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MEMORANDUM

TO: **Nechako Water Engagement Initiative Technical Working Group**
FROM: **Rachel Chudnow, Ph.D., João Braga, Ph.D., and Adam Lewis, M.Sc., R.P.Bio., Ecofish Research Ltd.**
DATE: **December 16, 2022**
FILE: **1316-09**

RE: **Issue #50 – Nechako River Salmon – Supplemental Nechako Chinook Salmon Escapement Analysis**

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1. INTRODUCTION

During Main Table and Technical Working Group meetings of the Nechako Water Engagement initiative (WEI), concerns were raised about potential effects of Rio Tinto (Alcan) operations on fish populations in the Nechako watershed. One priority is to better understand trends in Nechako River Chinook Salmon abundance (estimated by escapements). The Technical Working Group (TWG) asked Ecofish Research Ltd. (Ecofish) to review literature and conduct a preliminary analysis of Nechako Chinook Salmon escapement trends and develop recommendations for WEI consideration. This memo provides an updated analysis of Chinook Salmon escapement to the Nechako River to include the most recent escapement data and comparison to trends for two other populations within the same CU.

2. BACKGROUND

2.1. Geographic Scope

A hydrological overview of the Nechako watershed is provided by Beel *et al.* (2022), summarized here. The Nechako Reservoir is located approximately 200 km west of Prince George, British Columbia and was created to provide water for Rio Tinto Alcan's Kemano Hydroelectric Project, which was constructed in the 1950s to provide energy to operate an aluminium smelter in Kitimat, BC. The reservoir was formed by the construction of the Kenney Dam on the Nechako River (at the east end of the reservoir), which inundated a chain of six major lake and river systems (Ootsa, Whitesail, Knewstubb, Tetachuck, Natalkuz, and Tahtsa, ~420 km total length).

The Nechako Reservoir is ~910 km^2 with a normal annual drawdown of ~3 m (10 ft); low water is in late spring, and high water occurs in late summer. All flow from Nechako Reservoir to the Nechako River is currently via Skins Lake Spillway, which directs flow into the Cheslatta watershed, from where water flows into the Nechako River, downstream of Cheslatta Falls, located 9 km downstream of Kenney Dam (Map 1). The Nechako Reservoir provides the majority of flow in the upper Nechako River (there is minimal local inflow); here, flow is reduced to ~30% of pre-dam conditions and mean flow ranges from ~40 to 240 m^3/s (Figure 1). The Nautley River (~95 km downstream of the dam) and local inflows together make moderate contributions and mean flow in the Nechako River at Vanderhoof (~150 km downstream of the dam) ranges from ~65 m^3/s to 270 m^3/s. The Stuart River contributes significant inflow and by Isle Pierre (~215 km downstream of the dam), mean flows range from ~120 m^3/s to 560 m^3/s. The Nechako River flows into the Fraser River at Prince George ~275 km downstream of the dam. The Nechako River has a hydrograph dominated by snowmelt with a summer freshet.

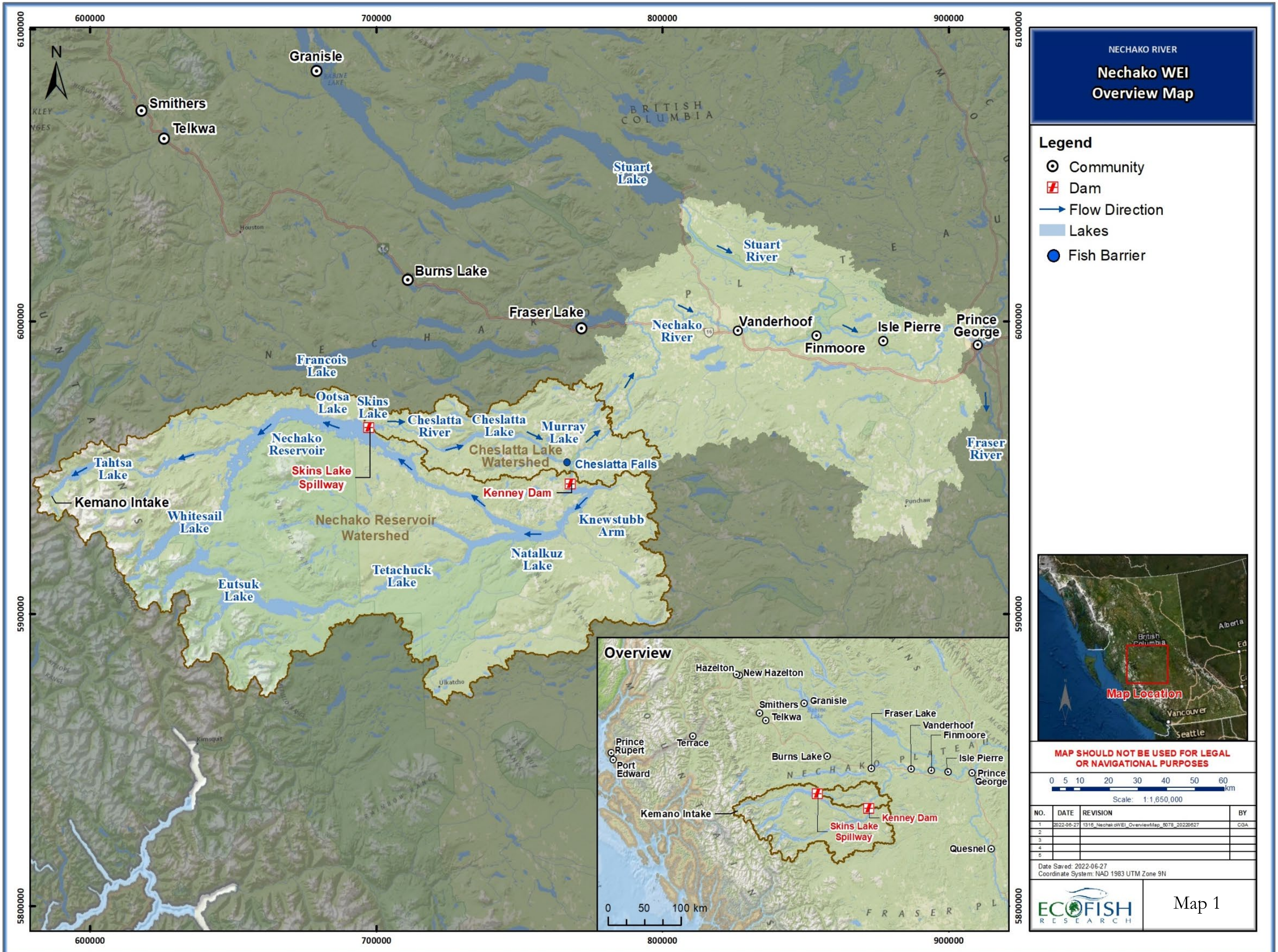

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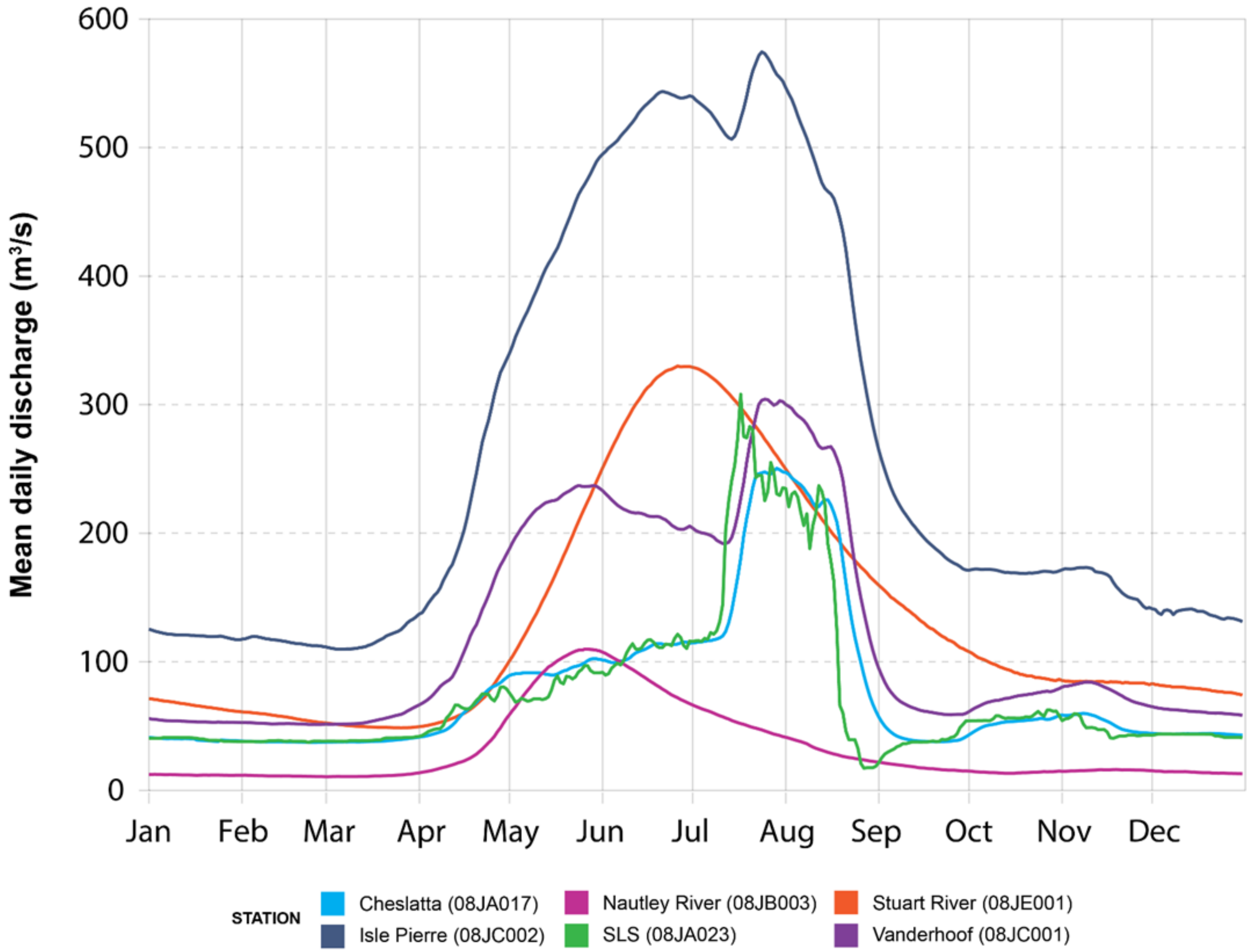
Figure 1. Mean daily discharge during 1990 - 2020 at selected Nechako River monitoring stations.



2.2. Chinook Salmon Life History

Chinook Salmon life history is detailed in (Chudnow *et al.* 2022), summarized here. Chinook Salmon, also commonly referred to as tyee, quinnat, king, or spring salmon, are one of North America's seven native anadromous and semelparous Pacific salmon species (*Oncorhynchus* spp.; Healey 1991). The species demonstrates the general anadromous salmonid life history composed of six distinct life stages, a subset of which occur exclusively in freshwater or the marine environment (i.e., life stages include egg, alevin, fry, smolt, adult, spawner; McPhail 2007). Chinook are unique among Pacific Salmon by demonstrating significant life history strategy diversity across all life stages, driven by both environmental conditions and genetics (Healey 1991; Quinn 2005; Brown *et al.* 2019; COSEWIC 2019). This diversity has resulted in substantial variation between different populations, including those that use the same habitats. Notable variation surrounds the timing, duration, and habitat used during freshwater, estuarine, and ocean residency, the age at which individuals reach maturity, and spawning migration timing (Healey 1991; Brown *et al.* 2019).

2.3. Population Structure / Conservation Status

Chinook Salmon populations in southern British Columbia are divided into 38 Conservation Units (CUs; Brown *et al.* 2019). Chinook present within the Nechako River belong to either the Nechako population, which spawns in the Nechako River mainstem primarily upstream of Vanderhoof or the Stuart population, which use the Nechako River as a migration corridor to spawning habitat in the Stuart River (Levy and Nicklin 2018). Both populations are designated within the middle Fraser Summer 5_2 Conservation and Designatiable Units (CK-11/DU-10; COSEWIC 2019). Other spawning locations in this CU include the Bridge, lower Cariboo, Chilko, Endako, Kuzkwa, Quesnel, Seton, and Stellako rivers and Kazchek Creek (DFO 2020a). All populations within the aggregate are dominated by 5-year-old spawners which have spent two full years in freshwater before migrating to the ocean and were assessed by COSEWIC (2019) as "Threatened".

2.4. Current Level of Knowledge

Abundance data are available for a subset of British Columbian Chinook Salmon populations beginning in the 1950s (DFO 2021). To our knowledge, Fisheries and Oceans Canada (DFO) has only verified data back to 1995 (Riddell *et al.* 2013). Therefore, data collected prior to this should be interpreted with caution because sampling methodologies have varied substantially over time, and most data are based on visual surveys with unknown precision (Riddell *et al.* 2013). Interpretation of escapement data is further complicated because estimates do not account for interannual fluctuations in mortality (i.e., natural and/or fishing mortality) which can confound interpretation of population abundance and productivity (Levy 2020). In addition, data from the inception of monitoring to present does not accurately quantify the influence of hatcheries or other enhancement methods (Riddell *et al.* 2013). As a result of these factors, our understanding of long-term trends in

Chinook Salmon productivity and abundance across the province continues to be limited by data quality and quantity (Riddell *et al.* 2013; DFO 2016; Brown *et al.* 2019).

Nechako River Chinook abundance data are available as escapement estimates since the mid 1920s and the population has been well studied since the 1970s (Jaremovic and Rowland 1988; NFCP 2005; NFCP Technical Committee 2016). DFO and collaborating consultants undertook numerous fisheries studies during the late 1970s and 1980s. Research related primarily to the Kemano hydroelectric project and Salmon Enhancement Program (SEP) and focused on providing biophysical descriptions of the watershed, assessing the distribution and habitat use of juvenile and adult Chinook Salmon, and assessing past Chinook Salmon escapements (Jaremovic and Rowland 1988; NFCP 2005). This work ultimately formed the basis of the 1987 Settlement Agreement between the Province of British Columbia, Government of Canada, and Rio Tinto (Alcan), and the establishment of the Nechako Fisheries Conservation Program (NFCP; (2005)).

The NFCP mandate is to conserve Chinook and Sockeye Salmon within the Nechako River through physical and biological monitoring, ensure the annual "Conservation Goal"[1] is met, and to provide flow and summer water temperature (STMP) oversight and management (NFCP 2005; NFCP Technical Committee 2016). NFCP projects targeting Chinook Salmon can be grouped into three main areas: (1) Identifying stock performance and life history trends; (2) Assessing the status of in-river habitat and use of artificial and natural juvenile habitats; and (3) Applied research to fill knowledge gaps regarding Chinook Salmon in-river ecology. The bulk of NFCP directed work occurred prior to the cancelation of the Kemano Completion Project (KCP) in 1995 (NFCP Technical Committee 2016; NFCP 2022). Following KCP cancelation, the NFCP has continued work in a reduced capacity to fulfill its mandate under the 1987 Settlement Agreement, with program and technical data review conclusions occurring in 2019, and an ongoing role in water allocation under the STMP (NFCP 2022).

Currently, Chinook Salmon monitoring is conducted by DFO stock management. Recent DFO and academic research external to Chinook Salmon escapement monitoring is limited primarily to the recovery potential assessment for Fraser River Chinook (DFO 2020b) and the recent work of Bradford and Taylor (2021) and Bradford *et al.* (2021). There have also been four previous studies that have compared run size trends for a subset of middle Fraser Summer 5_2 populations using both escapement data (Riddell *et al.* 2013) and run reconstructions (English *et al.* 2007; Levy and Nicklin 2018). Escapement comparisons included the Cariboo, Chilko, Quesnel, Nechako, and Stuart populations while later run reconstruction comparisons omitted the Stuart population due to questions surrounding the reliability of the dataset (Levy and Nicklin 2018; Levy 2020).

[1] *The "Conservation Goal" is defined as: … the conservation on a sustained basis of the target population of Nechako River Chinook salmon including both the spawning escapement and the harvest as referred to in paragraph 3.1 of the Summary Report….*(NFCP 2005).

3. METHODS

3.1. Escapement Data

Chinook Salmon escapement data was sourced from the DFO Salmon Escapement Database (NuSEDS), the central database containing individual spawner survey and abundance estimate data (DFO 2021). Escapement data for three middle Fraser Summer 5_2 Conservation Unit populations (CK-11) were selected for the analysis (Nechako, Cariboo, and Quesnel). The choice of populations for inclusion in this analysis (in addition to the Nechako) was based on geographic proximity to the Nechako River and data availability (i.e., continuous time-series over the last 30 to 40 years), which excluded 16 of 19 populations within the CU. The Stuart population was also excluded based on DFO statements that escapement data for this population are unreliable due to difficulty enumerating the population using visual counts as a result of physical habitat characteristics of the Stuart River (i.e., high turbidity; Levy and Nicklin 2018; Levy 2020). An initial data exploration detected that escapement data prior to 1981 was inadequate for application within the modeling approach chosen for this analysis due to: 1) lack of continuous escapement data for most populations and 2) variability in stock estimates reflected different sampling methods during collection of earlier data. Thus, we only considered Chinook escapement from 1981 to 2020 (hereafter assessment period) for populations within the Nechako, Cariboo, and Quesnel rivers.

3.2. Statistical Analysis

The escapement analysis aimed to compare Nechako Chinook escapement trends with control populations (i.e., Cariboo and Quesnel populations). To ensure observed inter-population variation in escapement estimates were due to population dynamics and not from differences in escapement sizes, we standardized each escapement to a mean of zero and a standard deviation of one. This standardization procedure shifted the interpretation of escapement trends from the number of spawning fish over time to deviations from each escapement mean during the assessment period. A preliminary analysis revealed that residual variance was not uniform; thus, escapement estimates were log transformed prior to standardization to ensure residual homogeneity.

We used generalized additive models (GAM) to estimate Chinook escapement trends in each river and test differences between modeled populations during the assessment period (i.e., Nechako, Cariboo, and Quesnel rivers). GAMs combine smoother functions of one or more predictors to estimate non-linear model relationships between predictors and response variables (Wood 2017). Here, we modeled the Chinook Salmon escapement trends using factor-smoother interactions parameterized as:

$$standardized\ stock_{ij} = a_0 + a_{1_j}(Population) + f_j(Brood\ Year) + f_j(Brood\ Year * Population) + \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma^2)$$

where a_0 is the model intercept, which refers to the mean escapement estimated for the Nechako population, a_{1_j} represents the overall stock mean differences between the Nechako population and the other *jth* populations (i.e., Cariboo or Quesnel), $f_j(Brood\,Year)$ is a factor-smooth function that estimates the temporal trend in Nechako population escapement, $f_j(Brood\,Year * Population)$ is an interaction factor-smooth function that estimates temporal trends in escapements as differences between the Nechako population and the *jth* populations, and ε_i represents normally distributed model residuals with mean of zero and a standard deviation of σ^2.

Since Chinook escapement was standardized before modeling, estimates of a_0 and a_{1_j} are predicted to be approximately zero, whereas $f_j(Brood\,Year)$ and $f_j(Brood\,Year * Population)$ factor-smooth functions explicitly estimate escapements temporal mean deviations and test for differences between Nechako and each control escapement. Cubic regression splines were used to estimate f_j. All statistical analyses were conducted in R statistical software, version 4.2.0 (R Core Team 2022) using the *mgcv* package, version 1.80-40 (Wood 2017).

4. RESULTS

4.1. Chinook Escapement

Average Nechako River Chinook escapement over the full assessment period (1981 to 2020) was approximately 2900 (± 1803 SD) spawning individuals. From 1981 to 1999, Nechako River escapements were stable, varying around approximately 2000 individuals (Figure 2; Table 1). This was followed by a two-fold increase in decadal average escapement between 2000 and 2009. During this decade, average escapement was approximately 4100 (± 1606 SD) with noticeably higher interannual variability relative to 1981 – 1999. After 2010, we observed a 18% decrease in average escapement size (approximately 3,350 individuals), compared to the previous decade, while variability increased. Escapement estimates reached both the time series maximum and minimum over a two-year period (Maximum in 2015, ~ 8,300 individuals; minimum in 2017, ~ 600 individuals). Increases in interannual escapement variability became more apparent when escapement was standardized (i.e., ± deviations from the mean increased over time; Figure 3).

Average Cariboo and Quesnel escapements during the assessed period were approximately 900 (± 680 SD) and 2800 spawning individuals (± 1910 SD), respectively. We observed systematically lower escapements in the Cariboo River when compared to the Quesnel and Nechako rivers. However, escapement estimates within the Cariboo and Quesnel rivers generally followed similar patterns to those observed for the Nechako River. Between 1980 and 1990, escapement for both populations increased and reached the maximum values observed in the time series (Quesnel River: ~ 9,000 individuals in 1986; Cariboo River: ~ 2,500 individuals in 1990; Table 1). After 1990, escapement decreased until the end of the time series for both populations. The lowest escapement estimates observed in the time series occurred for both the Quesnel and Cariboo populations in 2019 (171 and 29 individuals for Quesnel and Cariboo rivers, respectively).

Table 1. Decadal estimates of Chinook escapement as average numbers of spawning fish and decadal differences (in percentage) from the previous decade for Nechako, Cariboo, and Quesnel rivers.

Decade	Average Escapement Nechako River	% Change From Previous Decade	Average Escapement Cariboo River	% Change From Previous Decade	Average Escapement Quesnel River	% Change From Previous Decade
1980	2296.0	n/a	952.2	n/a	3303.4	n/a
1990	1883.0	-17.99%	1491.6	56.64%	3643.1	10.28%
2000	4108.5	118.19%	781.6	-47.60%	2872.9	-21.14%
2010	3356.1	-18.31%	332.1	-57.51%	1581.9	-44.94%
2020	1836.0	-45.29%	245.0	-26.23%	289.0	-81.73%

Figure 2. Log scale Chinook Salmon escapement estimates (numbers of fish) within Nechako River (red) and control populations, Cariboo (black), and Quesnel rivers (purple).

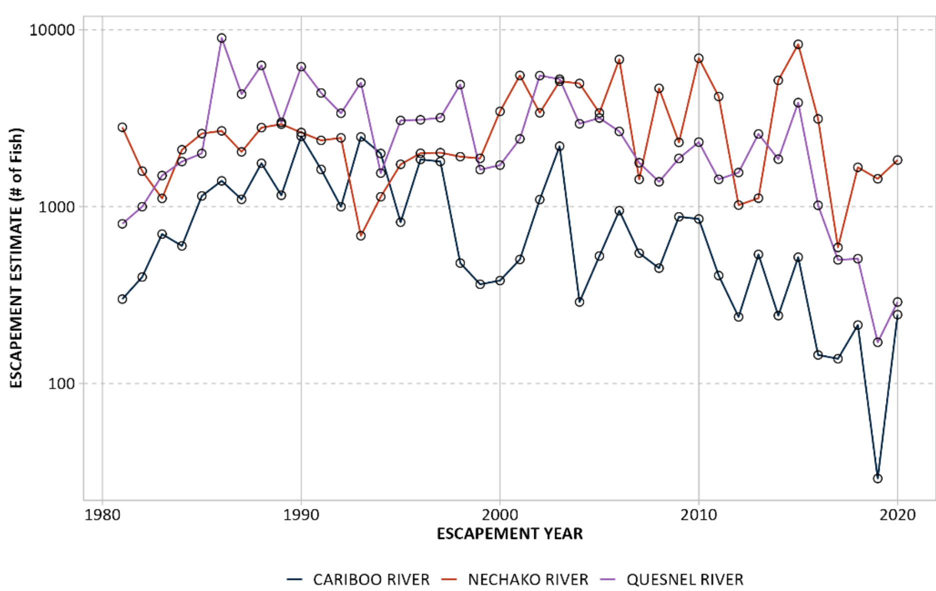
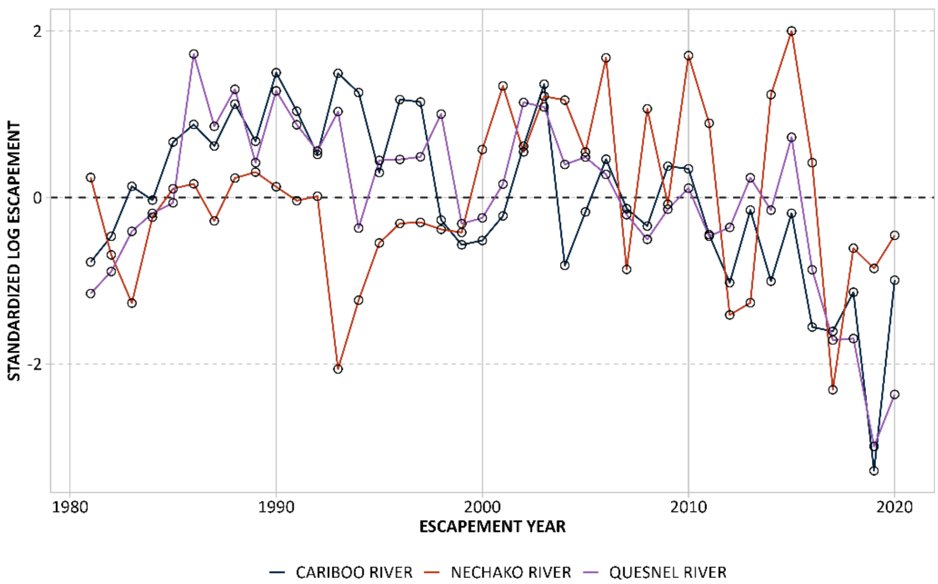


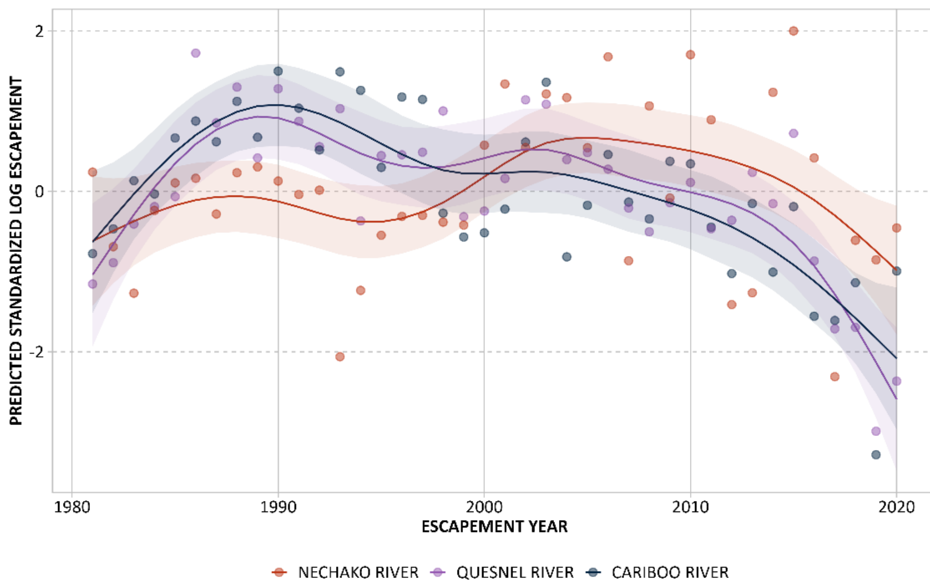
Figure 3. Standardized log scale Chinook Salmon escapement within Nechako River (red), Cariboo (black), and Quesnel rivers. (purple). Black dashed line depicts mean annual escapement (centered at zero). Each data point represents deviations from population's respective mean.



4.2. Population-specific Comparison of Escapements

Chinook escapement estimates in the three assessed rivers have decreased over the last 20 years (Figure 4). Despite all populations sharing this overall trend, our analysis demonstrates that Nechako River Chinook escapements vary from those observed within either the Cariboo (*p-value* = 0.001; Figure 5) or Quesnel (*p-value* = 0.0001; Figure 6) rivers. Escapement trends between 1980 and the mid-1990s for either comparison (i.e., Nechako vs. Cariboo or Nechako vs. Quesnel) demonstrate an inverse relationship between trends in Nechako River escapement and those within the reference river (i.e., Cariboo or Quesnel). During this period, both Cariboo and Quesnel escapement estimates were above average and increased until 1990. In contrast, Nechako escapement was generally stable below the average of the assessment period (Figure 4). After 1990, Cariboo and Quesnel escapement estimates decreased, and by the mid-2000s, trends in the three rivers were similar (i.e., escapements deviated from their respective means in a similar fashion).

Figure 4. Observed (points) and predicted standardized log escapement (lines) for Nechako (red), Cariboo (black), and Quesnel (purple) rivers. Predicted values result from a GAM and shaded areas depict the 95% confidence intervals around predicted standardized log escapement.



Since 2000, fitted differences in escapement trends indicate that Nechako escapement decreased at a slower rate than Cariboo (Figure 5). During this period, Cariboo escapement progressively declined below the mean of the assessment period and reached the lowest value observed over the 40-year time series. Note that from 2006 onwards, the lower 95% confidence interval for predicted difference was above zero and increased over time, suggesting strong evidence of a significant difference during that period.

Predicted differences in escapement trends suggest that after 2002, Nechako escapement decreased at a slower rate than Quesnel (Figure 6). Between 2002 and until mid-2010s, Nechako and Quesnel escapements decreased at similar rates, as indicated by constant fitted differences over time. After that period, fitted differences indicate that Nechako escapement decreased at a slower rate than Quesnel escapement, and by 2019, Quesnel reached the lowest value observed over the 40-year time series. Note that between 1996 to 2014, the 95% confidence interval of the predicted differences between Nechako and Quesnel trends overlapped zero, suggesting weak evidence for significant differences during that period.

Figure 5. GAM predicted standardized log escapement differences between Nechako and Cariboo rivers. Shaded areas depict 95% confidence intervals. Escapement years where predicted differences and respective confidence intervals cross zero are assumed to be not different across populations.

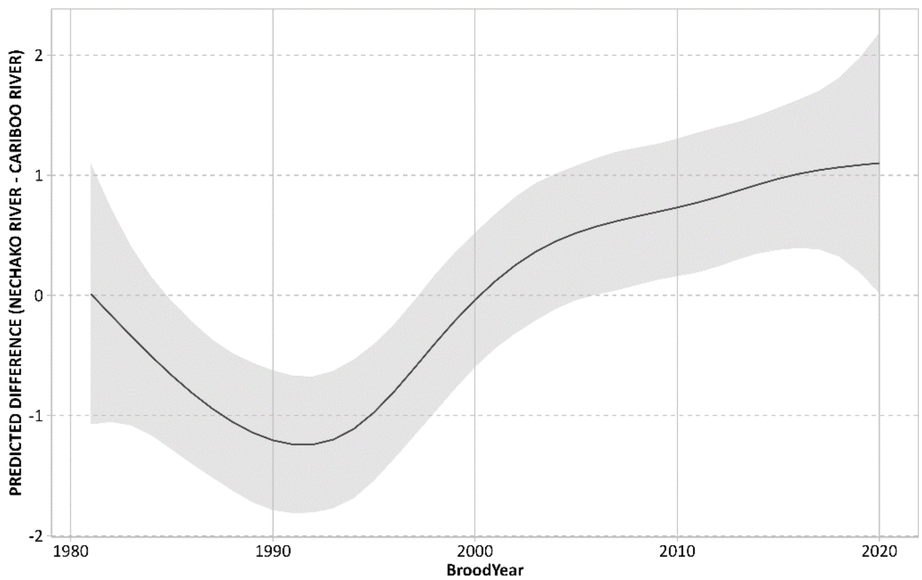
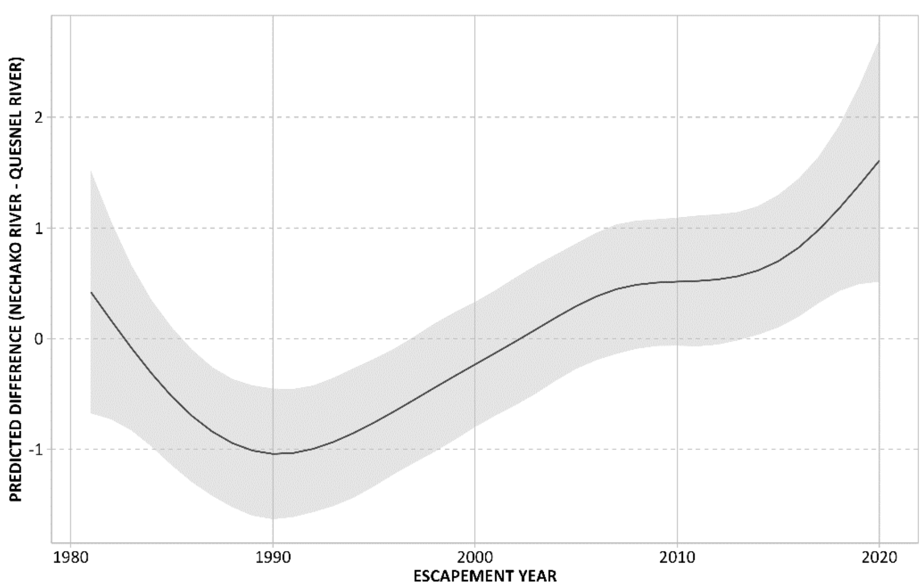


Figure 6. GAM predicted standardized log escapement differences between Nechako and Quesnel rivers. Shaded areas depict the 95% confidence intervals. Escapement years where predicted differences and respective confidence intervals cross zero were assumed to be not different across populations.



5. DISCUSSION

5.1. Escapement Trends

5.1.1. Nechako River Chinook Escapement

Available escapement estimates suggest Nechako Chinook abundance declined significantly (between 1952 to 1956) and subsequently dropped to zero (1958-1959) following the construction of Kenney Dam (Jaremovic and Rowland 1988). From 1960 to the late 1980s, escapement estimates gradually increased (Jaremovic and Rowland 1988). Escapements then declined before temporarily stabilizing in the mid to late 1990s, peaking in the early 2000s. Run reconstruction by Levy and Nicklin (2018) and assessment by COSEWIC (2019) both documented population declines from the mid-2000s to present. COSEWIC (2019) estimated the magnitude of the decline as 38% over three generations, with additional data from 2016-2018 showing continued declines (DFO 2020a). Levy and Nicklin (2018) note that declines in run reconstruction derived escapement estimates were not mirrored in annual in-river catches (Levy and Nicklin 2018). This suggests[2] that productivity declined for multiple stocks within the CU over this period (Levy and Nicklin 2018).

The trend described above mirrors observations of Chinook population abundance for stocks across southern British Columbia. Available data suggest many populations began to recover from reduced abundances following the 1985 Pacific Salmon Treaty and subsequent harvest reductions (Riddell *et al.* 2013). However, since these initial increases, abundance of most southern British Columbia Chinook populations have continued to decline (DFO 2016, 2020a; COSEWIC 2019). Riddell *et al.* (2013) reported spawner abundances across southern British Columbian populations with minimal enhancement activity have decreased substantially over three fish generations (i.e., over 50%).

Chinook returns across the middle Fraser Summer 5_2 Conservation Unit were further threatened by the 2018 Big Bar landslide, which may have negatively affected returns in the last three years of data, though the magnitude of effect can not yet be determined (DFO 2020a). DFO spawner enumeration in September 2019 estimated Nechako Chinook escapement below the 1987 Settlement Agreement Conservation Goal, but at a higher level than returns in five previous years of NFCP monitoring since 1989 (Levy 2020). It is possible that the variable age class of spawners will buffer the effects of reduced escapements from slide impacts on future returns (Healey 1991; Levy 2020). Despite both observed and estimated declines in Nechako Chinook abundance over the past two decades, the Conservation Goal has been met in all but seven years (as of 2020; not met in 1994, 1995, 2007, 2012, 2013, 2017, or 2019; Levy and Nicklin 2018).

[2] Under the assumption that marine catches were stable or decreasing over the timeseries length.

5.1.2. Population Trend Comparison

Run size trend comparison for CK-11 populations suggests an inverse correlation between Nechako Chinook abundance and that of other investigated populations during a portion of the timeseries. Average Nechako population escapements increased between the early 1990s and mid-2000s, while escapements for other assessed populations declined (Riddell *et al.* 2013; Levy and Nicklin 2018). Drivers of these escapement trend differences between the Nechako River and other CK-11 populations are unknown. Despite this dissimilarity, there have been instances where observed declines in Nechako Chinook abundance have been mirrored in other populations. For example, in 2017, escapements of four populations (Cariboo, Chilko, Nechako, and Quesnel) declined, suggesting decreased productivity resulted from a common cause (e.g., marine conditions; Levy and Nicklin 2018).

Our analysis is the first to note increased interannual variability in CK-11 escapement estimates from the 2000s to present. This trend is present in all populations analysed in this analysis (i.e., Nechako, Cariboo, and Quesnel), however, the magnitude of variation between populations differed. In the 1980s and 1990s, Nechako escapement variation appeared smaller than that observed for either the Cariboo or Quesnel population. In contrast, from 2000 to the end of the assessment period, variation was noticeably higher for the Nechako population.

There are multiple natural and anthropogenic factors that contribute to annual escapement which may contribute to observed variation. For example, changes in fishing mortality, population sampling, or escapement estimation methodology over the time series may be factors contributing to interannual escapement variability. Substantial changes to Chinook Salmon fisheries management over the past 20+ years may further account for some of the observed variability (e.g., introduction of rolling harvest closures). However, if fisheries management actions were the sole driver, we would expect a similar magnitude of variation across CK-11 populations, which is not apparent from our analysis. Further causes of increased variation either across populations or for the Nechako River population specifically are not currently clear. The presence of increased variation across populations (i.e., over geographic areas) suggests they are driven by environmental drivers that are shared across the regions (i.e., climatic or oceanographic conditions; NFCP 2005; Lindley *et al.* 2009). However, the exact mechanism is not known and will be difficult to determine without further information regarding the impacts of marine fisheries and trends in juvenile marine survival, which do not currently exist (i.e., lack of coded wire tag data; DFO 2020b).

Despite these unknowns, given that past research has demonstrated Nechako Chinook escapement estimates to be a reliable proxy for abundance (Levy and Nicklin 2018), observed escapement declines and increased interannual escapement variability since the early 2000s are potential cause for concern. When a population is reduced to critically low abundance, it increases its extinction risk. This can occur as the result of decreased fitness (i.e., reduced genetic variation and decreased ability to survive naturally occurring environmental variation or human activities; Schindler *et al.* 2010) or increased risk associated with human exploitation (i.e., with diminishing numbers of individuals exploitation rate can exceed the rate of maximum population increase; Paulik *et al.* 1967; Ricker 1973; Hilborn 1985). Further, increased variation in abundance, productivity, or other parameters characterizing population dynamics have been associated with population collapse in multiple species, including some salmonids (Ishida *et al.* 2002; Lindley *et al.* 2009; Krkošek and Drake 2014; Atlas *et al.* 2022). The significant life-history variation both within, and between Chinook Salmon populations as well as the relatively high escapements observed since 2000 serve as buffers against extrinsic factors that can impact population productivity and survival (Sturrock *et al.* 2020). High life-history plasticity in factors such as out-migration timing and/or age-at-maturity also reduce the probability that an entire cohort or population will encounter unfavorable conditions (Healey 1991; Schindler *et al.* 2010; Yeakel *et al.* 2018).

5.2. Uncertainties

Lack of long duration, continuous escapement time series (i.e., population specific data available to directly compare with the Nechako population) limited the generalization of our results. A preliminary analysis showed that most Chinook populations within CK-11 had substantial data gaps, rendering direct escapement comparisons unviable (i.e., years of missing escapement data). To bypass this limitation, we only considered escapement timeseries for Nechako, Cariboo, and Quesnel populations for a period extending from 1981 to 2020, inclusive. Consequently, observed inter-annual variability in Nechako population escapement lacks broader regional context. Such context would be valuable to increase our confidence about how the Nechako population may differ from other similar populations, or in determining the scale at which external drivers may be impacting multiple populations.

Sampling methodology and escapement estimation techniques varied during the assessment period. Prior to 1988 spawner counts were obtained by DFO Fishery Officers through visual counts (i.e., live spawner counts, redd counts, and carcass recovery; Jaremovic and Rowland 1988). From 1988 to 2015, spawner enumeration was conducted by the NFCP using area-under-the-curve and maximum likelihood estimation reliant on visual counts and female redd residence time estimates (NFCP 2005; Levy and Nicklin 2018). Since 2015, the DFO Stock Assessment Division has conducted escapement surveys using visual counts and peak count expansion methods (Levy and Nicklin 2018). Our current assessment did not test or account for the effect of different sampling and estimation methods on Chinook escapement temporal trends. A more thorough assessment would be required to assess any underlying systematic bias associated with different protocols over time.

We assumed that data quality and survey effort were constant throughout the assessment period. The former assumption could not be verified; however, the NuSED database classifies each escapement estimate as "Preliminary", "Near Final" and "Final" (DFO 2021). “Preliminary” estimates refer to escapement estimates where data sources may be incomplete, or their accuracy was not yet verified and are likely to change. In contrast, "Near Final" estimates are based on data verified for completeness and accuracy and is less likely to change over the lifetime of the database. Although "Preliminary" estimates represented only 5% of the total data, "Near Final" represented approximately 30% and occurred before 2000. Including "Preliminary" and "Near Final" estimates in our model may have introduced some uncertainty into our results prior to 2000; however, we are confident that removing these data from our analysis would have inflated uncertainty in escapement trends further. We also assumed that survey effort and escapement estimate quality was similar across populations. This assumption was necessary for the application of the GAM model in this preliminary analysis. However, it is likely that sampling methodology and data quality varied between populations, given that the more intensive and higher quality AUC method was used on the Nechako population.

5.3. Potential Next Steps

Here we presented the results of a preliminary analysis of Chinook Salmon abundance trends using escapement data from the Nechako River and two other CU11 stocks. There are several ways that this analysis could be modified or further expanded to potentially address future specific questions raised within the WEI process. However, all analytical approaches would likely be impacted by data quantity and quality limitations, similar to those that occurred in this assessment. It is important to note that the magnitude of each limitation's impacts on model results and thus the utility of each alternative analytical approach in answering specific questions of importance within the WEI process could negate the value of undertaking such analyses. Therefore, any future work would require thorough assessment prior to analysis. Regardless of approach, the limited overlap in time series will remain.

It may be possible to standardize escapement data to reduce bias and increase data precision (i.e., remove the effects of different survey methods on escapement estimates) as suggested by Hill and Irvine (2001). However, such an approach would add significant model complexity, and may not be possible for all stocks. The analysis could also be expanded to include additional populations within the same CU or other CUs. It is expected that factors acting at a regional scale would affect populations within the CU or wider geographic region in a similar way (e.g., factors within migration corridors or the ocean). Expanding the escapement comparison to include data from other populations would allow us to investigate the spatial scale over which observed population declines are occurring. It would also potentially allow us to determine what environmental factors are responsible for the relative trend in Nechako escapements. This would allow us to infer the effect of local environmental factors on Nechako Chinook relative escapement trends. To provide adequate data for future analysis, other Chinook populations in Fraser CUs would need to be included. However, the shorter time series overlaps with other populations may limit the effectiveness of this additional analysis.

It may also prove valuable to explore Nechako Chinook abundance and productivity trends using an alternative proxy such as reconstructed run size or an analysis of interannual variation in recruits per spawner. Escapement estimates do not account for fluctuations as the result of either natural mortality or fishing mortality, which can confound the interpretation of population abundance and/or productivity using this type of data (Hilborn and Walters 1992; Levy 2020). An approach using an alternative proxy for population abundance could remove fishery dependent variables, allowing us to estimate shifts in population abundance and productivity through time in a more robust manner. Use of a meta-analysis or hierarchical meta-analysis would provide a robust approach for future analyses by providing a mechanism to account for uncertainty and leverage data from populations with longer time-series or higher quality data (Myers and Mertz 1998; Myers 2002; Prévost *et al.* 2003; Punt and Dorn 2014). However, even with such an approach it is important to note that key uncertainties would remain (e.g., spatial or temporal variation in escapement estimate accuracy).

6. CLOSURE

Ecofish was asked to support the WEI by conducting a preliminary analysis of Nechako River Chinook escapement trends in comparison to other populations within the same Conservation Unit. The following key points summarize our current understanding of Nechako Chinook Salmon escapement trends:

- Multiple CK-11 Chinook populations have experienced substantial declines since the mid-2000s.
- Nechako River Chinook Salmon escapements show an inverse trend to that observed for other populations within the CU for which data are available.
- Since the early 2000's, Nechako escapements have been higher than average compared to Quesnel or Cariboo river escapements, the two CU-11 stocks whose escapement time series most overlap with the Nechako.
- Escapement estimates for multiple CK-11 Chinook populations show increased variability since the mid-2000s. The magnitude of this variability is higher for the Nechako population than in the Quesnel or Cariboo rivers.
- Our confidence in the relative Nechako Chinook escapement trend may be increased by comparison to additional Fraser River Chinook populations (i.e., in addition to Quesnel and Cariboo). However, the shorter duration of timeseries overlap between these populations and the Nechako River may limit the effectiveness of additional analysis.

Yours truly,

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