvenile production metrics in the upper Nechako, (1) emergent fry production, using inclined plane traps operated during March through May, and (2) outmigration, via monthly electrofishing surveys at spatially-distributed index sites and rotary screw trapping. This work has shown that fry begin emerging in the upper Nechako River in mid-March, 3-4 weeks earlier than in the Stuart River (a major Nechako tributary). This is likely due to elevated water temperatures experienced during incubation downstream of Kenney Dam, which releases reservoir water that is 2 – 4 °C warmer than the river water during the fall months (Bradford 1994). Fry emergence in the upper Nechako peaks in late April/early May and tapers off through the end of May.

As in other Fraser River systems and, as documented in Russell et al. (1983), most subyearling (as age-0 fry) outmigration occurs in early-mid May, sometimes followed by a smaller, second peak of outmigration in early July (NFCP 2005). Most yearling (age-1 smolts) juveniles are thought to leave the upper river by early spring and are not easily sampled. Electrofishing surveys were also conducted at index sites, during April – November, albeit late summer-fall surveys ceased after a few years because “there was little additional benefit gained from sampling in the late summer and early fall” (pg. 122, NFCP 2005). Indeed, catch per unit effort declined precipitously at index sites in August as fish moved downstream in preparation for overwintering. Downstream habitat use (duration and location) by upper Nechako Chinook salmon is not addressed in the NFCP report, but juveniles presumably overwinter in the lower Nechako or mainstem Fraser River.

### Chilcotin River Basin

The Chilcotin River flows for 250 km before joining the Fraser River just south of Williams Lake. The Chilcotin Basin includes several tributary rivers that historically supported large Chinook salmon runs, particularly within the Chilko River. Delaney et al. (1982) conducted spring-summer surveys for juvenile Chinook salmon in the Chilcotin Basin during the 1970s using a variety of trapping methods (minnow traps, seining, inclined plane trap). Inclined plane traps examined outmigration during late April through August on the mainstem Chilcotin River and during May on the Chilko River. On the Chilcotin River, most juvenile Chinook salmon outmigration occurred during the first half of May; also see (Taylor et al. 1995), with a second, smaller outmigration peak in early-mid June; most outmigrants were subyearlings (age-0 fry), with small numbers of yearling (age-1) smolts captured during the same time period. Large numbers of subyearling juvenile Chinook salmon were also documented rearing in the mainstem upper Chilcotin using beach seining and minnow traps during June through August. It was speculated that most of these juveniles were produced in tributaries since little Chinook salmon spawning occurs in the mainstem Chilcotin River. Indeed, ~200,000 and 600,000 Chinook salmon fry were observed outmigrating from the Chilko River during May 1978 and 1979, respectively.

### Thompson River Basin

In a recent study, Shrimpton et al. (2014) used otolith microchemistry to reconstruct catchment-scale movement of juvenile Chinook salmon from a headwater tributary, the Coldwater River, which flows into the Fraser River via the Nicola and Thompson rivers. Individual Chinook salmon exhibited “tremendous” diversity in movement and habitat use (Shrimpton et al. 2014). The authors suggest that juveniles typically move into the lower Coldwater River to rear, albeit, the microchemistry of the Thompson River was quite similar to the Coldwater River, making it difficult to tease apart rearing between the two rivers from the otoliths. However, it was clear that ~40% of fish spent time rearing in the Nicola River. Interestingly, there was no evidence of Fraser River rearing, which could be a consequence of the larger size of the Thompson system compared to the other Fraser River tributaries examined.

### Non-natal tributary and estuary habitat use

In addition to the widespread use of larger, mainstem riverine habitats located major distances downstream of spawning areas, e.g. (Levings and Lauzier 1991), several studies have documented the use of non-natal tributaries to the Fraser River by juvenile Chinook salmon. Scrivener et al. (1994) documented juvenile Chinook salmon in Hawks Creek, a small upper Fraser tributary that does not support spawning; the authors suggested that juveniles were using the habitat as refuge during high spring-summer flows in the mainstem Fraser River. Russell et al. (1983) and Delaney et al. (1982) similarly documented juvenile movement into downstream tributaries within the Nechako and Chilcotin rivers, respectively, and juvenile Chinook salmon have been documented using several non-natal tributaries in the lower Fraser River (Murray and Rosenau 1989). Large numbers of Chinook salmon have also been documented using Fraser River estuary habitat as rearing habitat, with individuals documented within the estuary environment for up to a month (Levy and Northcote 1982). The extent to which upper and mid-Fraser stocks use estuary habitat, compared to its use by lower Fraser stocks, remains unclear, but is currently being investigated by researchers at the Raincoast Conservation Foundation and University of Victoria (https://www.raincoast.org/fraser-river-estuary-project/).

### Bridge River (Pre-BRGMON1 studies)

Prior to initiation of flow releases at Terzaghi Dam, BC Hydro and consultants conducted some limited studies of Chinook salmon juvenile life history variation in the Lower Bridge River. Note that all pre-BRGMON1 studies cited herein were conducted during the 1990s, and grey literature reports were reviewed opportunistically, as available.

Greenbank (1995) operated an outmigrant fish fence on the Bridge River, above its confluence with the Yalakom River, from mid-March – mid-June 1994, to examine the migration timing of juvenile Chinook salmon and other species. However, and as indicated in the report, the beginning of the outmigration period was likely missed because the author began trapping juvenile Chinook salmon immediately following fence installation. Of the ~14,000 juvenile Chinook salmon trapped during the study, ~4,400 (~30%) were sub-yearlings and 9,900 (~70%) were yearlings. Most Chinook salmon yearlings were captured during mid-March through mid-May, but sub-yearlings continued to be trapped in small numbers through trap removal. Given the high proportion of yearling Chinook salmon captured in the study, the authors suggest that most juveniles remain in the system for a year. This is a surprising conclusion, given the limited trapping duration, and one that is in contrast to the findings from other, longer-term studies of systems in the mid- and upper-Fraser. However, the authors also acknowledge a need to operate up-and downstream traps throughout the life cycle of the species to gain better insight into juvenile production and fry-to-adult survivorship (Greenbank 1995).

In another study conducted during October 30 – December 10 1993, Jussinoja (1995) documented juvenile Chinook salmon occurrence using a series of three fyke nets located on the Bridge River 0.7 km, 5.4 km, and 8.1 km upstream of the Yalakom confluence. A total of 958 Chinook salmon sub-yearlings were captured during the study, and primarily at the “5.4 km” trap; the authors suggest that there was little evidence of outmigration during the study because this trap captured the most fish. However, the study did not estimate trap efficiency and as such, the differences in trapping success could be related to this methodological issue alone. Moreover, in a limited mark-recapture trial, 12 marked Chinook salmon were released above the “8.1 km” trap. Two of three recaptured Chinook salmon juveniles were trapped in the 5.4 km trap (one fish was trapped at the 8.1 km trap), suggesting that these fish were indeed moving downstream, to some extent, and that trapping efficiency was, in general, low. Overall, this study supports habitat use by Chinook salmon in the upper reaches of the Lower Bridge River during November and early December, but provided little insight into juvenile abundances or movement.

Other evidence suggests that Bridge River Chinook salmon use the lower mainstem Fraser River as rearing habitat. Genetic stock identification analysis conducted by Fisheries and Oceans Canada on juvenile Chinook salmon sampled during fall 1997 from the Fraser River near Lillooet, Hope, Chilliwack, Rosedale, and Cheam suggested that Bridge River Chinook salmon comprised ~3-4% of juveniles detected within the multi-stock group that was largely comprised of fish from the Nechako, Chilcotin, and Stuart basins (M. Bradford, DFO, pers. comm.; Rempel 2004).

**Table 3.1 Summary of juvenile life history diversity exhibited by "stream-type" populations of Chinook salmon; see document text for additional detail on data collection methods and associated limitations.**

| River system | Study locations | Life history stage at outmigration from natal river | Outmigration timing | Downstream rearing locations | Citation(s) |
|---|---|---|---|---|---|
| Snake River Basin, Idaho | Various tributaries | Fry (subyearling) | March | (unknown) | Copeland and Venditti 2009, Copeland et al. 2014 |
| | | Subyearling smolt | April – June | Salmon/Snake/Columbia used as migratory corridor | |
| | | Parr (subyearling) | August – November | Overwinter in Salmon/Snake rivers | |
| | | Yearling smolt | March – April | Salmon/Snake/Columbia used as migratory corridor | |
| Upper Willamette River, Oregon | McKenzie River | Fry mover – subyearling smolt | January – March | Mainstem Willamette | Schroeder et al. 2015 |
| | | Fry mover – autumn smolt | January – March | Mainstem Willamette | |
| | | Fry mover – yearling smolt | January – March | Mainstem Willamette | |
| | | Stayer, fall migrant – subyearling | October – January | Mainstem Willamette | |
| | | Stayer, spring migrant – yearling | February – May | Willamette used as migratory corridor | |
| | | Stayer, fall migrant – yearling | October – January | Willamette used as migratory corridor and/or overwintering | |
| Fraser River (upper) | Slim Creek, Bowron River | Subyearlings | May – early June (majority); July – August (minority) | Mainstem Fraser | Taylor et al. 1994, Allen et al. 1995 |
| | | Yearling | April – May | Downstream used as migratory corridor (?) | |
| | Upper Nechako River | Subyearlings | March – May (majority), July (minority) | Lower Nechako, Fraser River (?) | NFCP 2005 |
| | | Yearling | February – March (?) | Fraser used as migratory corridor (?) | |
| Fraser River (middle) | Chilcotin River | Fry (from Chilko) | April – June | Fraser River (?) | Delaney et al. 1982, Taylor et al. 1995 |
| | | Subyearlings (from Chilcotin) | April – August | Fraser River (?) | |
| | | Yearling | May (?) | Overwintering in mainstem Chilcotin River (?) | |
| | Bridge River | Subyearlings, Yearlings | March-May (knowledge limited by duration of trap operations) | Fraser River (?) | Greenbank et al. 1994, DFO unpubl. |

### 3.1.2. Influence of hydropower operations on juvenile salmon life history strategies

Exposure to appropriate seasonal conditions is considered one of the key drivers of recruitment variability in fishes, also known as the "match/mismatch hypothesis" (Cushing 1990). It is generally accepted that juvenile emergence should coincide with food availability, which, in temperate regions, typically peaks in the spring-summer months (Cushing 1990). In salmonid fishes, temperature is a major determinant of developmental rate and the timing of critical life history transitions (Alderdice and Velsen 1978; Skoglund et al. 2011). Thus, modifications to thermal regime may have wide-reaching life history and recruitment implications for salmon populations (Webb and Walling 1993; Angilletta et al. 2008).

Hydropower dams can influence the temperature profiles of rivers by impounding large quantities of water into reservoirs, which are subject to seasonal warming/thermal stratification (Angilletta et al. 2008; Rounds 2010; Tillotson 2015). Thermal impacts to rivers are generally greatest at the dam site but can also persist considerable distances downstream (Webb and Walling 1993, Rounds 2010). Modeling studies have predicted diverse impacts to the invertebrate and fish communities found below dams, including impacts to incubation/development periods (Webb and Walling 1993; Lewis and Tesch 1996) and performance (survival), and could thus impose strong selection pressures on phenotype (Angilletta et al. 2008).

A few recent studies, conducted under experimental conditions, have begun to empirically parse the influence of thermal regime shifts on juvenile Chinook salmon emergence timing and development. Fuhrman et al. (2018) examined juvenile emergence timing in response to thermal treatments that mimicked natural and "below-dam" temperature profiles in four populations of Chinook salmon. The below-dam treatment exhibited less diurnal variation in temperature and temperatures in the fall and early winter months that were ~1-4°C warmer than the natural environment treatment (see Figure 2 in Fuhrman et al. 2018). Fry from the natural treatments emerged ~2.5 months later than juveniles exposed to the below dam treatment and juveniles from two populations (Clackamas and McKenzie) emerged at lower accumulated thermal units than the other populations (Yakima and Santiam) (Fuhrman et al. 2018). In a related study, Steel et al. (2012) examined the influence of thermal variance (high daily fluctuations in temperature during development vs. low daily fluctuations) on Chinook salmon emergence timing and development. Juveniles exposed to higher thermal variation emerged at different times and more fully developed, based on yolk sac consumption, than juveniles exposed to less variable temperatures during incubation. Overall, thermal regime shifts have been empirically shown to influence Chinook salmon emergence timing and condition, and some populations (and individuals within populations) appear to be more sensitive to thermal shifts than others. This latter finding supports modeling studies that have shown the potential for thermally-induced selection processes and adaptation in Chinook salmon populations affected by dams (Angilletta et al. 2008).

Within the Lower Bridge River, Lewis and Tesch (1996) predicted that accelerated Chinook salmon juvenile development could occur in the river's upper reaches as a result of surface water releases from Carpenter Reservoir, particularly during the fall months. It was recommended that dam infrastructure be modified to allow for water releases from multiple reservoir strata, to improve temperature control (Lewis and Tesch 1996). These multi-level intakes were never implemented; however, infrastructure associated with the low-level outlet at the dam was modified to allow release water to be drawn from the bottom of the reservoir rather than the surface. Despite these modifications, Chinook salmon juvenile emergence has been observed as early as November in the upper reaches of the Lower Bridge River, since continuous flow releases began in 2000 (Sneep et al. 2018).

## 3.2. Life History in the Lower Bridge River

### 3.2.1. Spawning

*Spawn timing & distribution*

Chinook salmon spawners enter the Lower Bridge River and spawn between mid-August and early October, based on data collected by visual surveys, radio telemetry surveys, and a multi-beam sonar counter (White et al. 2019; Ramos-Espinoza et al. 2018; Burnett et al. 2016 McCubbing et al. 2013). Peak counts are typically noted between early to mid-September. Existing data suggest that the majority of spawning occurs in reaches 3 and 4 (i.e., upstream of the Yalakom River confluence); however, monitoring of reaches 1 and 2 has been limited to-date. Prior to the flow release from Terzaghi Dam (when Reach 4 was dry), Chinook spawners were distributed to the upstream wetted extent of Reach 3, indicating that the full length of that reach was utilized for spawning. Access above Reach 3 was precluded by a lack of flow.

When the flow release was initiated in August 2000, Chinook spawners were observed utilizing the newly re-wetted reach for a period of years during Trial 1 (e.g., the majority of scale samples from Chinook spawner carcasses were collected in Reach 4 between 2007 and 2011), in addition to the full length of Reach 3. Unfortunately, site-specific or reach-specific spawning location data were not available for Trial 1, so the evidence for spawning use of Reach 4 during that period remains anecdotal. Since the start of Trial 2 in spring of 2012, Chinook spawners were more rarely documented in Reach 4 based on visual observation and redd surveys conducted under BRGMON-3 (Figure 3.1). Since 2017 spawners have again been observed in Reach 4; however, the majority of documented Chinook spawning has been in Reach 3 since the start of the monitoring program. It should also be noted that, since the start of the release from Terzaghi Dam in 2000, flow volumes in the river during the Chinook spawning period have been very consistent each year (i.e., between approx. 3 and 7 $m^3 \cdot s^{-1}$; see Figure 1.2) so spawning distribution among years has not been affected by varying discharges from the dam.

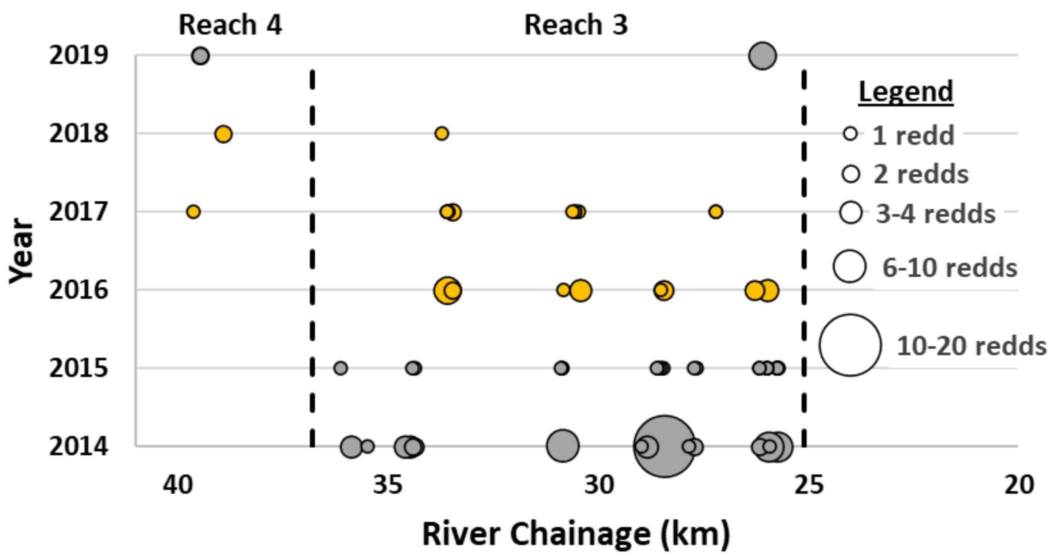


**Figure 3.1 The distribution of Chinook salmon redds in reaches 3 and 4 of the Lower Bridge River during years with Trial 2 flow releases (2014, 2015 and 2019; grey dots) and in Trial 3 (2016-2018; yellow dots). The vertical dashed lines represent the reach breaks. Note: data on specific Chinook redd locations prior to 2014 were not available.**

*Spawner Age Classes*

Ageing analysis of scale samples collected from spawner carcasses during the Pre-flow (1983–1988; *n*= 212), Trial 1 (2007; n= 14), Trial 2 (2013–2015; *n*= 35), and Trial 3 (2016–2018; *n*= 13) periods enabled determination of age designations for returning spawners (Table 3.2). For the Gilbert-Rich (G-R) age designation provided, the first number refers to the "year of life" of the fish when the sample was collected on the spawning grounds (i.e., includes the first year of life as an Age-0+ fish), and the second, subscript number refers to the year of life at ocean entry (i.e., as a smolt). For this reason, a spawner given the G-R classification $5_2$ is actually "Age-4" and would have entered the ocean as an "Age-1" fish. We use the G-R classification here since this is consistent with the DFO method and reporting.

Results reflected a range of life history strategies employed by Chinook that spawn in the Lower Bridge River (i.e., the presence of age classes $3_1$, $3_2$, $4_2$ and $5_2$ in the sample) although, interestingly, the range was much smaller for the Trial 2 and Trial 3 samples (i.e., $4_2$ and $5_2$ only). For the Pre-flow and Trial 1 samples, the dominant age class was $4_2$ (representing 51% and 42% of the samples, respectively). For the Trial 2 and 3 samples, the dominant age class was $5_2$ (94% and 92%, respectively). On average, the fish that spent the least time in the ocean (i.e., Age $3_2$) were the smallest, and the oldest fish (i.e., Age $5_2$) were the largest. Despite smolting a year-in-age apart, fish that were Age $3_1$ and $4_2$ tended to be similar in size, as each had spent a similar amount of time feeding and growing in the ocean. There was no evidence of a significant change in size within age class designations across periods. However, substantial differences in sample sizes limited the certainty of comparisons of age class proportions or size characteristics among the flow treatment periods.

**Table 3.2 Relative proportions and mean size characteristics by Gilbert-Rich age designation (read from scales) for Chinook spawners sampled in the Lower Bridge River during the Pre-flow, Trial 1, Trial 2 and Trial 3 periods.**

| Sample Period [a] | Gilbert-Rich Age [b] | *n* | Relative % | Mean POHL[c] (cm) ± SD |
|---|---|---|---|---|
| **Pre-flow** (1983 – 1988) | $3_1$ | 3 | 2% | **64.2** ± 4.3 |
| | $3_2$ | 22 | 12% | **36.8** ± 4.8 |
| | $4_2$ | 95 | 51% | **63.7** ± 6.5 |
| | $5_2$ | 63 | 34% | **85.4** ± 9.5 |
| | $6_2$ | 2 | 1% | - |
| | $R_2$ | 27 | - | - |
| **Trial 1** (2007) | $3_1$ | 4 | 33% | **62.1** ± 6.2 |
| | $3_2$ | 2 | 17% | **49.8** ± 5.0 |
| | $4_2$ | 5 | 42% | **65.4** ± 3.3 |
| | $5_2$ | 1 | 8% | **79.2** |
| | $6_2$ | 0 | 0% | - |
| | $R_2$ | 2 | - | - |
| **Trial 2** (2013 – 2015) | $3_1$ | - | - | - |
| | $3_2$ | - | - | - |
| | $4_2$ | 2 | 6% | -[d] |
| | $5_2$ | 33 | 94% | -[d] |
| | $6_2$ | - | - | - |
| | $R_2$ | - | - | - |
| **Trial 3** (2016 – 2018) | $3_1$ | - | - | - |
| | $3_2$ | - | - | - |
| | $4_2$ | 1 | 8% | -[d] |
| | $5_2$ | 12 | 92% | -[d] |
| | $6_2$ | - | - | - |
| | $R_2$ | - | - | - |

[a] The samples from the 1980s were collected during dead-pitch surveys by DFO personnel (data provided by DFO). The Trial 1 samples were collected by Jeff Sneep and analyzed by DFO. The trials 2/3 samples were collected, analyzed and reported by Instream Fisheries Research Inc. under BRGMON-3 (White et al. 2019).

[b] For the Gilbert-Rich age designation, the large number is the total age of the fish on the spawning grounds and the subscript number is the age at ocean entry (i.e., as a smolt). Each designation represents a different life history strategy.

[c] Post-orbital hypural length is measured from the posterior edge of the eye socket (orbit) to the plate at the posterior end of the spinal column (hypural plate).

[d] Forklength (tip of the snout to fork of the tail) was measured for these fish instead of POHL. Mean forklengths were 67.3 ± 2.9 cm and 81.2 ± 11.1 cm for age $4_2$ and $5_2$ fish, respectively (White et al. 2019).

*Spawner Abundance*

Chinook spawner abundance has generally declined across the 24-year monitoring period to-date (Figure **3.2**). Within the Lower Bridge River, abundance estimates tended to be highest during the Pre-flow release period (mean = 1207 fish; range = 851 to 2005) based on AUC estimates derived from visual survey data (Figure **3.2** lower panel). Mean abundance during the Trial 1 period was similar (i.e., 1119 fish); however, abundances were highest during the first half of this period (range = 1784 to 3106 from 1999 to 2004) and declined dramatically in the latter half (range = 21 to 591 between 2005 and 2009). Spawner abundances have remained low since the decline starting in 2005, with mean abundance of 283 fish during Trial 2 (range = 82 to 591) and 181 during Trial 3 (range = 120 to 265). Notably, 2005 was the first year that fish that had been recruited under the flow release conditions returned to the Lower Bridge River as adult spawners.

For comparison of the trends in Chinook escapements in the Lower Bridge River with broader regional trends, we also plotted the total escapement estimates for the mid-Fraser spring-$5_2$ Chinook populations (Conservation Unit CK-10), which includes the Lower Bridge River fish (Figure **3.2** upper panel; data provided by DFO – Fraser River Stock Assessment). CK-10 also shows a declining trend across the monitored period, suggesting that some of the decline observed for the Lower Bridge River fish may be linked to broader conditions or changes in marine survival that have affected the mid-Fraser conservation unit (CU) generally. However, there are also some notable differences between the trends as well. The drop to a consistently low level in the LBR starting in 2005 was not as apparent in the estimates for the CU or, alternatively, years with improved abundance estimates for the CU (e.g., 2008, 2010, 2014) were not as strongly reflected in the Lower Bridge River estimates.

Comparison of the percent change in mean escapements among flow trials for the CU versus the LBR highlight some of these differences (Table 3.3). From the Pre-flow period to Trial 1 there was a 51% decline in the mean estimates for the CU, but only a 7% decline for the mean LBR estimates. This is because the higher annual estimates for the LBR in the early part of this flow treatment (+106%) largely mitigated the sharp decline in the annual estimates starting in 2005 (i.e., -88%) in the calculation of the trial average. In other words, the largest decline for the CU happened across the Pre-flow period to the start of Trial 1, whereas for the LBR the largest decline occurred 5 years after the start of Trial 1. This degree of change is reflected in the percent change value from Trial 1 to Trial 2 (-75%). The percent change from Trial 2 to the High Flow years was similar for the CU and the LBR (i.e., -34% and -36%, respectively). These results further suggest that while the overall trend in Chinook escapements declined over the monitoring period, the timing of the decline and the consistently low estimates in the Lower Bridge River since 2005 may be, at least in part, attributable to freshwater habitat conditions in the LBR since the start of the continuous flow release.

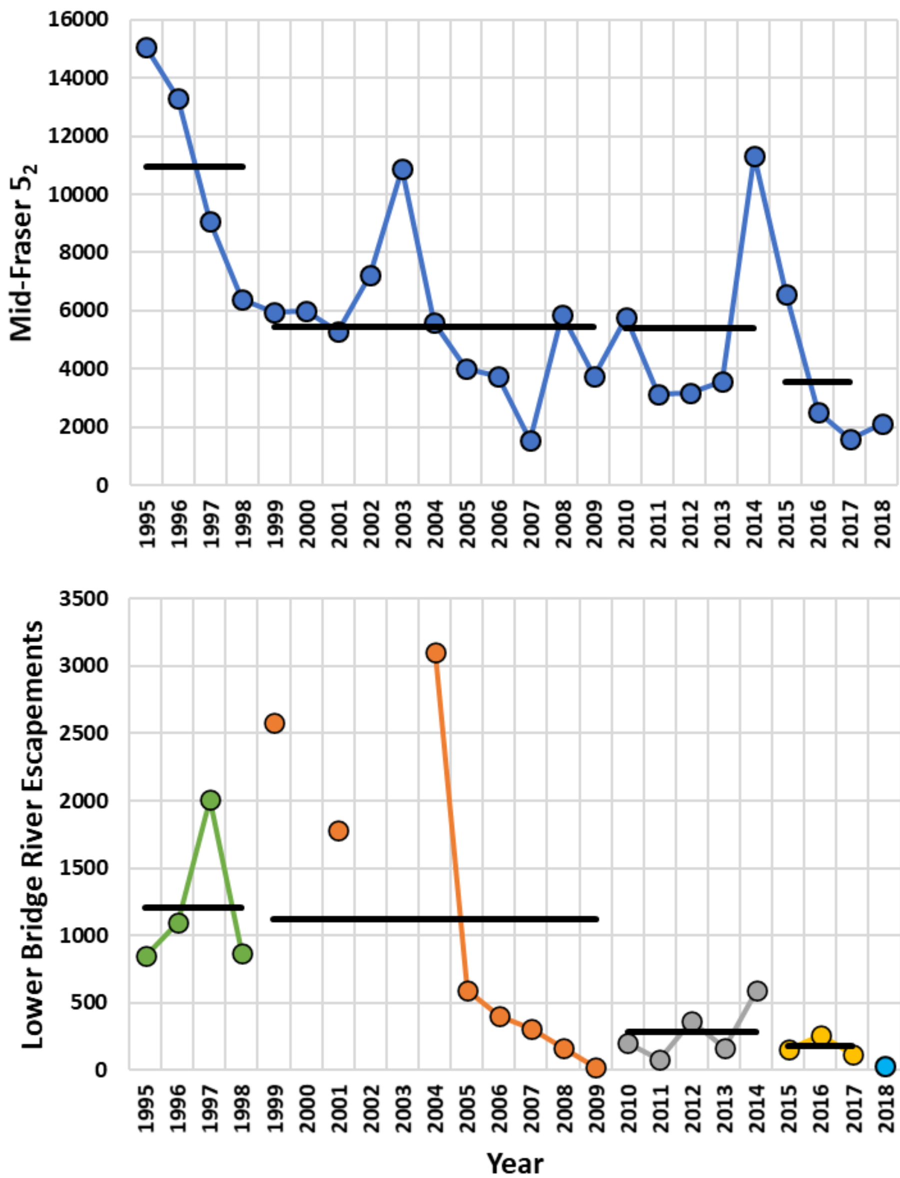


**Figure 3.2** **Total Chinook Spring-$5_2$ escapement estimates for the Middle Fraser River populations (Upper panel; Data provided by DFO) and the AUC-based escapement estimates for reaches 3 and 4 of the Lower Bridge River (Lower panel; Data provided by BRGMON-3) from 1995 to 2018. The horizontal black bars represent the average escapements for each flow trial period.**

**Table 3.3 Mean escapements and percent change among flow trial periods for the Mid-Fraser Spring-$5_2$ conservation unit (CK-10) and the Lower Bridge River Chinook populations. Trial 1 has been broken into two periods (1999-2004 and 2005-2009) based on the inflection point of reduced escapements that occurred mid-way through this trial (see Figure 3.2 and the text for further explanation). Trial averages are shown in bolded font.**

| Flow Treatment | Year Range | Mean Escapement | | Percent Change from Previous Treatment | |
|---|---|---|---|---|---|
| | | CU (CK-10) | LBR | CU (CK-10) | LBR |
| **Pre-Flow** | **1995 – 1998** | **10,967** | **1,207** | | |
| Trial 1 | 1999 – 2004 | 6,815 | 2,489 | -38% | +106% |
| | 2005 – 2009 | 3,764 | 297 | -45% | -88% |
| **Trial 1 Total** | **1999 – 2009** | **5,428** | **1,119** | **-51%** | **-7%** |
| **Trial 2** | **2010 – 2014** | **5,406** | **283** | **0%** | **-75%** |
| **High Flows** | **2015 – 2017** | **3,551** | **181** | **-34%** | **-36%** |

### 3.2.2. Incubation and Emergence

Based on the timing of spawning, the incubation period for Chinook eggs in the LBR starts in early September (McCubbing et al. 2013; Burnett et al. 2016; Ramos-Espinoza et al. 2018; White et al. 2019). Egg and larval development rates are driven by several factors, including: fertilization date (spawn timing), water temperature, photoperiod, hyporheic flow, chemical cues, etc.; however, water temperature is a significant factor (Alderdice and Velsen 1978; Skoglund et al. 2011). With the exception of water temperature and possibly spawn timing (see comment on this in the paragraph below), most of the other factors were not expected to substantively change during the Chinook spawning and incubation period among the flow treatments implemented to-date.

Water temperatures in the Lower Bridge River were altered by the flow release at Terzaghi Dam, which draws water from the bottom of Carpenter Reservoir through a low-level outlet. Temperatures in Reach 3 have been warmer at the start of incubation and across the fall period under Trial 1, Trial 2 and Trial 3 (the high flow years) relative to the Pre-flow period (Figure **3.3**). There is also a gradient of temperature from upstream to downstream across the study area; Reach 4 is the warmest during this period.

As a result of the thermal regime of the release, which has been between 2° and 4°C warmer than under the Pre-flow conditions during fall, the eggs acquire the necessary thermal units (ATUs) earlier and develop more rapidly, particularly in the upstream portion of the study area (i.e., Reach 4 and the top half of Reach 3). The predicted peak emergence timing dates are represented by the coloured dots on the x-axis in Figure **3.3** and summarized in During the Pre-flow period, the predicted peak emergence date in the middle of Reach 3 (i.e., km 30.4) was April 3. This timing was generally corroborated by the results of trapping efforts in 1994: Peak catches of emerged Chinook fry in the Lower Bridge River occurred on 21 April

(Greenbank 1995). Under the various flow release treatments, the predicted peak emergence date moved up by more than a month (i.e., the predicted range was between 31 Jan and 4 Mar among trials). The most extreme incubation conditions were in Reach 4 where predicted peak emergence dates (based on ATUs) were between 12 and 22 December among each of the flow trials, which was over 3 months earlier than the Pre-flow timing in Reach 3. Emergence timing in Reach 2 did not change as substantively, with predicted estimates ranging from mid-April to early May across all flow treatments due to a combination of ambient cooling across the length of reaches 3 and 4 and the moderating influence of the Yalakom River inflows.

**Table 3.4**. These dates were modelled based on the requisite ATUs from the mean peak spawning dates determined from the BRGMON-3 AUC results, which were: 3 Sep (SD 5 days), 4 Sep (SD 5 days), 8 Sep (SD 4 days) and 8 Sep (SD 9 days) for the Trial 0 (Pre-Flow), Trial 1, Trial 2 and Trial 3 (high flow) periods, respectively. Interestingly, based on notes from DFO technicians during dead-pitch surveys in the 1980s (i.e., 1983–1988), peak spawn timing was in late August and complete by mid-September during those years (DFO unpublished data) suggesting that spawn timing has shifted later since the onset of the flow release. It’s possible that the emergence timing effects of the warmer fall water temperatures under the flow release have begun selecting for later spawn timing in the LBR.

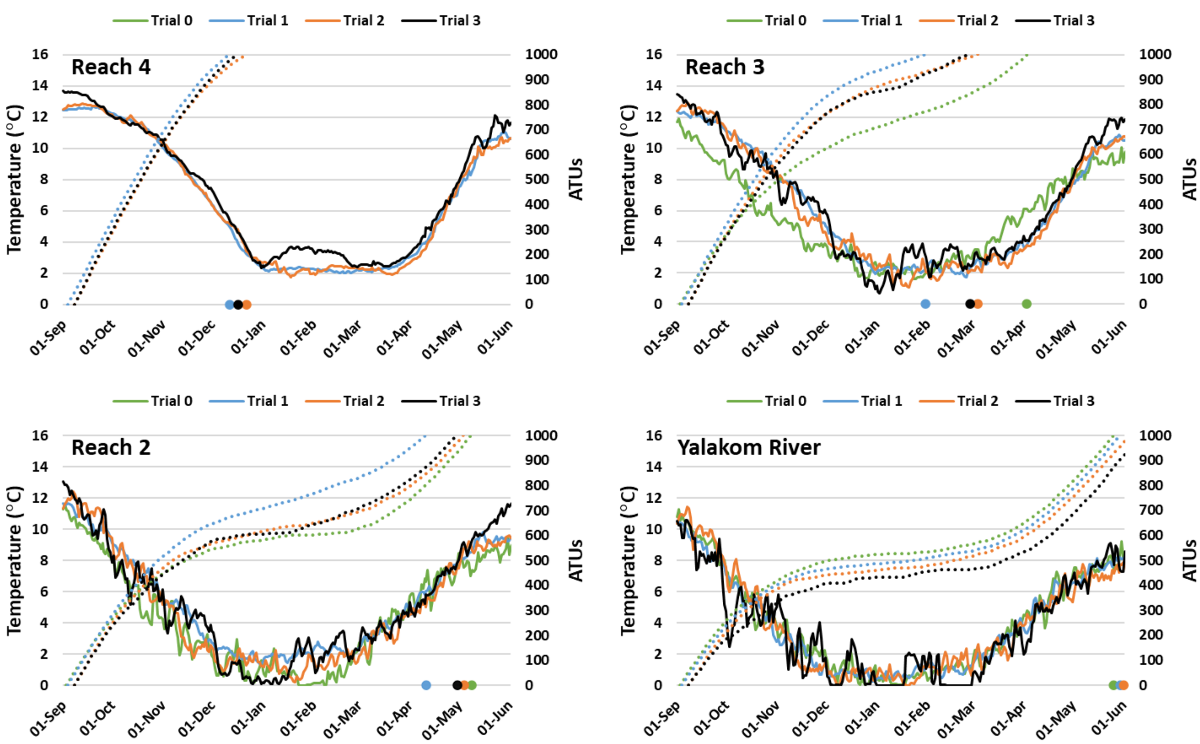


**Figure 3.3 Water temperature profiles (solid lines) and accumulated thermal units (ATUs; dotted lines) during the Chinook incubation period by flow trial and reach (Reach 4 = top left; Reach 3 = top right; Reach 2 = bottom left). Predicted peak emergence timing is represented by coloured dots on the x-axis. Data for the Yalakom River (bottom right) are included for reference.**

During the Pre-flow period, the predicted peak emergence date in the middle of Reach 3 (i.e., km 30.4) was April 3. This timing was generally corroborated by the results of trapping efforts in 1994: Peak catches of emerged Chinook fry in the Lower Bridge River occurred on 21 April (Greenbank 1995). Under the various flow release treatments, the predicted peak emergence date moved up by more than a month (i.e., the predicted range was between 31 Jan and 4 Mar among trials). The most extreme incubation conditions were in Reach 4 where predicted peak emergence dates (based on ATUs) were between 12 and 22 December among each of the flow trials, which was over 3 months earlier than the Pre-flow timing in Reach 3. Emergence timing in Reach 2 did not change as substantively, with predicted estimates ranging from mid-April to early May across all flow treatments due to a combination of ambient cooling across the length of reaches 3 and 4 and the moderating influence of the Yalakom River inflows.

**Table 3.4 Summary of predicted emergence dates (modelled based on ATUs from peak spawn date) and incubation period (days) for each reach of the LBR and the Yalakom River during the Pre-flow period and Trials 1, 2 and 3.**

| Flow Treatment | Incubation Flow ($m^3 \cdot s^{-1}$) [a] | Predicted Emergence Date (modelled) | | | | Incubation Period (# days) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Reach 4 | Reach 3 | Reach 2 | Yalakom | Reach 4 | Reach 3 | Reach 2 | Yalakom |
| Pre-Flow | 0.0 | | 03-Apr | 09-May | 26-May | | 212 | 248 | 265 |
| Trial 1 | 2.0 | 12-Dec | 31-Jan | 11-Apr | 30-May | 99 | 149 | 219 | 268 |
| Trial 2 | 1.5 | 22-Dec | 04-Mar | 04-May | 01-Jun | 105 | 177 | 238 | 266 |
| Trial 3 | 1.5 | 17-Dec | 27-Feb | 30-Apr | 08-Jun | 100 | 172 | 234 | 273 |

[a] Flow release from Terzaghi Dam during the incubation period for Chinook salmon in the LBR.

By cross-referencing the spawning distribution information available from 2014 to 2019 (Figure **3.1**) with the temperature data for each index monitoring site in reaches 3 and 4 of the LBR (spaced approx. 3 km apart), we have estimated the proportion of redds that correspond to the predicted peak emergence timing for each location in the past six years (Table **3.5**). Based on the distribution of redds across these years, 29% of deposited eggs were predicted to develop to emergence between mid-December and early February in the upper portion of the study area (i.e., Terzaghi Dam to km 33.3); whereas 71% of deposited eggs had predicted median emergence dates between early February and the end of March in the lower part of the surveyed area (i.e., km 33.3 to the Yalakom confluence). Note: the percentages generated by this analysis assume that all spawning has occurred in reaches 3 and 4, which are the only reaches that have been consistently monitored.

**Table 3.5 Proportion of Chinook spawning, according to observed redd locations, by distance from dam and predicted median emergence timing in reaches 3 and 4 for 2014 to 2019.**

| Species | Reach | Station (Rkm) | Dist. From Dam (km) | Predicted Median Emergence Date | Percentage of observed redds [a,b] |
|---|---|---|---|---|---|
| Chinook | 4 | A (39.9) | 1.0 | 17-Dec | 5% (5%) |
| | 3 | B (36.5) | 4.4 | 3-Jan | 13% (18%) |
| | | C (33.3) | 7.6 | 6-Feb | 11% (29%) |
| | | D (30.4) | 10.5 | 31-Mar | 41% (70%) |
| | | E (26.4) | 14.5 | 21-Mar | 30% (100%) |

Early emergence was qualitatively confirmed during the Trial 1 years by the collection of recently emerged Chinook fry during some late fall backpack electrofishing surveys (i.e., during November and December) between 2002 and 2010 (Photo 3.1; Table 3.6). This sampling was not quantitative (it was intended for collecting a consistent sample of juvenile fish monthly for assessment of size) and late fall sampling was discontinued during trials 2 and 3, which precluded confirmation of potential early emergence during those years (i.e., >2010).

**Photo 3.1 Since the start of the flow release, the newly emerged year-class of Chinook juveniles began to appear in the river as early as December, which coincides with the start of winter. Photo taken in Reach 4 near the dam (December 2005).**

**Table 3.6 Summary of early emerged Chinook fry incidentally sampled in the Lower Bridge River during late fall juvenile fish growth sampling surveys in Trial 1 (2000 to 2010).**

| Year | Sampling Dates | # of CH fry Sampled | Size Range (mm) |
|---|---|---|---|
| 2002 | 10-17 Dec | 3 | 34 – 35 |
| 2003 | 12-14 Dec | 24 | 31 – 39 |
| 2004 | 15-17 Nov | 7 | 32 – 36 |
| | 11-14 Dec | 53 | 32 – 40 |
| 2005 | 14 Nov | 2 | 25 – 34 |
| | 12-14 Dec | 14 | 32 – 42 |
| 2006 | 11 Dec | 1 | 23 |
| 2007 | 30 Nov | 1 | 33 |
| 2010 | 8 Dec | 1 | 32 |

In most cases, catches were relatively sparse reflecting that the sample timing typically corresponded with the very earliest emergence predictions, and because of the generally poor catchability for these fish due to the combination of small body size and cold water temperatures at the time of the surveys. Survival of fry that emerge in early or mid-winter and remain in the LBR may be poor since their activity levels and food availability tend to be lowest at this time of year. It is unknown what proportion of the total recruits remain versus outmigrate to rearing areas outside of the LBR study area. As a comparison, coho salmon spawn later in the LBR and have not experienced early emergence issues, at least not to the same degree. This species responded positively to flow trials 1 and 2, reinforcing that changes to emergence timing are likely the key issue for Chinook rather than rearing habitat changes associated with the flow release (which would presumably have affected coho fry in a similar manner).

Across surveys in late fall (for years shown in Table 3.6), Chinook fry were sampled in all of the study reaches, suggesting that the fry had distributed beyond the immediate areas where they were spawned, post-emergence. However, it is not possible to assess the temporal or spatial distribution of Chinook fry emergence, the survival of early emerging fry, or accurately characterize their post-emergence distribution and movements within or outside the study area from these data.

### 3.2.3. Freshwater Rearing and Outmigration

Following emergence, a proportion of Chinook fry remain in the Lower Bridge River to rear for their first year, and the population size (juvenile standing stock) of this group is measured annually by closed-site depletion sampling in September. Like in other systems referenced in the literature review (in Section 3.1), a proportion may also leave the LBR more immediately following emergence to rear in the Fraser River or another tributary (as noted by the information from DFO in Section 3.1.1 (M. Bradford, DFO, pers. comm.)), but that proportion has not yet been assessed or documented for the LBR. As such, we do not know what proportion of the total juvenile production in the LBR the fall recruitment estimate represents, or if that proportion has changed among the flow treatments (e.g., possibly due to poor rearing conditions in mid-winter for early emergers).

Chinook fry abundance estimates from the juvenile stock assessment in September were highest in the LBR, on average, during the Pre-flow period (assessed between 1996 and 1999), and highest production for this species was in Reach 3 (Figure 3.4). Age-0+ Chinook abundance increased slightly in Reach 2 under the Trial 1 treatment relative to Trial 0 but declined in Reach 3, likely owing to higher incubation temperatures resulting in premature emergence in that reach. Earlier emergence timing may have contributed to reduced recruitment success or a change in outmigration timing (i.e., prior to the annual stock assessment sampling), or both, but this remains uncertain. Chinook recruitment in Reach 4 has been low across all flow treatments. As a result of these factors, Age-0+ Chinook abundance under the Trial 1 and 2 treatments and high flows (Trial 3) have been 0.6-, 0.3- and 0.3-fold of the abundance under Trial 0, respectively. Interestingly, the high spring peak flows in 2016 – 2018 did not result in a further decline in Age-0+ Chinook abundance (relative to Trial 2), as it did for coho and steelhead fry in the LBR (Sneep et al. 2019), perhaps because their abundance was already depressed due to other factors (e.g., water temperatures during the incubation period).

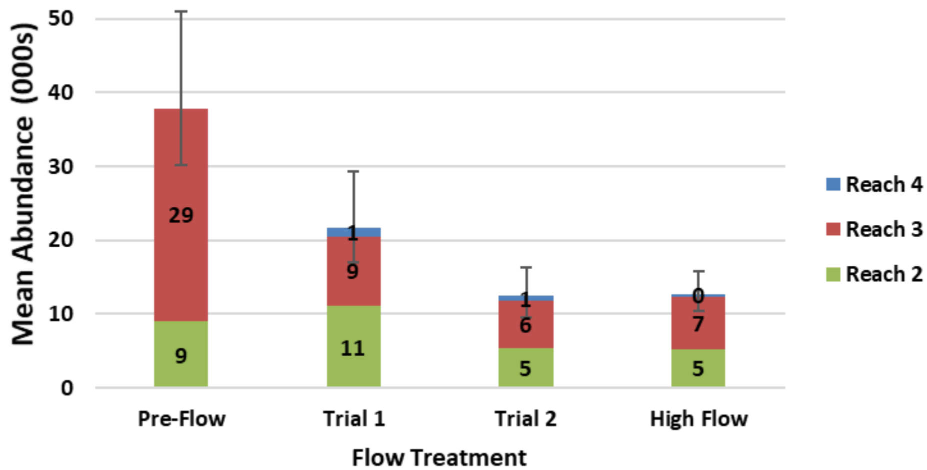


**Figure 3.4 Mean abundance (in thousands) of Chinook fry (age-0+) in the Lower Bridge River by reach for each flow treatment. Vertical lines show 90% credible intervals from posterior distributions of abundance for each treatment from the hierarchical Bayesian model.**

The distribution of Chinook fry catches among sites within the LBR study reaches has also changed across the flow treatments (Figure 3.5). During the Pre-flow period, catches were generally higher, and quite variable, among sites in Reach 3 compared to Reach 2. The highest catches during this period were primarily at sites between Fraser Lake (Rkm 33.3) and the area immediately below Hell Creek (Rkm 29.8), which is also the section where a substantial proportion of spawning has been documented in recent years (see Figure 3.1 and Table 3.5, above). Under Trial 1 flows, catches decreased at almost all of the sites in Reach 3; whereas catches at some Reach 2 sites increased. The data points across the study area for Trial 1 show a generally negative correlation between catches (among the reaches) and proximity to the dam for this flow treatment (Figure 3.5). Under both trials 2 and 3 (high flows) the catches were lower and more consistent among the sites than they were during the Pre-flow period, and catches at the Reach 4 sites remained the lowest among the reaches.

In terms of habitat use, characterized by mean site depth and velocity, there has been no obvious differences between sites where Chinook fry *were* captured and sites where Chinook fry *were not* captured, as evidenced by the extensive overlap of data points in Figure 3.6. The maximum range of mean site depths and velocities for all flow treatments was from 10 to 75 cm, and 0 to 80 cm/s, respectively, although it must be noted that the range of depths and velocities are also constrained by limitations of the sampling method (i.e., site conditions must allow for enclosure with nets).

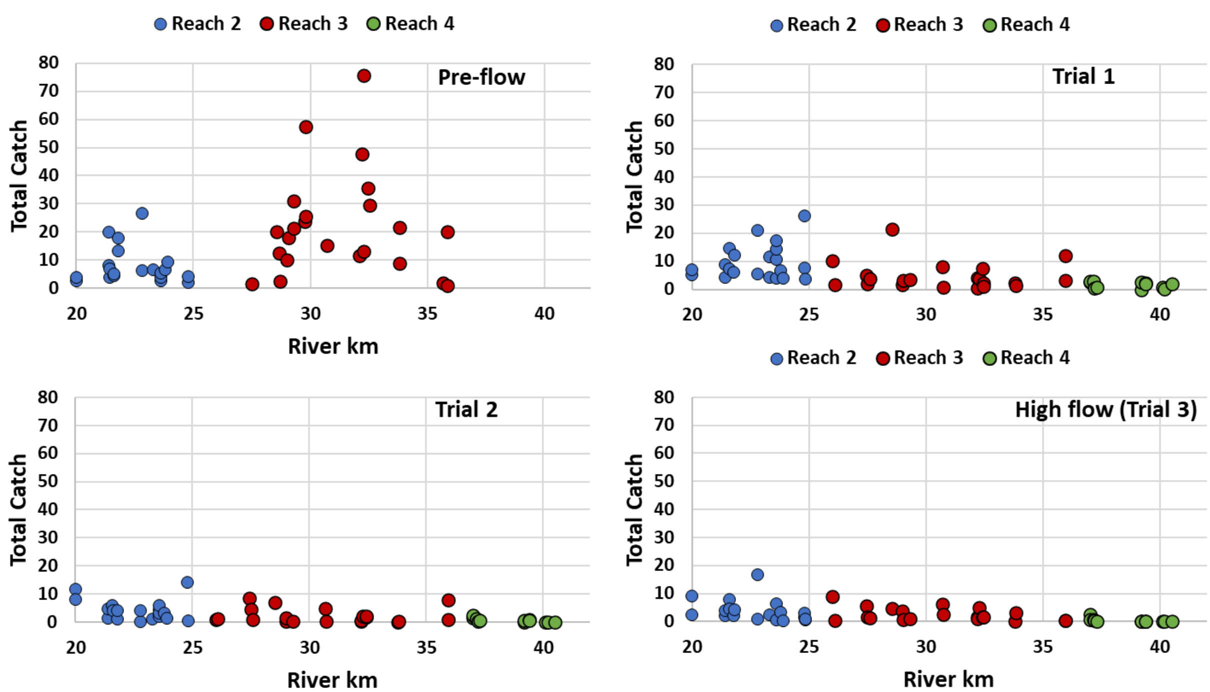


**Figure 3.5** **The distribution of Chinook fry catches by site within reaches 2, 3 and 4 of the Lower Bridge River for each flow treatment. Datapoints are colour-coded according to reach.**

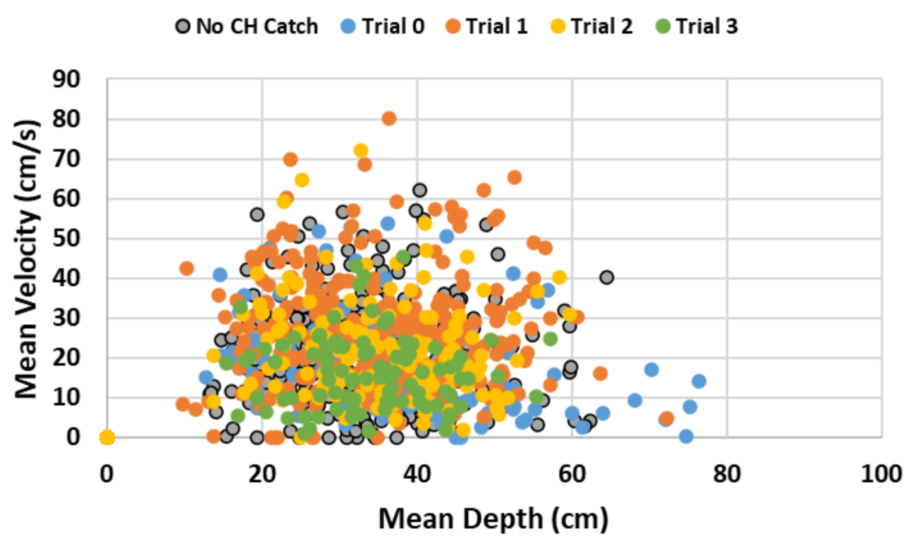


**Figure 3.6** **The distribution of mean site depth and mean site velocity for sites where Chinook fry were captured during the fall stock assessment under trials 0 to 3. Mean site depth and mean site velocity for sites where Chinook were not captured are also included for reference (grey circles).**

Median values varied most narrowly for site depth, between 30 and 36 cm, among flow treatments (Figure 3.7). Median values for site velocity ranged between 16 and 24 cm/s, and there were some moderate differences among flow treatments (although the total ranges for each completely overlapped – as shown in Figure 3.6). The increase in median site velocities between the Pre-flow period and Trial 1 may reflect the influence of the added discharge from the flow release (i.e., 3 $m^3/s$ from the dam). The slight differences in median site velocity among the three flow trials was mirrored between Chinook sites and non-Chinook sites, so this likely has more to do with overall site differences among the trials rather than changes in Chinook habitat-use.

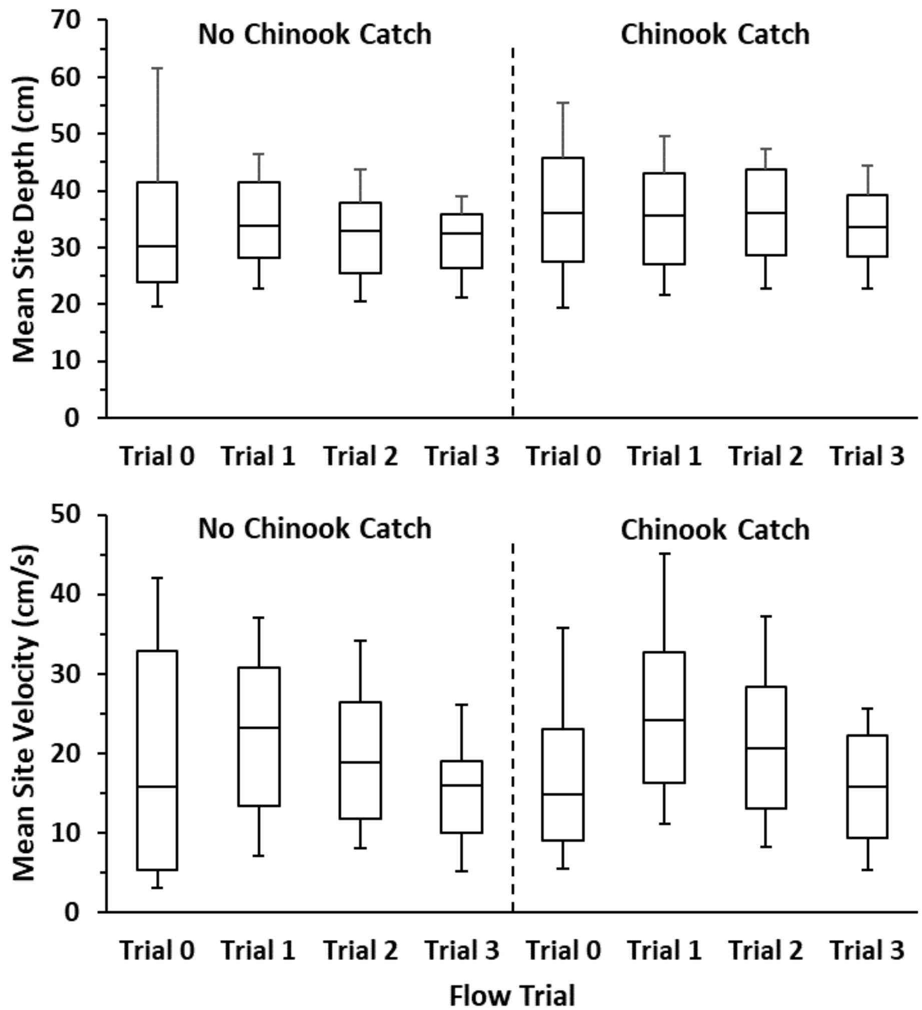


**Figure 3.7 "Box-and-whisker" plots representing site depths and velocities for each flow treatment at sites where Chinook fry *were not* captured (left side) and sites where Chinook fry *were* captured (right side). The boxes are bounded on the top by the 75th percentile, and on the bottom by the 25th percentile. The median divides each box. The whiskers represent the 10th and 90th percentiles.**

Catches of yearling Chinook in the study area have always been low (total *n*= 481 for all juvenile fish sampling combined between 1996 and 2019), comprising about 4% of all the Chinook sampled. During monthly fish sampling for growth data conducted from spring to late fall (1996 – 2017), yearling Chinook were typically noted in the March, April and May samples, after which their numbers tended to be very sparse for the remainder of the sampling season each year. While not based on quantitative sampling methods, this suggests a general timing of movement out of the study area for yearling Chinook of approx. late May or early June. As noted by Healey (1991), the movement of stream-type Chinook to the ocean usually occurs in the spring and often coincides with the migration of ocean-type fry to estuaries. Anecdotally, Chinook yearlings were sometimes captured during early spring sessions in the beaver ponds in Horseshoe Bend (Reach 2 – Rkm 23.6), which may indicate some degree of overwintering use of off-channel ponds by this age class, similar to what has been documented in the Nicola River (Swales and Levings 1989).

Based on the analysis of scale samples collected from returning spawners in the Lower Bridge River (see Table 3.2 in Section 3.2.1), the vast majority (97%) of Chinook were yearlings when they entered the ocean and the remaining 3% were under-yearlings across all flow treatments. Within the Trial 1 sample, there was an increased proportion of fish that had smolted as sub-yearlings (i.e., 33% of the sample); however, the sample size for this trial period was small (total *n*= 14 fish), so any conclusions from this result would be highly tenuous.

Overall, these data suggest that even though very few yearling Chinook have been detected within the LBR during the 24 years of juvenile stock assessment monitoring and periodic growth sampling, the majority of Chinook produced in the Lower Bridge River do rear in freshwater for a year before going to sea. Therefore, it seems likely that this rearing occurs outside of the LBR study area (i.e., reaches 2 to 4), and quite possibly in the Fraser River mainstem or the lower extents of other Fraser River tributaries, as is the case for other Mid- and Upper-Fraser Chinook populations (see “Non-natal tributary and estuary habitat use” in Section 3.1.1). Also, based on genetic stock identification conducted on a multi-stock group of Chinook juveniles sampled from various locations on the Fraser River by DFO in fall 1997, between 2% and 4% were determined to be Bridge River origin (M. Bradford, DFO, pers. comm.; Rempel 2004). However, specific rearing locations have not been more specifically determined for the LBR population to-date.

# 4. Discussion

Information from the literature review highlights the remarkable diversity of life history variants for Chinook Salmon throughout their distribution, but even within individual watersheds and populations (Schroeder et al. 2015; Copeland et al. 2014; Copeland and Venditti 2009). As cited in Shrimpton et al. (2014), individual Chinook salmon in the Thompson River system exhibited “tremendous” diversity in movement and habitat use. In several cases in both the Columbia and Fraser river systems, both “mover” and “stayer” types, as well as sub-yearling and yearling migrant strategies are described for juvenile outmigrants within the same Chinook populations. As noted in the introduction, varied life history pathways are an important survival strategy for Chinook populations that can face changing environmental and instream flow conditions in their natal watersheds. Data collected from over 24 years of monitoring also point to a range of life history strategies employed by the Chinook population in the Lower Bridge River.

Results from the BRGMON-1 and BRGMON-3 programs, as well as the results from some additional Pre-flow release studies, have enabled characterization of several of the freshwater life history stages of LBR Chinook, including: a) Spawning (timing, spatial distribution, age classes, and annual escapement estimates), b) egg incubation and fry emergence timing (using predicted and available qualitative information); c) in-river rearing (annual abundance estimates, distribution and habitat use), and d) outmigration (data from pre-flow studies and qualitative information only). Collectively, these results have noted some variations and changes for the different life history stages among time periods, some of which may be attributable to the flow release. However, data to more specifically characterize these variations and changes are sparse since data collection to-date has primarily focussed on in-river juvenile and spawner *abundances* among years and flow treatments. Data collection has not focussed on the life history variations among individuals within the population, or the differential survival associated with each strategy.

Arguably, the most significant effect of the flow release on Chinook salmon in the LBR has been the modified thermal regime in the fall. Water drawn from the bottom of Carpenter Reservoir through the Low-level Outlet at Terzaghi Dam is cooler than the surface of the reservoir during the summer months, but it tends to be 2°–4°C warmer than background (i.e., pre-flow) river temperatures in the fall (particularly Sep-Nov). These warmer temperatures accelerate the development of eggs and alevins towards emergence between December and February, which is 1-3 months earlier than under the pre-flow conditions. Changes in water temperatures associated with the flow release were predicted for the LBR during water use planning discussions (Failing et al. 2004); however, potential impacts to emergence timing were not factored into the design of the fall/winter flow regime. As a result, early emergence has been an aspect of Chinook life history in the LBR for all three flow trials to-date.

The fate or survival of the “early emergers” in the LBR is unknown but their emergence timing is likely problematic given that it is mismatched with seasonal patterns of ecosystem productivity (i.e., food availability in the form of aquatic invertebrates). However, given the phenotypic diversity exhibited by juvenile Chinook salmon, as documented by the literature review, it is also conceivable that alternative life history pathways or other phenotypes could arise from this scenario. Presumably, this could include early outmigration to more productive downstream rearing environments, akin to the “mover” life history pathway exhibited in some Willamette River spring Chinook salmon populations (Schroeder et al. 2015).

Based on the available data, LBR Chinook salmon spawn timing has ranged between mid-August and early October. According to unpublished notes from DFO (recorded during multi-year dead pitch surveys in the 1980s), spawn timing during the Pre-flow period was between mid-August and mid-September with a peak timing of late August. Over the course of years since the flow release began, this timing has shifted a few weeks later with the peak now occurring in early to mid September. This apparent change in timing may be an adaptation to flow release effects on emergence timing, as described above. If earlier spawn timing is associated with earlier emergence (since eggs are exposed to the warmer water earlier and for a longer period), which has a survival consequence for the population, then natural selective forces would likely favour a shift toward later spawn timing.

Chinook spawning distribution in the LBR has been primarily concentrated in Reach 3 since the start of monitoring. Some spawning use of Reach 4 has been noted during the flow trials, but it has typically contributed less than Reach 3 based on available data. Use of reaches 1 and 2 was lower relative to Reach 3 when spawner surveys of the entire length of the LBR were done by helicopter during the Pre-flow period (DFO unpublished data), and this has been suspected to be the case since, but has not been confirmed by equivalent levels of monitoring effort during the flow trials (Note: initiation of survey effort in reaches 1 and 2 has been applied starting in the last couple of years under BRGMON-3).

According to redd distribution data available since 2014 from BRGMON-3, the majority of spawning has been in the lower half of Reach 3 (i.e., approx. 10.5 – 15.9 km below Terzaghi Dam) between river kms 25.0 and 30.4, at least since monitoring of distribution became more quantitative during the Trial 2 period. Since the flow release began, this portion of Reach 3 has more favorable incubation conditions (relative to areas further upstream) since there is a gradient of temperature with distance below the dam – water temperatures cool according to duration of exposure to ambient influence and the attenuation of cooler tributary inflows at this time of year. Similar to spawn timing changes, it is also possible that the observed spawning distribution patterns are driven by selective forces as well, particularly if early emergence has a survival consequence. In that regard, the thermal effects of the flow release may be limiting the area of effective spawning habitat available for Chinook in the LBR.

The set of age class data available from scale samples collected from returning spawners during the Pre-flow period, Trial 1, and Trials 2 and 3 reflect the range of life history strategies adopted by LBR Chinook. Interestingly, the greatest variation was in the length of time spent in the ocean, which ranged from 1 to 3 years (Age $3_1$/$3_2$ to $5_2$). The majority (87%) had spent either 2 or 3 years at sea (Age $4_2$ or $5_2$) among all flow treatment periods combined. Only two age classes ($4_2$ and $5_2$) were represented in the Trial 2 and 3 samples (n= 48); however, given the variation in sample sizes (and low *n* values for the flow trials) it was not possible to draw conclusions about the similarities or differences in the age class distributions or size characteristics of the spawners among treatments. Only a small minority of fish sampled (i.e., 3%) were sub-yearlings (Age-0) when they went to sea and the remainder were yearlings (Age-1), indicating that the vast majority had reared in freshwater for a year before smolting.

Spawner abundance data reflected the general decline in escapements since the start of the monitoring period for both the LBR population and the broader Mid-Fraser Spring $5_2$

conservation unit (CK-10) suggesting that at least some of the decrease observed for the LBR fish may be attributable to factors outside of the LBR (e.g., marine survival) that have affected the CU as a whole. However, there were also differences in the timing and extent of the decline for the LBR, that also indicate the potential for a flow release effect. For instance, the biggest decline for the CU occurred across the Pre-flow period, whereas the biggest decline for the LBR began five years after the start of the flow release (i.e., the first year of returns for fish that had been spawned under the release conditions). Also, the LBR escapements have remained consistently low since that drop, whereas the CU has seen some years of modest recovery (e.g., 2008, 2010, 2014). These data seem to support the theory that flow release effects on Chinook recruitment may be limiting spawner escapements in addition to the general declines in Fraser River Chinook escapements more broadly.

Chinook juvenile abundance has also declined since the start of the flow release. Chinook production was highest during the Pre-flow period, dropped during Trial 1 and has remained low during Trials 2 and 3. In terms of distribution, abundances were highest at sites in Reach 3 during the pre-flow years, and lower in Reach 2. Since the start of Trial 1 that pattern has shifted such that Reach 2 sites contribute more than Reach 3. Abundances for Reach 4 have consistently been low for Chinook. Data on mean depth and velocity for sites where Chinook juveniles were captured during fall depletion sampling have indicated a distribution between 10 to 75 cm and 0 to 80 cm/s (across all flow treatments), respectively, with substantive overlap among the treatments and between sites where Chinook were captured and where they were not. This suggests the likelihood that habitat conditions at the site level have not substantively changed and that these metrics are not likely meaningful explanatory variables for the observed changes in juvenile chinook abundance.

An important consideration in assessing the changes in juvenile recruitment is the annual stock size which, as noted above, has decreased during the flow trials relative to the pre-flow period. Stock-recruitment curves were not included in this review but are available and updated every year in the annual report for BRGMON-1 (Sneep et al. 2019). Despite the 24-year monitoring period for this program, the available data points for stock-recruit analysis are limited since there have been different conditions and productive capacities for Chinook imposed by the flow trials, which require that separate curves be drawn for each treatment. While there has been reduced juvenile production associated with the flow trials relative to the pre-flow period (as noted above), there has not been strong evidence to suggest under-seeding due to the change in Chinook escapements across the available time series. For more detailed description of this analysis, refer to the BRGMON-1 report.

Taken together, these results point to the change in incubation conditions as being the most likely instream factor contributing to the change in juvenile Chinook abundance noted within the LBR study area across the years of monitoring to-date. Unlike Chinook, other salmonid species (i.e., coho and steelhead/rainbow trout) that were not affected by thermal changes to incubation conditions due to different spawn timing, responded positively to Trials 1 and 2 (Sneep et al. 2019).

Following are responses to the management questions for Chinook life history and emergence timing based on the information summarized for this review:

5) Do increased water temperatures and early emergence associated with Terzaghi Dam flow releases affect the survival of juvenile Chinook salmon in the Lower Bridge River?

Based on the results of monitoring, the answer to this question is a qualified “Yes”. Since the onset of the release and its associated effects on incubation conditions and emergence timing, there has been a corresponding decrease in abundance for both juveniles (recruits) and, subsequently, returning spawners in the study area relative to the Pre-flow treatment. Given each of the factors described in the Discussion above, it is unlikely that the observed reduction in abundance was directly caused by instream flow changes (i.e., flow rate, depths, velocities) associated with the flow trials. Coho and steelhead/rainbow trout abundances increased under the Trial 1 and 2 hydrographs, but then declined sharply under the Trial 3 high flows. Conversely, Chinook abundance declined early on and then has remained quite stable and low across each of the flow trials.

The main reason the answer is qualified is the juvenile abundance results are based on the numbers of fish that remain in the study area (i.e., “stayers”) following emergence. Given the diversity of life history strategies exhibited by Chinook (and documented by the LBR spawner scale samples) it is certainly possible that a proportion of Chinook recruits produced in the LBR migrate soon after emergence and rear outside of the study area (i.e., “movers”). The available data do not provide insight into the magnitude of this proportion, or what the differences in survival rate and contribution to the adult population for stayers vs. movers might be. Recommendations for additional monitoring approaches to fill these information gaps are provided in Section 6.

6) What freshwater rearing habitats are used by Lower Bridge River juvenile Chinook salmon and is rearing habitat use influenced by Terzaghi Dam flow releases?

At the site level, there was no strong evidence for a change in the habitat criteria (i.e., depths and velocities) selected for rearing by juvenile Chinook at the time of the annual stock assessment in September; however, the range of depths and velocities included in the sample is also constrained by the limitations of the sampling method. At the reach level, there has been a change in juvenile Chinook distribution. Prior to the flow release, the majority of rearing occurred at sites in Reach 3. Under the flow trials, the contribution of Reach 3 diminished and Reach 2 increased. This shift may reflect a downstream migration tendency for Chinook juveniles which are still primarily produced in Reach 3 (based on BRGMON-3 streamwalk and redd survey data). Abundances in Reach 4 have always been low. Considering that conditions (e.g., food availability) may be poor for fish that emerge early under the flow release, they may move downstream in search of better conditions. Additional monitoring would be required (as described in Section 6) to determine the extent to which this is occurring and whether there is a survival consequence for early emergers.

Between mainstem habitats and the off-channel habitats that have been sampled, Chinook have been much more abundant in the mainstem of the LBR. Chinook abundance has been very low in two constructed off-channel rearing habitats (i.e., “Bluenose” in Reach 4 and “Applesprings” in Reach 1) that were sampled in September 2018 and 2019 (see BRGMON-1 report for more information on these results; Sneep et al. 2019). However, Chinook yearlings were periodically sampled out of a series of off-channel beaver ponds in the Horseshoe Bend (Reach 2; Rkm 23.6) in early spring, suggesting the possibility of overwintering use of off-channel habitats, as has been observed on the Nicola River (Swales and Levings 1989). Given the lack of quantitative sampling in this case, however, this observation remains somewhat anecdotal.

So, based on the results of monitoring, the answer to this question is also a qualified “Yes”; rearing habitat use (in the form of juvenile Chinook distribution at the time of the fall stock assessment) has been influenced by the flow release. The reason this answer must also be qualified is because there is also the possibility that a proportion of LBR Chinook are rearing outside of the BRGMON-1 study area and therefore have not been detected by the monitoring to-date. If that is the case, we do not know what proportion of the total juvenile production in the LBR is “missing” from the fall recruitment estimate, or if that proportion has changed among the flow treatments. Such a change would be further evidence of a shift in habitat use (e.g., between the LBR to the Fraser River or other tributaries); however, data to support this are not presently available. While rearing outside of the study area may be an important survival adaptation for the LBR Chinook population (if successful), it should be acknowledged that an original goal for the flow release was to maintain or increase productive capacity for juvenile salmonids *within the LBR study area* itself.

## 5. Uncertainties – Lower Bridge River juvenile Chinook salmon life history

The 24 years of continuous monitoring has provided a tremendous time series of information on juvenile Chinook abundance and habitat use in the Lower Bridge River in response to various flow treatments from Terzaghi Dam. This also includes data on various physical parameters and is coupled with monitoring of Chinook adult escapements conducted under BRGMON-3. However, despite this extensive data set which was directed by the objective of linking results with flow trial effects, there were some aspects of Chinook life history (i.e., emergence and outmigration) that were not directly or routinely included in the monitoring. Given that some of the flow effects on Chinook recruitment and life history were either not foreseen or manifested differently than expected, some residual uncertainties remain, which can be characterized as follows:

- What is the actual emergence timing for Chinook in the LBR under the flow release hydrographs, and to what extent does it vary throughout the study area?

- Does early emergence in the LBR have a survival consequence (immediate or latent) relative to later timing (e.g., under Pre-flow temperature conditions)?
- Do Chinook fry migrate out of the BRGMON-1 study area shortly after emergence, and if so, does emergence timing influence moving versus staying?
- What proportion of the Chinook fry in the LBR are movers versus stayers, and how have those proportions changed or varied over time?
- What rearing habitats do juvenile Bridge River Chinook salmon use outside of their natal watershed? Research from other mid-upper Fraser River Chinook salmon populations suggest that the mainstem Fraser River and non-natal tributaries can be highly viable options for juvenile growth and survival.
- What is the timing (start/peak/end) of outmigration and how much does it vary (e.g., according to emergence timing or rearing location)?
- Do LBR Chinook outmigrate to sea as yearlings only, or is there a proportion of sub-yearling smolts as well?
- What proportion of adult production is derived from each of the juvenile life history types?

Some additional life history uncertainties that are pertinent, particularly in light of the Big Bar slide that created an obstruction to salmon passage on the Fraser River starting in 2019:

- What is the incidence of straying (fish from other populations spawning in the Bridge River) among years?
- How much do these potential strays contribute to juvenile Chinook production annually?
- If strays successfully spawn in the LBR, what is the influence of their offspring on life history strategies (i.e., proportion of movers vs stayers) and does this change over time?

# 6. Recommendations for addressing life history uncertainties in the Lower Bridge River

Our understanding of Chinook salmon emergence and outmigration timing in the Lower Bridge River is largely based on a handful of limited studies conducted in the mid-1990s, prior to flow releases being initiated at Terzaghi Dam. Moreover, if there is a diversity of life history pathways for the LBR population, the existing juvenile stock assessment framework may routinely underestimate juvenile production on an annual basis; as in other spring-summer type Chinook salmon populations, there is potentially sub-yearling juvenile outmigration occurring throughout the spring and summer months. Given the diversity of phenotypes expressed by Chinook salmon, a sampling regime aimed at examining juvenile life history diversity would need to be implemented (potentially year-round or to the longest seasonal extent possible) to describe all outmigrant types and more accurately quantify juvenile recruitment.

Sampling options for addressing the various uncertainties described above include:

Emergence Timing

- Monitor Chinook fry emergence timing using inclined plane traps (as done in the Nechako and Chilcotin rivers). They should be operated near known spawning areas at varying distances from the dam (i.e., preferably across reaches 3 and 4) during the spring, prior to the onset of high flows/spring freshet. By incorporating a mark-recapture design, this sampling could also provide another fry production estimate (i.e., in addition to stock assessment, but at an earlier point in the year which could allow for better estimates of egg-to-fry survival).

Migration Within & Out of the LBR

- A passive integrated transponder (PIT) tagging program, coupled with the installation of a PIT array at the mouth of the Lower Bridge River (if feasible) and operation of 1-2 rotary screw traps (e.g., one above Yalakom confluence, one near the mouth of Bridge River) could be used to better monitor outmigration timing and contributions of the upper and lower river to smolt production. A PIT tagging program would also allow for the development of population and life-history-specific smolt-to-adult survival estimates and improved monitoring of adult run timing, with the caveat that smaller Chinook salmon outmigrants (emergent fry) would likely be too small to tag (<60mm).
- The recovery of otoliths from adult spawners in the Bridge River should also be prioritized (i.e., additional focussed effort relative to past years). As seen in Shrimpton et al. (2014) adult otoliths could be used to reconstruct rearing habitat use, at least to the catchment level (Bridge and Seton rivers, Fraser River, marine environment) and would provide further insight into the timing and extent of use of the Lower Bridge River and downstream environments during freshwater rearing. Given sufficient sample sizes, otolith-based life history reconstruction would also allow for an estimation of adult production attributable to various juvenile outmigration strategies, and possibly estimation of smolt sizes (see Bradford and Geen 1987). Between 2017 and 2020, otoliths were extracted from 95 adult Chinook in the LBR, of which 34 were confirmed Bridge River fish via genetic stock identification, and the remainder were from other stocks or were undetermined.

Adult Life History

- Continued collection of scales from returning spawners to further characterize the diversity of life history types in terms of age-at-ocean-entry and total age at spawning. Scales can be non-lethally collected and are relatively simple to mount and read. Note: A small number of additional scale samples (*n*= 8) were opportunistically collected during the Trial 1 period, although most or all were from carcasses that had been partially eaten by bears or were in an advanced state of decomposition. As such, it may not be feasible to determine total age from these scales as the outer edge may have been affected by resorption, rot or regeneration, but it may be possible to assess age-at-ocean-entry as this is nearer to the scale origin or focus. Handling of adult Chinook for the tagging and telemetry component of BRGMON-3 and for broodstock collection during fish fence operations provide opportunities for collecting additional scale samples from fish that are still in good condition.
- Scale samples are also useful for sampling DNA (whereas otoliths are not) which will be pertinent for tracking the proportion of strays that spawn in the Bridge River going forward (see comments about this under Uncertainties, above). Any historical scale samples that are still available could be used for this purpose as well.
- When Chinook spawners or intact carcasses are handled, post-orbital hypural length (POHL) should be measured (instead of – or in addition to -- forklength). POHL is considered the best measurement for sexually mature salmon in a spawning stage because it is not affected by an eroded tail or development of a lengthened snout and is therefore a more standardized measure. The post-orbital hypural length is measured from the posterior edge of the eye socket (orbit), in a straight line with the fish laid on its side in a natural position, to the plate at the posterior end of the spinal column (hypural plate). This plate can be located by bending the tail upwards until a deep crease is formed anterior to the base of the tail (Shaw 1994). These measurements would then be directly comparable to historical data for assessing potential changes in spawner size by age class across flow treatment periods.

<u>Juvenile Stock Origin</u>

- DNA samples should be collected from a representative set of juvenile Chinook salmon in each reach of the LBR given the high incidence of straying related to the Big Bar slide. These samples should be analyzed to determine stock origin, such that the relative contributions of Bridge River stock versus other stocks can be better understood. Tissue samples from juvenile Chinook (*n*= 106) were collected from each of the study reaches for genetic stock identification in 2020. These efforts were included under the monitoring activities for BRGMON-1.

## 7. References Cited

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

Allan, J., Taylor, G., and Bradford, M. 1995. Juvenile Chinook sampling data, Slim Creek and the Upper Fraser River mainstem, British Columbia, 1994. Can. Data Rep. Fish. Aquat. Sci. **964**: 47.

Angilletta, M.J., Steel, A., Bartz, K.K., Kingsolver, J.G., Scheuerell, M.D., Beckman, B.R., and Crozier, L.G. 2008. Big dams and salmon evolution: changes in thermal regimes and their potential evolutionary consequences. Evol. Appl. **1**(2): 286–299. doi:10.1111/j.1752-4571.2008.00032.x.

BC Hydro. 2018. BRGMON-1 Lower Bridge River Aquatic Monitoring – Monitoring Program Terms of Reference Revision 1. Bridge-Seton Water Use Plan. November 30, 2018.

Bourret, S.L., Caudill, C.C., and Keefer, M.L. 2016. Diversity of juvenile Chinook salmon life history pathways. Rev. Fish Biol. Fish. **26**(3): 375–403. Springer International Publishing. doi:10.1007/s11160-016-9432-3.

Bradford, M. 1994. Trends in the abundance of Chinook salmon (Oncorhynchus tshawytscha) of the Nechako River, British Columbia. Can. J. Fish. Aquat. Sci. **51**: 965–974.

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

Bradford, M.J., and G.H. Geen. 1987. Size and growth of juvenile chinook salmon back-calculated from otolith growth increments. Pages 453–461 in R. C. Summerfelt and G. E. Hall, editors. The age and growth of fish. Iowa State University Press, Ames.

Burnett, N., D. Ramos-Espinoza, and D. Braun. 2016. Lower Bridge River Adult Salmon and Steelhead Enumeration – Implementation Year 4 (2015). Ref. BRGMON-3. Report prepared for St’at’imc Eco-Resources by Instream Fisheries Research Inc.

Copeland, T., and Venditti, D.A. 2009. Contribution of three life history types to smolt production in a Chinook salmon (Oncorhynchus tshawytscha) population. Can. J. Fish. Aquat. Sci. **66**(10): 1658–1665. doi:10.1139/F09-110.

Copeland, T., Venditti, D.A., and Barnett, B.R. 2014. The importance of juvenile migration tactics to adult recruitment in stream-type Chinook salmon populations. Trans. Am. Fish. Soc. **143**(6): 1460–1475. doi:10.1080/00028487.2014.949011.

Cushing, D.H. 1990. Plankton production and year-class strength in fish populations: An update of the match/mismatch hypothesis. Adv. Mar. Biol. **26**: 249–293. doi:10.1016/S0065-2881(08)60202-3.

Delaney, P., Kahl, A., Olmstead, W., and Pearce, B. 1982. Studies of Chinook salmon in the Chilcotin watershed 1975-1980. Can. Manuscr. Rep. Fish. Aquatuc Sci. **1674**: 162.

Ellner, S. 1997. You bet your life: life-history strategies in fluctuating environments. *In* Case Studies in Mathematical Modeling — Ecology , Physiology , and Cell Biology. *Edited by* H. Othmer, F. Adler, M. Lewis, and J. Dallon. Prentice-Hall. p. 415.

Evans, M.L., Neff, B.D., and Heath, D.D. 2010. Quantitative genetic and translocation experiments reveal genotype-by-environment effects on juvenile life-history traits in two populations of Chinook salmon. J. Evol. Biol. **23**(4): 687–98. doi:10.1111/j.1420-9101.2010.01934.x.

Failing, L., R. Gregory, and P. Higgins. 2013. Science, uncertainty and values in ecological restoration: a case study in structured decision-making and adaptive management. *Restoration Ecology* 21:422-430.

Failing, L., G. Horn, and P. Higgins. 2004. Using expert judgment and stakeholder values to evaluate adaptive management options. *Ecology and Society* **9**:13.

Figge, F. 2004. Bio-folio: applying portfolio theory to biodiversity. Biodivers. Conserv. **13**(4): 827–849. doi:10.1023/B:BIOC.0000011729.93889.34.

Fuhrman, A.E., Larsen, D.A., Steel, E.A., Young, G., and Beckman, B.R. 2018. Chinook salmon emergence phenotypes: describing the relationships between temperature, emergence timing and condition factor in a reaction norm framework. Ecol. Freshw. Fish **27**(1): 350–362. doi:10.1111/eff.12351.

Gilbert, C.H. 1912. Age at maturity of the Pacific coast salmon of the genus Oncorhynchus. Bull. United States Bur. Fish. **XXXII**: 1–22.

Greenbank, J. 1995. Bridge River Downstream Trapping Report March-June 1994. Burnaby, BC.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). pp. 314–393. *In* C. Groot and L. Margolis (eds.). Pacific salmon life histories. University of British Columbia Press, Vancouver.

Healey, M.C. 1983. Coastwide distribution and ocean migration patterns of stream- and ocean-type Chinook salmon. Can. F. Nat. **97**: 427–433.

Hilborn, R., Quinn, T.P., Schindler, D.E., and Rogers, D.E. 2003. Biocomplexity and fisheries sustainability. Proc. Natl. Acad. Sci. U. S. A. **100**(11): 6564–6568. doi:10.1073/pnas.1037274100.

Hutchings, J.A. 2011. Old wine in new bottles: reaction norms in salmonid fishes. Heredity (Edinb). **106**(3): 421–37. Nature Publishing Group. doi:10.1038/hdy.2010.166.

Jussinoja, H. 1995. Winter movement patterns of salmonids in Bridge River, 1993. Burnaby, BC.

Levings, C.D., and Lauzier, R.B. 1991. Extensive use of the Fraser River basin as winter habitat by juvenile chinook salmon (Oncorhynchus tshawytscha). Can. J. Zool. **69**(7): 1759–1767. doi:10.1139/z91-245.

Levy, D.A., and Northcote, T.G. 1982. Juvenile salmon residency in a marsh area of the Fraser River Estuary. Can. J. Fish. Aquat. Sci. **39**(2): 270–276. doi:10.1139/f82-038.

Lewis, A.F.J., and Tesch, R.D. 1996. Bridge River Instream Flow Study. Richmond, BC.

McCubbing, D., C. Melville, S. Hall, and J. Korman. 2013. Lower Bridge River Adult Salmon and Steelhead Enumeration – Implementation Year 1 (2012). Ref. BRGMON-3. Report prepared for St'at'imc Eco-Resources by Instream Fisheries Research Inc.

Moore, J.W., Yeakel, J.D., Peard, D., Lough, J., and Beere, M. 2014. Life-history diversity and its importance to population stability and persistence of a migratory fish: steelhead in two large North American watersheds. J. Anim. Ecol. **83**(5): 1035–1046. doi:10.1111/1365-2656.12212.

Murray, C., and Rosenau, M. 1989. Rearing of juvenile Chinook salmon in nonnatal tributaries of the Lower Fraser River, British Columbia. Trans. Am. Fish. Soc. **118**: 284–289. doi:10.1577/1548-8659(1989)118.

NFCP. 2005. Nechako Fisheries Conservation Program technical data review 1988-2002.

Ramos-Espinoza, D., M. Chung, G. Poole, C. Melville, and C. White. 2018. Lower Bridge River Adult Salmon and Steelhead Enumeration – Implementation Year 6 (2017). Ref. BRGMON-3. Report prepared for St'at'imc Eco-Resources by Instream Fisheries Research Inc.

Rempel, L. 2004. Physical and Ecological Organization in a Large, Gravel-Bed River and Response to Disturbance. doi:10.1017/CBO9781107415324.004.

Rounds, S.A. 2010. Thermal effects of dams in the Willamette River Basin, Oregon. Sci. Investig. Report, U.S. Geol. Surv. **5153**: 74.

Russell, L.R., Conlin, K.R., Johansen, O.K., and Orr, U. 1983. Chinook salmon studies in the Nechako River: 1980, 1981, 1982. Can. Manuscr. Rep. Fish. Aquatuc Sci. (1728): 185.

Schindler, D.E., Hilborn, R., Chasco, B., Boatright, C.P., Quinn, T.P., Rogers, L.A., and Webster, M.S. 2010. Population diversity and the portfolio effect in an exploited species. Nature **465**(7298): 609–612. doi:10.1038/nature09060.

Schroeder, R., Whitman, L., Cannon, B., and Olmstead, P. 2015. Juvenile life-history diversity and population stability of spring Chinook salmon in the Willamette River Basin, Oregon. Can. J. Fish. Aquat. Sci.

Scrivener, C., Brown, T.C., and Andersen, B.C. 1994. Juvenile Chinook salmon utlilzation of Hawks Creek, a small and nonnatal tributary of the Upper Fraser River. Can. J. Fish. Aquat. Sci. **51**: 1139–1146.

Shaw, W. 1994. Biological Sampling Manual For Salmonids – A Standardized Approach For The Pacific Region. Can. Tech. Rep. Fish. Aquat. Sci. 1998: xiii + 167 p.

Shrimpton, J.M., Warren, K.D., Todd, N.L., Mcrae, C.J., Glova, G.J., Telmer, K.H., and Clarke, A.D. 2014. Freshwater movement patterns by juvenile Pacific salmon Oncorhynchus spp. before they migrate to the ocean: Oh the places you'll go! J. Fish Biol. **85**(4): 987–1004. doi:10.1111/jfb.12468.

Skoglund, H., Einum, S., Forseth, T., and Barlaup, B.T. 2011. Phenotypic plasticity in physiological status at emergence from nests as a response to temperature in Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. **68**(8): 1470–1479. doi:10.1139/f2011-056.

Sneep, J., C. Perrin, S. Bennett, J. Harding, and J. Korman. 2019. BRGMON-1 Lower Bridge River Aquatic Monitoring, Year 7 (2018) Results. Report prepared for St'at'imc Eco-Resources and BC Hydro. July 2019.

Sneep, J., J. Korman, C. Perrin, S. Bennett, and J. Harding. 2018. BRGMON-1 Lower Bridge River Aquatic Monitoring, Year 6 (2017) Results. Report prepared for St'at'imc Eco-Resources and BC Hydro. November 2018.

Steel, E.A., Tillotson, A., Larsen, D.A., Fullerton, A.H., Denton, K.P., and Beckman, B.R. 2012. Beyond the mean: the role of variability in predicting ecological effects of stream temperature on salmon. Ecosphere **3**(11): 1–11. doi:10.1890/es12-00255.1.

Swales, S., and C.D. Levings. 1989. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. *Can. J. Fish. Aquat. Sci.* 46: 232–242.

Taylor, E.B. 1990. Environmental correlates of life-history variation in juvenile chinook salmon, Oncorhynchus tshawytscha (Walbaum). J. Fish Biol. **37**(1): 1–17. doi:10.1111/j.1095-8649.1990.tb05922.x.

Taylor, G., and Bradford, M. 1996. Juvenile Chinook Sampling Data, Slim Creek and Bowron River, British Columbia, 1995. *In* Canadian Data Report of Fisheries and Aquatic Sciences. doi:10.1017/CBO9781107415324.004.

Taylor, G.C., Allan, J.A., and Bradford, M.J. 1994. Juvenile Chinook sampling data, Slim Creek, British Columbia, 1993. Can. Data Rep. Fish. Aquat. Sci. **942**: 29.

Taylor, G.C., Allan, J.A., and Bradford, M.J. 1995. Juvenile Chinook salmon data, Chilcotin River system, British Columbia, 1994. Can. Data Rep. Fish. Aquat. Sci. **952**: 34.

Tillotson, A.E. 2015. Temperature-induced plasticity of emergence phenotypes in Chinook salmon. University of Washington. doi:10.1017/CBO9781107415324.004.

Watters, J. V., Lema, S.C., and Nevitt, G.A. 2003. Phenotype management: A new approach to habitat restoration. Biol. Conserv. **112**(3): 435–445. doi:10.1016/S0006-3207(02)00343-9.

Webb, B.W., and Walling, D.E. 1993. Temporal variability in the impact of river regulation on thermal regime and some biological implications. Freshw. Biol. **29**: 167–182. doi:10.1111/j.1365-2427.1993.tb00752.x.

White, C., D. Ramos-Espinoza, M. Chung, G. Poole, K. Cooke, and C. Melville. 2019. Lower Bridge River Adult Salmon and Steelhead Enumeration – Implementation Year 7 (2018). Ref. BRGMON-3. Report prepared for St’at’imc Eco-Resources by Instream Fisheries Research Inc.

Wilbur, H.M., and Rudolf, V.H.W. 2006. Life-history evolution in uncertain environments: Bet hedging in time. Am. Nat. **168**(3): 398–411. doi:10.1086/506258.