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Science Response 2023/001

PROPOSED CHANGES TO THE CONSERVATION UNIT FOR NANAIMO RIVER WATERSHED SPRING CHINOOK

Context

Several years ago the Committee on the Status of Wildlife in Canada (COSEWIC) served notice to Fisheries and Oceans Canada (DFO) that they wanted to review the status of Chinook Salmon (*Oncorhynchus tshawytscha*) in southern British Columbia (BC). Subsequently, DFO initiated a committee whose task was to prepare the information required and to review the Conservation Units (CU) which are used to subdivide the species on the basis of genetics and life history. This information was presented as Canadian Science Advisory Secretariat (CSAS) Science Response and Research Documents (DFO 2013, Brown et al. 2019, Brown et al. in prep.[1]).

In their assessment of Chinook (CK) stocks with low or no artificial releases in the last 12 years, COSEWIC assessed the East Vancouver Island Stream, Spring Chinook Designated Unit (DU 19) as ENDANGERED (COSEWIC 2018). This DU is comprised of the Conservation Unit CK-23 East Vancouver Island-Nanaimo_SP. The assessment triggered a response from DFO to prepare a Recovery Potential Assessment (RPA) report to inform a listing decision for the population under the *Species at Risk Act* (SARA).

During the process of assembling the information and data for the RPA, similarities were noted between the CK-23 East Vancouver Island-Nanaimo_SP CU and the CK-83 East Vancouver Island-Georgia Strait_SU_0.3 CU. The latter CU was designated by COSEWIC as East Vancouver Island Summer (DU 20), and assessed as ENDANGERED (COSEWIC 2020), also triggering the need for a Recovery Potential Assessment.

The objective of this Science Response is to examine the available biological characteristics of the early Chinook populations in the Nanaimo River in support of a review on the associated Conservation Units that will inform DFO Science and the Species at Risk Program. The alignment of Chinook populations within these CUs will need to be clarified prior to the completion of an RPA report.

The CSAS Research Document Wade et al. (2019) provides a framework for reviewing and approving changes to Wild Salmon Policy (WSP) CUs. Extant CUs can be changed to:

- Extirpated: There are no known sites with fish spawning successfully in the wild and there are no known hatchery sites.
- Deprecated: An extant CU was merged with another CU or CUs. The CU should no longer be used. A deprecated CU is neither deleted nor extirpated because at least one of its

[1] Brown, G.S., Baillie, S.J., Bailey, R.E., Candy, J.R., Holt, C.A., Parken, C.K., Pestal, G.P., Thiess, M.E., and Willis, D.M. Pre-COSEWIC review of southern British Columbia Chinook Salmon (*Oncorhynchus tshawytscha*) conservation units, Part II: Data, analysis and synthesis. DFO Can. Sci. Advis. Sec. Res. Doc. In prep.

populations persists or is believed to, and has been assigned to another CU. This category is used to manage changes to CUs, and is not a CU.

- Deleted: The CU was deleted after confirmation that no persistent populations were ever present within recorded history within the area of the CU. This category is used to manage changes to CUs, and is not a CU.

This Science Response results from the Regional Science Response Process of November 9, 2021 on the Proposed Changes to the Conservation Unit for Nanaimo River Watershed Spring Chinook.

Background

The Nanaimo River is located on the east side of Vancouver Island, British Columbia, approximately 90 kilometers northwest from the City of Victoria, and immediately southeast from the City of Nanaimo. The anadromous length is 48 kms, and there are two adjacent lakes (First and Second Lake) starting at km 29. A high flow barrier exists at km 13 (White Rapids Falls). There are three dam structures within the watershed. In 1930 the South Fork Dam was constructed on the South Nanaimo River to store water for domestic requirements. In 1952 a dam was constructed on Sadie Creek in the upper watershed to enlarge Fourth Lake, to store water for industrial requirements for the Harmac Pacific pulp mill. Finally, in 1974 a dam was constructed on Jump Creek, upstream from the South Fork Dam on the South Nanaimo Creek to store water for domestic requirements.

There are three known spawning areas that are used by Chinook Salmon. The lowest spawning area (~ km 2 to 7) is used by Chinook that enter the river from August to October and these fish are commonly referred to as a Fall population (2010-2019 average 4,000 escapement, n=10). The middle spawning area (~ km 26 to 29) is used by an early migrating population that is commonly referred to as a Summer population (2010-2019 average 760 escapement, n=9) and the upper spawning area (~ km 36 to 48) is used by an early migrating population (2012 estimate 5 Chinook) that is commonly referred to as a Spring population. This vernacular has been in general usage for many years.

Snuneymuxw First Nation

The Snuneymuxw First Nation (SFN) has a profound and essential relationship with the Nanaimo River. They consider this river as the artery of their society, the provider of food, the location of their Nation, their villages, and their community. The river and its components, including Chinook Salmon, are central to the culture of the Nation.

Chantelle Johnny (SFN Fisheries technician) spoke to the Nation’s Elders and to members who were knowledgeable on the Chinook Salmon of the river. Their knowledge and information has been summarized below.

> *There were three groups of Chinook Salmon that spawned in the Nanaimo River, a Spring group that entered the river as early as March with a peak of migration in April, a Summer group that peaked in June and a Fall group that peaked in September. The Spring and Summer runs overlapped in May.*
>
> *The Spring Chinook was the least abundant, usually numbering about 200-400, were small in size, had very red flesh and were very fatty. Although this group was not fished extensively as bivalve harvest was taking place at that time, some were captured for a First Salmon ceremony or if a family had food requirements. The Summer Chinook usually numbered 600-1500, were larger with some individuals weighing up to 40 pounds, and had very sweet flesh. The Fall Chinook numbered 2000-4000 spawners*

and the majority of fishing took place on this group because of the higher abundance. These fish had paler flesh and were not as sweet as the Summer Chinook.

Conditions in the river changed in the 1950s-1960s with Nation members seeing declining numbers of Chinook. They suggest that intense logging activity, log booming in the estuary, overfishing in the ocean and dam building were events that occurred at this time that contributed to the decline. In addition, Pink Salmon started spawning in the river in the 1950s. These were not present here historically.

The Elders have many thoughts about protecting and recovering the Chinook Salmon.

- *Cut back on herring fishery to allow them to replenish, so the species that depend on them for sustenance have something to eat*
- *Plant more trees to help to build more oxygen*
- *Pumping water during low flow periods which have increased in duration as temperatures rise*
- *Possibly guiding schools through seine netting (Note: the Elders are suggesting a project of moving the salmon by truck past the fishing areas in the river and the constrictions at the White Rapids Falls up to the holding areas in the Lakes)*
- *Use GPS for holding pools, so everyone has the same uniform area for dives (to estimate the abundance)*

Wild Salmon Policy Conservation Units

Holtby and Ciruna (2007) describe a process to delineate groups of a salmon species into Conservation Units (CU) such that the biological diversity of all wild Pacific Salmon would be safeguarded by protecting the CUs. This would preserve the local adaptations and genetic diversity within a species. They use the term “Local Population” in reference to the Conservation Unit, and “Subpopulation” for one or more groups that comprise a Local Population. The term “population” was used throughout the document to denote a group of salmon, whether at the species, CU or Subpopulation level. We will follow this practice in this document.

Holtby and Ciruna (2007) defined the EVI-Nanaimo Spring CU based on genetics and run timing (their Table 39). From page 59:

> *The genetic and morphometric distinctiveness of summer and spring runs in the Nanaimo River has been previously established (Carl and Healey 1984). Although the morphometric component of that study has recently been questioned (Swain and Foote 1999), the genetic distinctiveness of the three timing groups has been confirmed (e.g. Figure 41) as have their consistent differences in both life history and spawning and rearing habitats (Carl and Healey 1984, Healey 1991).*

Holtby and Ciruna (2007) used microsatellite based genetics (Beacham et al. 2006) to establish groupings of populations based on the dendrogram from that research and concluded that this work agreed with Carl and Healey’s earlier work. Juvenile life history (stream-type vs. ocean-type) was considered as a partitioning category however, because so many Chinook populations within the scope of their work exhibited both types, this analysis was not used.

At the time that Holtby and Ciruna were preparing the data for their WSP Conservation Unit work, there were no enumeration records for the spawning location above Second Lake in the New Salmon Escapement Database (NuSEDs). In 2015, Watson reviewed all observational records at the Nanaimo River Hatchery and created Stream Estimate Narratives for the Chinook population spawning above Second Lake and submitted them to the NuSEDs database (Watson 2015).

Holtby and Ciruna (2007) defined the EVI-Nanaimo Summer CU based on genetics and run timing, noting that this was one of two summer populations within this Joint Adaptive Zone, with the Puntledge River Summer Chinook as the other population.

In the pre-COSEWIC review Brown et al. (2019) used numerous processes to examine and refine the WSP CU list and made several recommendations including combining the Puntledge Summer Chinook and the Nanaimo Summer Chinook populations into one CU. The EVI-Nanaimo Spring CU was confirmed and the review noted that this population has a stream-type life history. As part of their review, the Fixation Index (F_{ST}) was used to examine genetic relatedness between 30 CUs. The EVI-Nanaimo Spring CU was not included in this process. Brown et al. (2019) changed the name of this CU to CK-23 East Vancouver Island-Nanaimo_SP. The new name of the combined Summer population CU was CK-83 East Vancouver Island-Georgia Strait_SU_0.3.

COSEWIC used the CK-23 EVI-Nanaimo_SP CU as a basis of their Designatable Unit (DU) of East Vancouver Island, Stream, Spring. Some CUs were combined into a single DU, e.g. the East Vancouver Island Fall Ocean type CUs, however the EVI, Stream, Spring type CU was considered to be unique enough to be left as a stand-alone DU. COSEWIC assigned a D1 code to this DU, indicating this population has a *Genetic distinctiveness including inherited traits (including life-history or behaviour) and/or neutral genetic markers (including DNA microsatellites)*. COSEWIC assessed this DU as ENDANGERED, with the stated reason that *This spring run of chinook to the Nanaimo River has been at a very low abundance for a long time. Declines in marine and freshwater habitat quality are threats facing this population.* (COSEWIC 2018).

COSEWIC examined the CK-83 EVI-Georgia Strait_SU_0.3 CU and accepted this as a DU. This DU was assessed as ENDANGERED and assigned a C2a(ii) code (remaining number of spawners is less than the threshold, declines are expected to continue, and only one subpopulation exists within the DU), with the stated reason that *Recent indices of wild abundances for this wildlife species are fewer than 1000 spawners, according to a consensus of expert opinion. Exploitation rates are relatively high (about 40%), and marine survival estimates have been low for many years now. The most important threats specific to this DU are ecosystem modifications and drought. Indicators of the hatchery contribution to total mature individuals are relatively high but variable, and such hatchery-origin spawners may represent a continued threat to the wildlife species* (COSEWIC 2020).

Enhancement Activity

(Brian Banks, Nanaimo River Hatchery, pers. comm. 2019)

The earliest known enhancement activity in the Nanaimo River was in 1885 when 150,000 Chinook and Sockeye fry from Harrison River (Rapids) were released into the Nanaimo River, location unknown.[2]

The Nanaimo River Hatchery (NRH), a Community Economic Development Project (CEDP) is responsible for enhancement activities on Nanaimo River salmon populations. The hatchery was constructed in 1978 and began enhancement of Chinook Salmon that year. See Appendix 1 for annual brood collection and release data for all three spawning groups.

[2] 2001 Nanaimo River Hatchery Upper Chinook (Group A) report

From the beginning of enhancement activities the NRH designated the three spawning populations as “Group A” (Fall population, spawning area below the White Rapids Falls), “Group B” (early population, spawning below First Lake), and “Group C” (early population, spawning above Second Lake). This designation allowed for identification of brood and progeny so that Chinook from the three areas could be kept separate during gamete collection and fry release.

“Group A” population (Fall Chinook)

Enhancement activities on the Fall population started when the Big Qualicum DFO hatchery collected brood stock in 1973 and released the progeny back into the Nanaimo River. When the Nanaimo River Hatchery started operations in 1978 the Fall Chinook were included. The number of brood collected that year, as well as the number that the Big Qualicum collected in 1973, could not be located. A coded-wire tag release group were included most years until BY (brood year) 2004 when all production was thermally marked starting with the 2005 brood year. Progeny are released from the hatchery into the lower Nanaimo River. Enhancement of this population is ongoing.

“Group B” population (early Chinook, spawning below First Lake)

Enhancement activities started with BY1980. The number of brood collected that first year could not be located. The progeny were coded-wire tagged most years until BY2001. Thermal marks were applied starting with the 2005 brood year. Progeny are reared at the hatchery for 3-4 months until the end of April, then transferred to net pens in First Lake and held for another 2-3 weeks, then released from the pens into the lake. This procedure is known to have been in place since 2004 and may have been initiated at the start of enhancement activities on this population. Enhancement of this population is ongoing.

“Group C” population (early Chinook, spawning above Second Lake)

Very little enhancement activity has taken place on Chinook Salmon from this spawning location. A Captive Brood project was initiated in 1982 between the NRH and the Pacific Biological Station (PBS) which started with 2 females and 4 males. This project ran for one cycle and all second generation progeny were released by 1987.

1982 Brood: 2 adult females were collected from above Second Lake whose eggs were fertilized with stored milt from four males (two per female). Approximately 3,000 eggs were used from the first female, and 1,875 eggs from the second female. Of these, 1,500 and 1,475 were retained at the NRH and 1,500 and 400 were sent to PBS for rearing in saltwater pens for a captive brood project. On 7-April 1983, 2,657 age 0+ fry (1.16 gms) were released into Green Creek and Nanaimo River above Second Lake.[3]

In fall 1985, 71 precocious fish from the captive brood were transferred to NRH freshwater tanks. Of these, 70 were male and 1 was female (2,200 eggs, but see the comment at the end of the next paragraph). The progeny (932 fry) of this female were released to the Nanaimo River above Second Lake.

In fall 1986, the remnant group of captive brood were transferred to NRH for freshwater maturing and egg takes. 47 females were used, of which 4 were crossed with males from this same group, 15 females were crossed with 15 males that were collected from the Nanaimo River above Second Lake (brood year 1986), and 28 were crossed with males collected from the Nanaimo River below First Lake (brood year 1986). An unknown number of early run males were used but likely ~28 assuming a 1:1 match with the available females. A total of 68,518 eggs were collected (1,458 eggs/female). From this egg take, 2,975 fry were released into the

[3] From Nanaimo River Hatchery archive files

Nanaimo River above Second Lake in spring 1987. The poor egg to fry survival was attributed to temperature related stress on the adults or gametes prior to spawning. The females from this captive brood had water retention issues in their abdomen which resulted in water hardening of some of the eggs.

1984 Brood: 6 females and 5 males were collected from above Second Lake, with 20,308 eggs retained (3,385 eggs/female). 16,974 fry (average weight 5.12 gms) were released on 11-12 June 1985 into the Nanaimo River near the confluence with Green Creek.

1986 Brood: 15 males were collected from above Second Lake to cross with Captive Brood females from Brood 1982. See *1982 Brood* paragraph for details.

Description of the Population

The first description in the scientific literature of three spawning populations of Chinook in the Nanaimo River is from Carl and Healey (1984) who described three different juvenile life history types (immediate migrants, 60 day sub-yearling migrants and yearling migrants). They used electrophoresis (16 enzymes) and body morphology of juveniles to examine differences between the three juvenile groups and concluded that the three populations of Chinook that spawn in the three geographic areas corresponded with the three juvenile life histories. This conclusion is not supported by their data on adult ages where they found both 0.x (sub-yearling migrants) and 1.x (yearling migrants) aged adults in both samples from above Second Lake and below First Lake (Healey and Jordan 1982). See Table 1.

Table 1. Freshwater ages from adult Chinook, three spawning locations, Nanaimo River. Adapted from Healey and Jordan (1982), Table 17.

Year	Lower River		Below First Lake		Above Second Lake	
	0.x	1.x	0.x	1.x	0.x	1.x
1977	21	1	12	6	Not Sampled	
1978	91	1	34	1	Not Sampled	
1979	74	0	131	10	1	5
1980	110	0	211	5	20	13
Sum	296	2	388	32	21	18
%	99%	1%	92%	8%	54%	46%

From Carl and Healey (1982):

> *Fry from both middle and lower spawning regions drift down to the estuary to become subyearling estuarine smolts. Subyearling riverine smolts generally rear downstream from the middle spawning region although some occur in the lower reaches of the river. Yearling riverine smolts rear downstream from the upper spawning region. These fish spend the winter in First and Second lakes and possibly also in deep river pools. Thus, although there is some physical separation of adult spawning groups that produce the juveniles showing different migratory behavior, the separation is not complete.*

Moran et al. (2012) notes that Healey (1991) “synthesized juvenile and adult life histories to develop a new racial model: stream types were derived from a northern glacial refuge, and ocean types were from a southern refuge”. If Healey believed that the stream-type and ocean-type originated from two different lineages, he may have interpreted the data in support of that theory.

Although Carl and Healey (1984) use the term 'Spring' in reference to run timing, they did not differentiate the timing between the two upper populations, describing them both as entering freshwater (FW) between February and June. Holtby and Ciruna (2007) could be the first document to refer to three separate run timing populations in the Nanaimo River, citing Carl and Healey (1984), however this report did not identify three different migration periods.

The Carl and Healey (1984) descriptions can be summarized as:

- Spawning in Nanaimo River above Second Lake = Adults entering FW Feb-June = yearling smolt
- Spawning in Nanaimo River below First Lake = Adults entering FW Feb-June = sub-yearling smolt
- Spawning in lower Nanaimo River = Adults entering FW late September = immediate migrant smolt

Throughout the scientific literature and field research notes, there has never been a project that documented the actual timeframe of when the early timed Chinook populations enter freshwater. There is a wide variety of the number of runs reported (from two to four) and of descriptions of the timing of the early run which range from December through to July (see Table 2). To the best of our knowledge no run timing data were used to support delineation of early groups of migrating adult Chinook in the Nanaimo River.

Table 2. Examples of reported subpopulations from the Nanaimo River and their references.

Source	# of subpopulations	Run timing
Aro (1972)	2 components	Spring (April-June) Fall (Aug-Sept)
Carl and Healey (1984)	3 subpopulations	Spring (Feb-June) Spring (Feb-June) Fall (late Sept)
Brahniuk et al. (1993)[4]	3 types	Upper-river Spring (Dec-Jul) Upper-river Fall (Aug+) Lower-river Fall (Aug+)
Carter and Nagtegaal (1997)	4 life history patterns	Upper Spring (ocean type) Upper Spring (river type) Upper Fall (ocean type) Lower Fall (ocean type)
Holtby and Ciruna (2007)	3 Conservation Units	Spring Summer Fall
Butler et al. (2014)[5]	3 runs	Spring (early spring) Summer (late spring to summer) Fall (late Aug to Sept)

[4] Brahniuk, R., Hurst, B., and Tutty, B. 1993. Nanaimo River Salmon Management Contingency Plan: An Overview. Unpublished Fisheries and Oceans Canada discussion paper. 24 p.

[5] Butler, G., Chapman,P., Gullison, R.E., Kellow, M., Walker, S. and Wolf, J. (Editors). 2014. Nanaimo River Baseline Report: Social, environmental and economic values of the Nanaimo River and watershed. 2nd Edition. Unpublished report prepared for the Nanaimo & Area Land Trust. 312 p.

The following analysis is based on existing information that was assembled in preparation for a Recovery Potential Assessment.

Analysis

Previous analyses used some or all of the following criteria to suggest two distinct populations in the upper Nanaimo River. These criteria will be assessed based on existing information that was assembled in preparation for a Recovery Potential Assessment. In addition, new data on run timing has been included as well.

- Run timing during upstream migration
- Holding areas and spawning location
- Genetic distinctiveness (originally enzyme electrophoresis and later DNA based)
- Life history (also morphological differences)

Run Timing During Upstream Migration

Available data suggest that early timed Chinook migrate into the Nanaimo River from February to July. There are numerous anecdotal reports of Chinook present in the Nanaimo River during the winter months; for example, on 28-February-2020, a fresh Chinook was angled by a Steelhead fisher, photographed, and released (see Figure 1).

Figure 1. Chinook capture in Nanaimo River on 28-February-2020

In February 2021 a fixed point enumeration project was initiated in the lower Nanaimo River to monitor salmonids migrating into the system during the late winter, spring and summer months. The following is a summary of the results.

Figure 2 shows the weekly count of adult Chinook salmon migrating upstream past the monitoring site. Steelhead trout were also enumerated between the start of the project and the end of May and have not been included here.

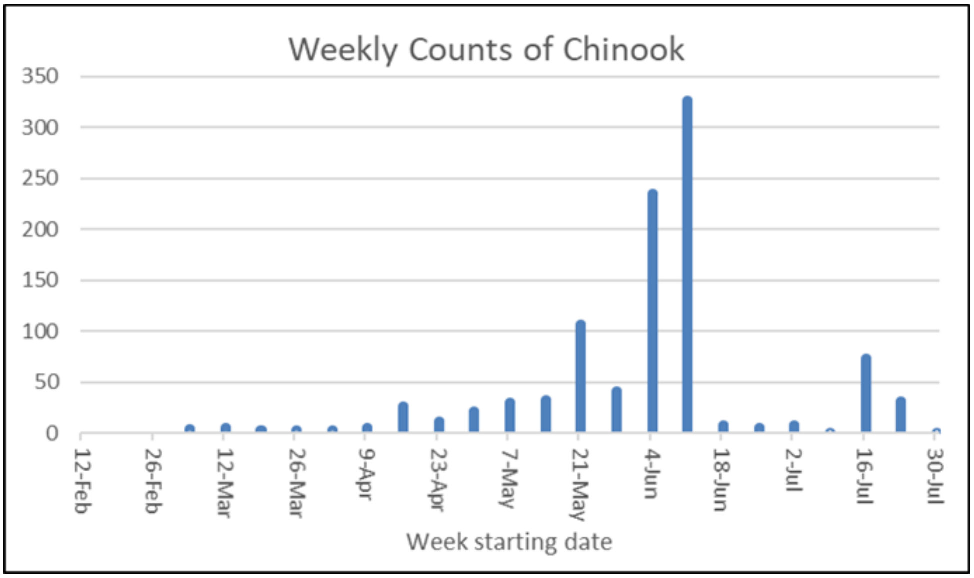

Figure 2. Weekly counts of Chinook Salmon, Nanaimo River, 2021

As can be seen, there is a peak in the early June period, with 52% of the Chinook recorded between 6-June and 13-June. It is assumed that 100% of the early migrants are in the river before August 1 as the monitoring project was terminated on August 3. The Fall Chinook population begin to enter the river in August (Carter et al. 2004).

The early run Chinook have reached the upper Nanaimo River holding areas by the end of July, with an apparent peak in migration in June. Based on the run-timing definition from Waples et al. (2004), we suggest the designation of Summer Run for the early migrant Chinook population.

Upriver Holding and Spawning Locations

River swim surveys have shown that after the early run of Chinook have entered the system, they can be found in three separate holding areas prior to spawning: the confluence pool with the South Nanaimo River, the First and Second Lakes, and the mainstem above Second Lake (Figure 3). All three of these areas have cold water habitats where adult Chinook are able to avoid hazardous warm water temperatures. Adult Chinook are able to move between all three holding areas, with no physical barriers in between however the water temperature may prevent them from moving during the July-August period. Spawning occurs above Second Lake and below First Lake starting in late September.

Some Chinook can be found in a pool below White Rapids Falls however this pool does not have a cold water refuge area, and the fish here are subject to non-sanctioned fishing efforts. It is unlikely that many fish survive from this area to contribute to the spawning population.

Figure 3. Early run Chinook spawning locations. The red line is Below First Lake, the blue lines are Above Second Lake.

Weekly abundance counts above Second Lake and below First Lake were estimated from direct observations of Chinook during swim surveys (counts by reach by date), from DFO swim enumerations, BC Conservation Foundation Steelhead swim enumerations and Nanaimo River Hatchery swim enumerations. Watson (2015) published a review of all available enumeration data and created Stream Estimate Narratives for the population spawning above Second Lake. Chinook Salmon that hold in the lakes are difficult to observe therefore abundance estimates cannot be made for this location.

Figure 4 below shows the assembled observation data of Chinook Salmon from 1979 to 2019 (183 surveys), plotted against the date of observation and averaged by week (data source: New Salmon Escapement Database, Stream Inspection Logs). The observations were grouped into the following geographic areas: *Above Second Lake* is the most upstream reach, *Below First Lake* includes the river from below the lakes downstream to the White Rapids Falls, and *Below White Rapids Falls* includes the river from the Falls downstream to the estuary. The *Above Second Lake* uses the estimated escapement of Chinook spawning above Second Lake, similarly the *Below First Lake* uses the estimated escapement of Chinook spawning below First Lake, and *Below White Rapids* uses the sum of both escapement estimates. The plot uses the average by week across all available years.

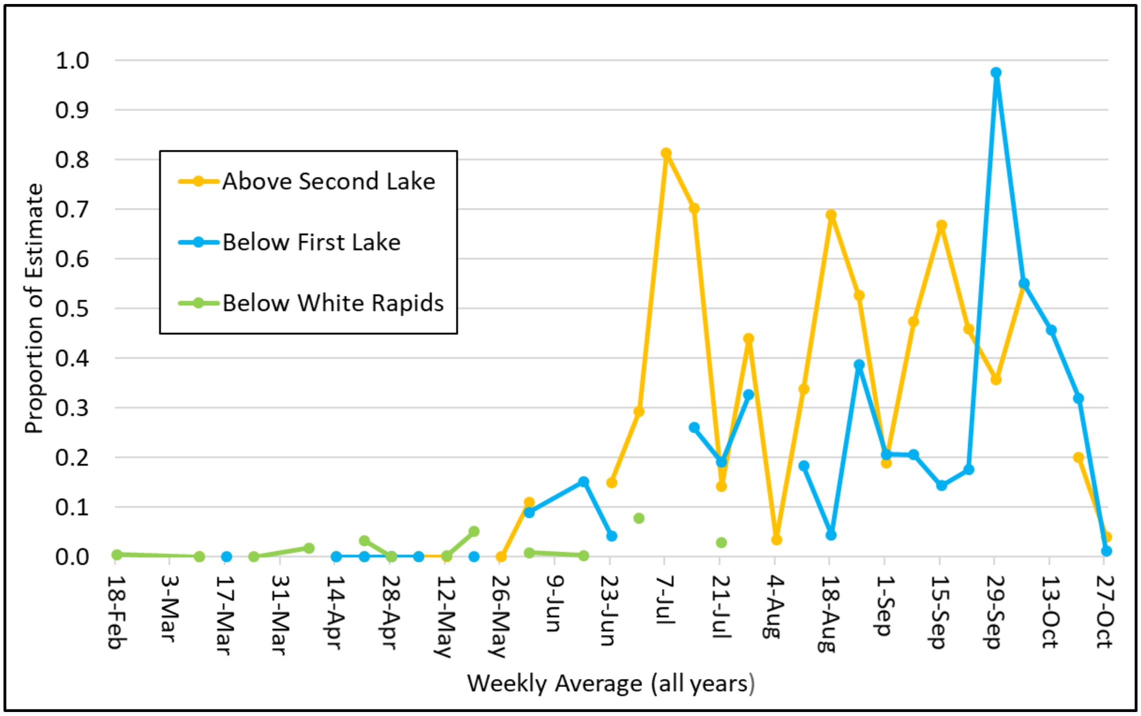

Figure 4. Weekly proportion of average annual estimate of early run Chinook Salmon, by location in the Nanaimo River, 1979-2019. Note that the y-axis scale is the observed raw count in each geographic segment expressed as a proportion of the estimated escapement of the population that are assumed to be present in that segment.

The green line represents early migration of Chinook to either Above Second Lake or Below First Lake. The majority of early timed Chinook appear to be in the upper river in July. The period after August 1 has not been included here as this is assumed to be the Fall population whose run timing is well documented from the DFO Productivity study (1995-2002 returns. See Carter et al. 2004 for example).

Swim survey observations below First Lake (blue line) show some fish holding in this area, with an increase in abundance at spawning time in late September – early October as fish holding in the lakes drop down to this area to spawn. This behavior is confirmed by Nanaimo River Hatchery staff during their brood stock capture and their direct observation of fish movement.

Swim survey observations above Second Lake (yellow line) vary between weeks but do not show a presence of Chinook prior to June or an increase in the late September – early October beginning of spawning timeframe, suggesting no late influx from fish holding in the lake(s). Physically, there is no barrier between the spawning area below First Lake, First Lake, Second Lake and the river above Second Lake.

The river swim data suggests that the Chinook that hold in the South Nanaimo confluence pool and the two lakes use the river below First Lake to spawn, and the Chinook that hold in the river above Second Lake use that area to spawn.

The Nanaimo River Hatchery release strategy for the population spawning below First Lake is to hold the progeny in net pens in the lake for several weeks prior to release into the lake. The net is opened and the Chinook fry can exit freely (B. Banks, pers. comm., 2020). Generally, releases from enhancement operations will home back to the release site if appropriate imprinting has taken place (Dittman et al. 2010). Moreover, at a finer scale, other processes such as competition, habitat selection and mate choice may take over as guiding forces

(Dittman and Quinn 1996). These behaviours suggests that the hatchery origin Chinook will return back to the lake to hold, and then continue to the spawning area below the lake along with the wild origin Chinook to spawn. The natural origin Chinook also show this pattern of behaviour.

Genetics

In 2004 and 2005, a rotary-screw trap was deployed in the Nanaimo River as it enters Second Lake to collect DNA samples from the migrating juveniles (age 0+ and 1+) from the *Above Second Lake* population. The DNA baseline data (Beacham et al. 2006) that was used in Holtby and Ciruna (2007) included these two samples, referenced as Nanaimo_Spring and Nanaimo_upper to represent the *Above Second Lake* population. These two samples are genetically closely related to the Nanaimo_summer and Puntledge_summer populations (Figure 5). The Nanaimo_Fall and Nanaimo_Summer samples likely come from adult salmon during broodstock collection.

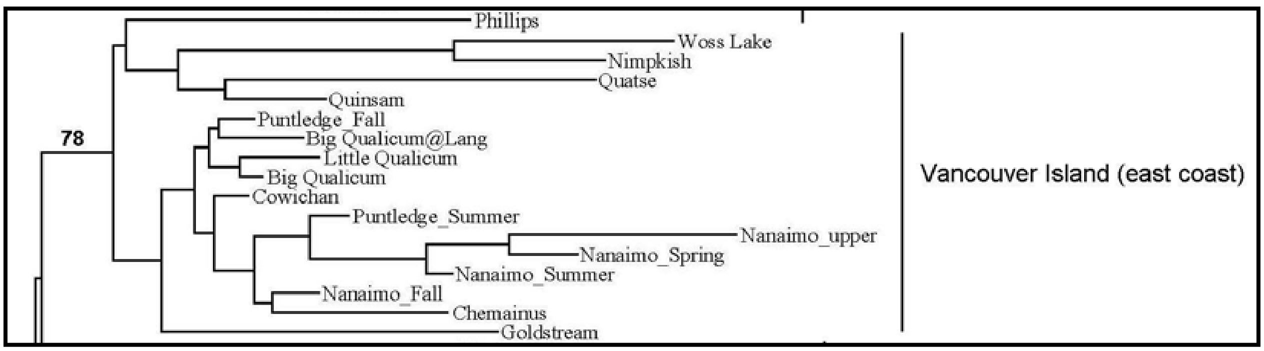

Figure 5: Genetic dendrogram of Chinook salmon, East Coast Vancouver Island (from Beacham et al. 2006)

More recently, staff at the DFO Genetics lab reviewed the genetic relatedness metric for the Nanaimo Chinook samples. The Fixation Index (FST) is a measure of population differentiation due to genetic structure. A broader version of this table was included in Brown et al. (2019) however CU #23 (EVI Nanaimo_SP) was not included in that analysis.

Table 3. Genetic relatedness for Chinook populations in the Nanaimo River.

Genetic Distance: Theta			
Group	Nanaimo_Upper (2005)	Nanaimo_Spring (2004)	Nanaimo_Summer
Nanaimo_Fall	0.0329	0.0289	0.0325
Nanaimo_Summer	0.0111	0.005	
Nanaimo_Spring (2004)	0.009		

Table 3 shows the F_{ST} distance matrix for the four groups. A F_{ST} value below 0.015 indicates that there is no evidence of genetic difference between the two samples. In the table the F_{ST} statistic between the *Nanaimo_Spring (2004)*, the *Nanaimo_Upper (2005)* and the *Nanaimo_Summer* groups do not support genetic differences. There is, however, a significant difference (F_{ST} > 0.015) between those groups and the *Nanaimo_Fall* Chinook (Andres Araujo, DFO, pers. comm., 2019). This result suggests there is mixing of Chinook between the upper spawning areas and that these upper groups do not spawn with the lower group to any extent.

An attempt in 2022 to re-examine the samples from 2004/2005 to analyze the Fixation Index and family groups within the sample was unsuccessful due to deterioration of the tissues. The original analysis used only the Age 0 samples and did not include any Age 1 samples.

There have been two known instances of genetic introgression through enhancement processes. First, a group of Chinook juveniles from Harrison River were released into the Nanaimo River in 1885 however the location of release is unknown, nor is there any reference or evidence of follow up assessment to understand where these Chinook returned to spawn, or if they survived at all. Second, in 1986 an unknown number of males (~28) were collected from below First Lake to cross with the adult progeny from the capture brood that originated from above Second Lake, to supplement 4 males from the capture brood and 15 males collected from above Second Lake. The resulting progeny from this mating had very low egg survival due to the eggs being exposed to water prior to fertilization and only 2,975 fry were released from 47 females. Given the proportion of First Lake males used (28 of 47) and the marine survival to age 2 at the time (~0.46%, data from the Pacific Salmon Commission's Chinook Technical Committee) an estimated return from this release would have been 8 adult Chinook. At an assumed exploitation rate of ~62.5% at the time, only 5 mature adults would be available to enter the river to spawn over a four year span (ages 2-5).

Early Life History – Age at Smolting

Information on the age structure of the *Above Second Lake* population is very limited. Healey and Jordan (1982) collected scale samples from all three spawning locations but in their report they only provided a summary of the freshwater age and did not include the ocean age component. Nonetheless, these are the only age data available on the *Above Second Lake* population from the adult stage. They found that the proportion of adults that migrated as yearling smolts (age 1.x) for the *Above Second Lake* population was 46%, and for the *Below First Lake* population was 8%. The remaining proportion of each population were sub-yearling smolt (age 0.x)(see Table 1). This result suggests that the early life history in these two spawning populations is variable, and is flexible to adapt to colder water above Second Lake (and slower growth) compared to below First Lake. Alternatively, the presence of yearling life history in the adults spawning below First Lake may be the result of *Above Second Lake* rearing juveniles returning as adults and remaining in this area. This speculation cannot be tested due to the lack of characteristics that separate the populations that spawn in the two locations.

In addition to DNA sample collection, the rotary-screw trap deployed in 2004 and 2005 was used to collect biological data as well. The trap was operated periodically during the migration period, in March-April 2004 and May-June 2005. Chinook juveniles which were continuing to rear in the Nanaimo River above Second Lake were assumed to not be vulnerable to the screw trap; that is, rearing in edge habitats and not migrating. The trap captured age 1+ yearling Chinook smolts (generally about 100mm length) as well as age 0+ sub-yearling Chinook juveniles (generally about 40mm length in April and 60-70mm length in June). This shows that both yearlings and sub-yearlings are present in the Nanaimo River above Second Lake. The size of the sub-yearling Chinook in June is consistent with the size of sub-yearling smolts migrating to sea in other East Vancouver Island (EVI) locations such as Cowichan and Englishman rivers. The conclusion from these data is that juveniles from the spawning population above Second Lake have both a yearling and sub-yearling life history, and sub-yearling migrants are a significant portion of the total, and so the presence of different juvenile life stages cannot be used to differentiate runs (see Figure 6). This conclusion is based on the assumption that the sub-yearling juveniles are continuing downstream and migrating to marine waters, which is suggested by the presence of age 0.x adults.

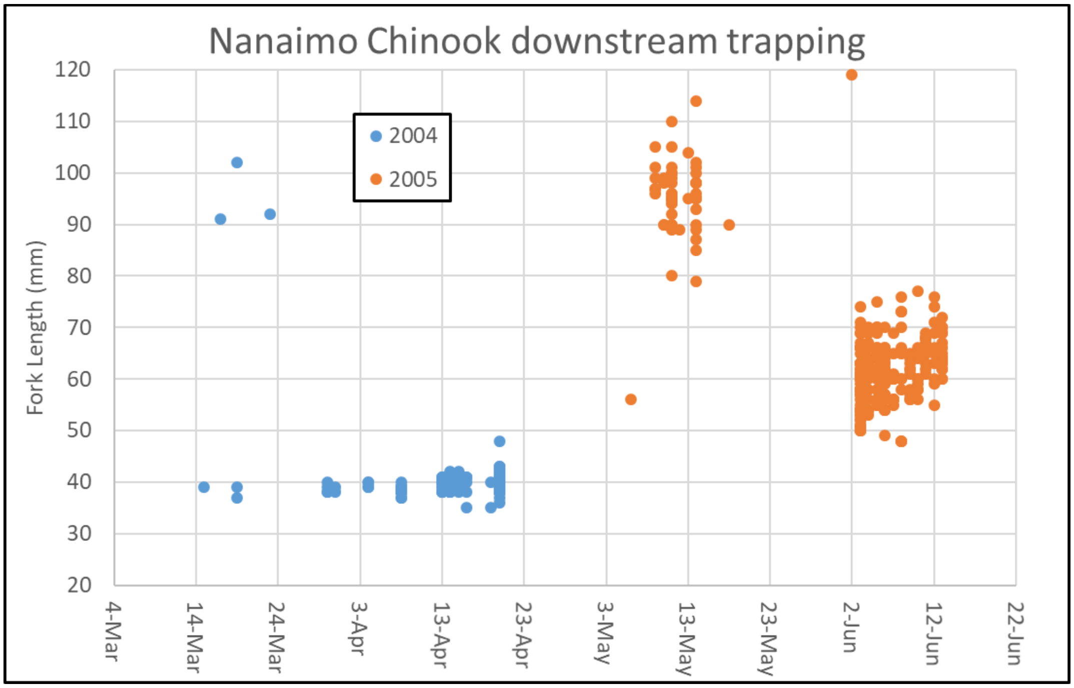

Figure 6. Nanaimo Spring run Chinook fry, plotted by length and date of capture. The juveniles that are 80mm and longer are age 1+ yearlings and those groups at ~ 40mm in April and at ~ 60-70mm in June are age 0+ sub-yearlings.

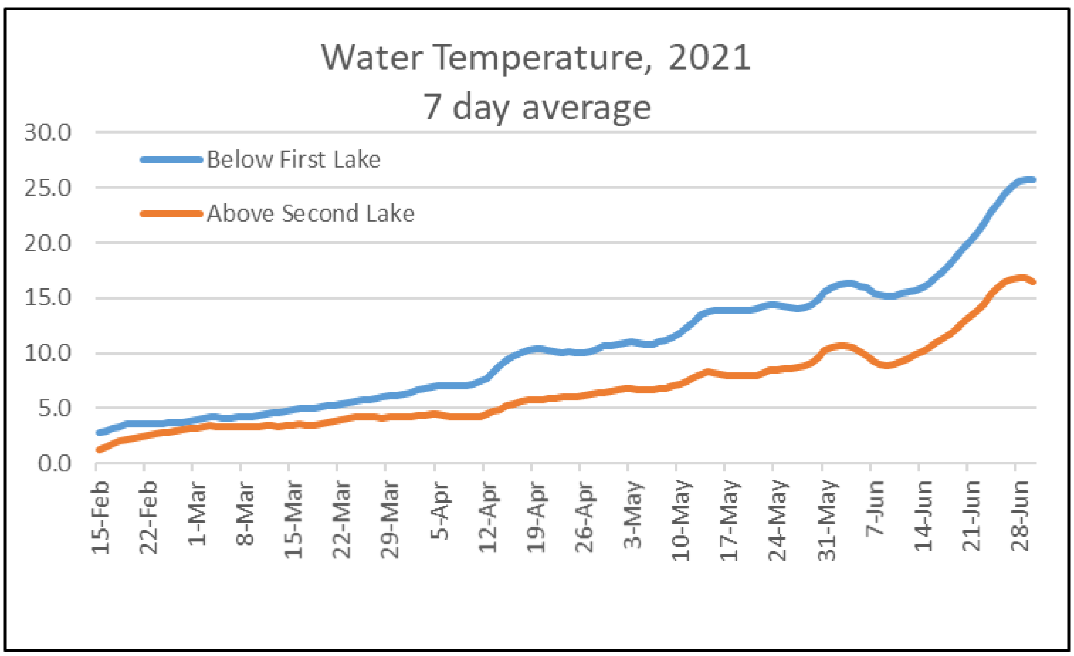

Figure 7. Average weekly water temperatures from the Nanaimo River below First Lake and Above Second Lake for the period between emergence and smolting of subyearling fry.

Additionally, the water temperature in the river above Second Lake is colder than below First Lake likely due to both the release of water from the Fourth Lake reservoir which draws its discharge from approximately 20 m depth, and the accumulated snow pack in the surrounding mountains. This colder environment may slow the metabolism and delay smolting. Figure 7 shows the water temperature from above Second Lake and Below First Lake. Oregon Department of Environmental Quality (ODEQ) (1995) found that positive growth takes place in water above 4.5^{O}C, below which growth ceases and may become negative as feeding ceases and respiration rates decrease. In 2020, this temperature was reached on 11-March in the area below First Lake, and a month later on 12-April in the area above Second Lake. In addition, emergence will be delayed as egg incubation is slowed in colder water.

Summary

The previous analyses used some or all of the following criteria to suggest two distinct groups of Chinook in the upper Nanaimo River. In this analysis, the authors suggest that the data do not support the previous designations of 2 separate early timed CUs (CK 23 and CK 83) in the Nanaimo River. The summary by criterion is provided below.

1. Run timing during upstream migration:
    - **Pre WSP:** The SFN Traditional Knowledge describes three separate run timing groups historically: Spring, Summer and Fall. Carl and Healey (1984) describe two early run timing groups with two spawning locations but with similar run timing.
    - **WSP CU 2007:** Holtby and Ciruna (2007) referenced Carl and Healey (1984) on spring and summer run timing, but this document did not actually state or show data supporting two early run timing groups.
    - **Current analysis:** River survey observations and a fixed point enumeration study show that the majority of early run Chinook enter and migrate upriver in early June. We did not find any basis for separating spring and summer migration of Chinook however at the current level of spawner abundance above Second Lake, distinguishing an increase in daily migration prior to the June mode would be difficult. The observations of Chinook above Second Lake indicate that these fish arrive in June and hold until fall spawning. The historic information suggests that an early, Spring-timed Chinook population did exist but with the current knowledge this group may have become extirpated.
2. Separation of spawning location:
    - **Pre WSP:** Carl and Healey (1984) describe different spawning locations below First Lake and above Second Lake.
    - **WSP CU 2006:** Holtby and Ciruna (2007) referenced Carl and Healey (1984).
    - **Current analysis:** The river swim data show that the Chinook that hold in the South Nanaimo confluence pool and the two lakes may use the river below First Lake to spawn, and the Chinook that hold in the river above Second Lake may use that area to spawn. There is no barrier preventing mixing of holding or spawning fish. The hatchery release practice of lake pen releases likely reinforces the natural behaviour to hold in the lakes prior to spawning.
3. Genetic distinctiveness (originally enzyme electrophoresis and later DNA based)
    - **Pre WSP:** Carl and Healey (1984) suggest genetic distinctiveness among juvenile life history types. They describe three subpopulations that differ in age of seaward migration, genetic diversity and body morphology, and associate these differences, principally, with the three spawning locations.
    - **WSP CU 2006:** Holtby and Ciruna (2007) used genetic microsatellite data to support the original findings from Carl and Healey (1984). The two DNA samples from the Above Second Lake project were not included in the Fixation Index analysis.
    - **Current analysis:** Recent analysis using Fixation Index metrics show that the genetic differences are not sufficient to be able to separate samples from the two populations.

4. Life history (including morphological differences, and age)
   - **Pre WSP:** Carl and Healey (1984) conclude that the two early life histories represent two distinct subpopulations.
   - **WSP CU 2006:** Holtby and Ciruna (2007) referenced Carl and Healey (1984).
   - **Current analysis:** Both *Below First Lake* and *Above Second Lake* populations can exhibit the two juvenile life histories as shown by the data in Healey and Jordan (1982) using adult scale analysis. The conclusion that the two life histories result from two geographically distinct spawning aggregations is not supported by their data and is a source of confusion. Further, Moran et al. (2012) concluded that different juvenile life histories do not represent different lineages that require specific management, due to the plasticity of the species. Additionally, they suggest that population descriptions should not use the juvenile life history (stream-type vs ocean-type) but use the adult return timing combined with location, e.g. East Coast Vancouver Island Summer run. The expression of the plasticity of the juvenile life history in the Nanaimo River may be related to the colder water habitat in the river above Second Lake.

Conclusion

We are recommending that the Conservation Unit CK-23 *East Vancouver Island-Nanaimo-SP* be deprecated, and the Census Site POP_ID 3333 and its associated Stream Estimate Narratives, representing the enumeration reach upstream from Second Lake, be included with the Conservation Unit CK-83 *East Vancouver Island_Georgia Strait_SU_0.3*.

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Appendix 1

Broodstock Removals and Subsequent Releases

Table A1. Population 'A' – Fall Chinook

Broodyear	Brood collected	CWT released	Total Release	Thermal marks
1973	Unknown	11485	12499	No
-	-	-	-	No
1978	Unknown	6469	6469	No
1979	41	16964	61474	No
1980	82	72623	179500	No
1981	23	0	11537	No
1982	146	21516	105114	No
1983	141	0	292260	No
1984	92	0	251047	No
1985	128	0	295387	No
1986	162	0	133198	No
1987	223	98941	542836	No
1988	261	104804	503107	No
1989	113	107434	254762	No
1990	119	101038	153204	No
1991	197	109766	613149	No
1992	256	107096	461165	No
1993	194	100289	370747	No
1994	219	75780	304213	No
1995	367	50223	526513	No
1996	278	75372	465936	No
1997	70	63126	84315	No
1998	278	0	493241	No
1999	235	176242	509434	No
2000	194	175664	368433	No
2001	142	176450	359165	No
2002	230	79876	404080	No
2003	83	0	120199	No
2004	135	199248	263669	No
2005	244	0	345494	Yes
2006	221	0	421467	Yes
2007	73	0	134552	Yes
2008	198	0	418068	Yes
2009	201	0	350722	Yes
2010	205	0	436769	Yes
2011	181	0	421147	Yes
2012	231	0	393565	Yes
2013	206	0	384140	Yes
2014	173	0	265473	Yes
2015	217	0	242796	Yes
2016	178	0	178906	Yes
2017	190	0	307656	Yes
2018	255	0	406052	Yes
2019	255	0	428638	Yes
2020	201	0	212780	Yes

Table A2. Population 'B' – early Chinook, below First Lake

Broodyear	Brood collected	CWT released	Total Release	Thermal marks
1980	Unknown	19231	20338	No
1981	6	0	2809	No
1982	51	1879	4766	No
1983	81	56911	57640	No
1984	85	0	99550	No
1985	67	0	74233	No
1986	127	0	70003	No
1987	117	0	72723	No
1988	141	0	157013	No
1989	183	0	157322	No
1990	34	0	39444	No
1991	0	0	49328	No
1992	92	0	50686	No
1993	338	0	418622	No
1994	124	0	153376	No
1995	109	49981	77895	No
1996	133	40274	171299	No
1997	141	50413	169098	No
1998	95	0	165595	No
1999	146	25185	257394	No
2000	168	24739	207955	No
2001	106	25102	186187	No
2002	128	0	173081	No
2003	119	0	187214	No
2004	96	0	154922	No
2005	122	0	204874	Yes
2006	176	0	223745	Yes
2007	138	0	229551	Yes
2008	194	0	232496	Yes
2009	165	0	221184	Yes
2010	116	0	226193	Yes
2011	101	0	236298	Yes
2012	114	0	206266	Yes
2013	39	0	72332	Yes
2014	129	0	195933	Yes
2015	59	0	100223	Yes
2016	51	0	85212	Yes
2017	146	0	195020	Yes
2018	116	0	183928	Yes
2019	59	0	90064	Yes
2020	64	0	104828	Yes

Table A3. Population 'C' – early Chinook, above Second Lake

Broodyear	Brood collected	Captive Brood	CWT released	Total Release	Thermal marks
1982	6	-	0	2657[1]	No
1983	-	-	-	-	No
1984	11	-	0	16974	No
1985	-	71[2]	0	932	No
1986	15[3]	51[3]	0	2975[4]	No

[1] Additional 1,900 progeny retained for captive brood at PBS

[2] 70 males and 1 female captive brood from 1982 brood

[3] 47 female and 4 males from 1982 captive brood, plus 15 males collected from above Second Lake and an unknown number of males from below First Lake

[4] Poor egg survival due to exposure to water

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