A Living Classroom without its Teacher:

Investigating the causes of, and possible solutions for poor Oncorhynchus keta (Chum salmon) returns to Spanish Bank Creek (Vancouver, BC, Canada)

Sara Alshanteer, Jessica Brown, Mark Pope, and Joshua Shepherd

Environmental Science Department, University of British Columbia

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Dr. Tara Ivanochko and Dr. Michael Lipsen

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Executive Summary

Background

In 2000, Spanish Bank Creek in Vancouver, British Columbia was daylighted, excavating dirt and debris to restore the creek, making it passable for salmon. These efforts were led by the Spanish Bank Streamkeepers in collaboration with Fisheries and Oceans Canada (DFO) primarily to increase awareness and educate the local community about Pacific salmon. After the daylighting, the Streamkeepers worked with the local community and DFO to release *Oncorhynchus keta* (chum salmon) and *Oncorhynchus kisutch* (coho salmon) fry, sourced from the Kanaka Creek Hatchery, and establish salmon runs at the creek. Despite their best efforts and a strong chum return in 2004, the creek has not established consistent or numerous returns of chum salmon since daylighting.

In September 2020, a team of four UBC Environmental Science students partnered with the Streamkeepers to investigate the potential causes of poor chum returns and suggest new approaches to improve the success of the creek and enable ongoing community engagement and education. The research team investigated two primary questions, with a subset of eight secondary questions:

I. *Why are Oncorhynchus keta returns to the Spanish Bank Creek low? What factors can we eliminate as to the reason of low chum returns? This is our broad scope question which will be answered by the following set of questions:*
    a. *Is the lack of nutrients, food and shelter normally provided by an estuary causing O. keta to die shortly after leaving the creek?*
    b. *Is sedimentation preventing O. keta from re-entering the stream as adults?*
    c. *Is there a decline in the water quality in the past 20 years? If so, is the decline in water quality impeding O. keta returns?*
    d. *Is the return of O. keta hindered by low and flashy streamflow?*

e. *How has the morphology of the stream changed over the past 20 years? Do any of these changes impact the return of O. keta to the creek?*

f. *Did increasing or decreasing the number of O. keta fry released into the Spanish Bank Creek, or adding artificial redds (2015,2017,2019), result in larger O. keta returns to the Spanish Bank Creek?*

g. *Are O. keta failing to imprint on the Spanish Bank Creek due to their very short residency in it?*

h. *Are the O. keta from the Spanish Bank Creek dying before they can return to spawn due to competition over food sources with other salmonid and fish species in the Pacific Ocean?*

i. *Are O. keta returns to Spanish Bank Creek correlated with returns to any other streams in the Lower Mainland?*

Results

Unfortunately, this project could not conclusively determine the cause of poor chum returns at Spanish Bank Creek. Based on the literature review and discussions with experts, several factors likely combine to have an overall negative impact on chum returns including climate change, marine mortality, preference for other spawning habitats, lack of estuary habitat, and limited olfactory imprinting of fry. The survival of Pacific salmon during their time spent in the ocean has decreased dramatically in recent decades—falling from a rate of approximately 10% to 0.1%—which reduces the probability that fry released by the Streamkeepers will even survive until reproductive maturity, much less manage to return to their natal stream. Additionally, the strongest return at Spanish Bank Creek corresponds to the strongest return to the Indian River during the same time period (Figure 1) suggesting that the most successful year may have been a result of Indian River chum salmon straying (searching for an alternative habitat). Lastly, there was no strong correlation identified between any abiotic factors (temperature, precipitation, water quality etc.) and salmon returns to Spanish Bank Creek, (Figure 2) though pollution tolerant index and yearly deviation in daily mean temperature came the closest.

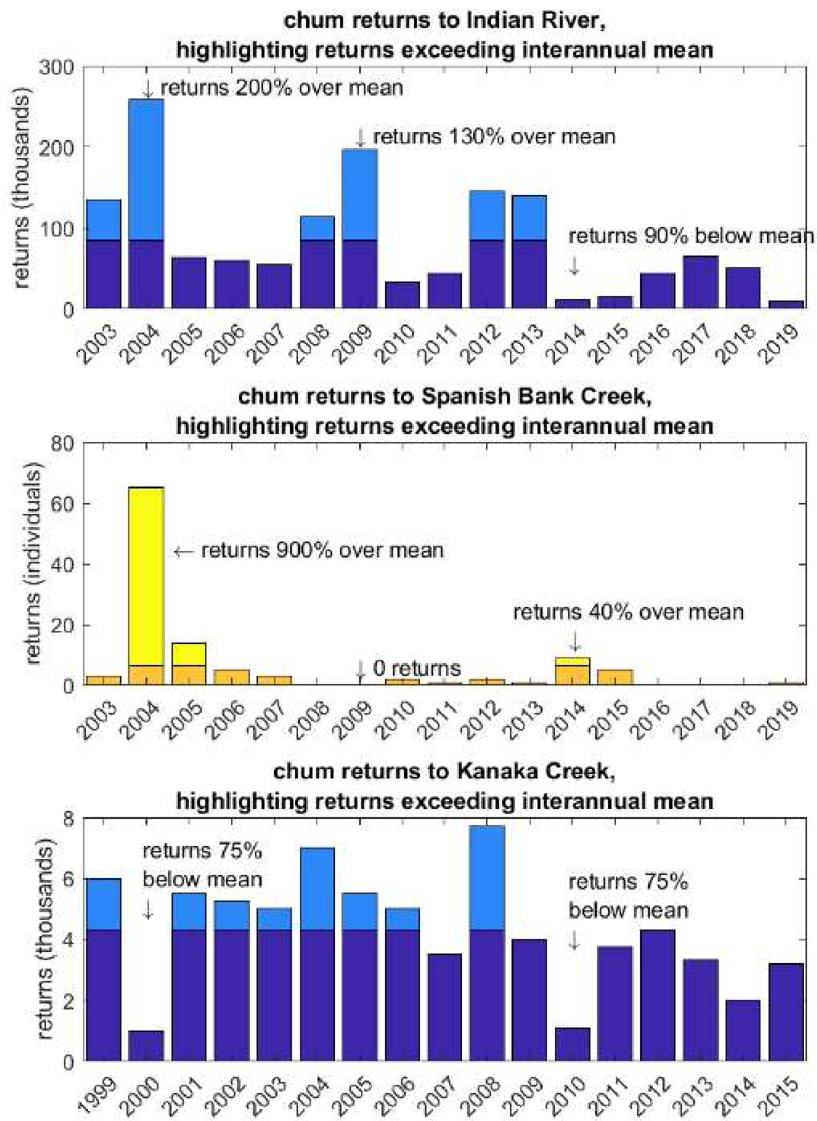


Figure 1: *O. Keta returns at Spanish Bank creek in comparison to Chum returns in the Indian River & Kanaka Creek. In 2004, Spanish Bank creek returns were 900% above average and The Indian river returns were 200% above average for that stock. This suggests Spanish Bank creek may have received overflow chum from the Indian River. Also, 2004 and 2014—the two peaks of Spanish returns—align with particularly poor returns at Kanaka four years prior (the lifespan of a chum salmon). This correlation is more difficult to explain, but it is worth further investigation.*

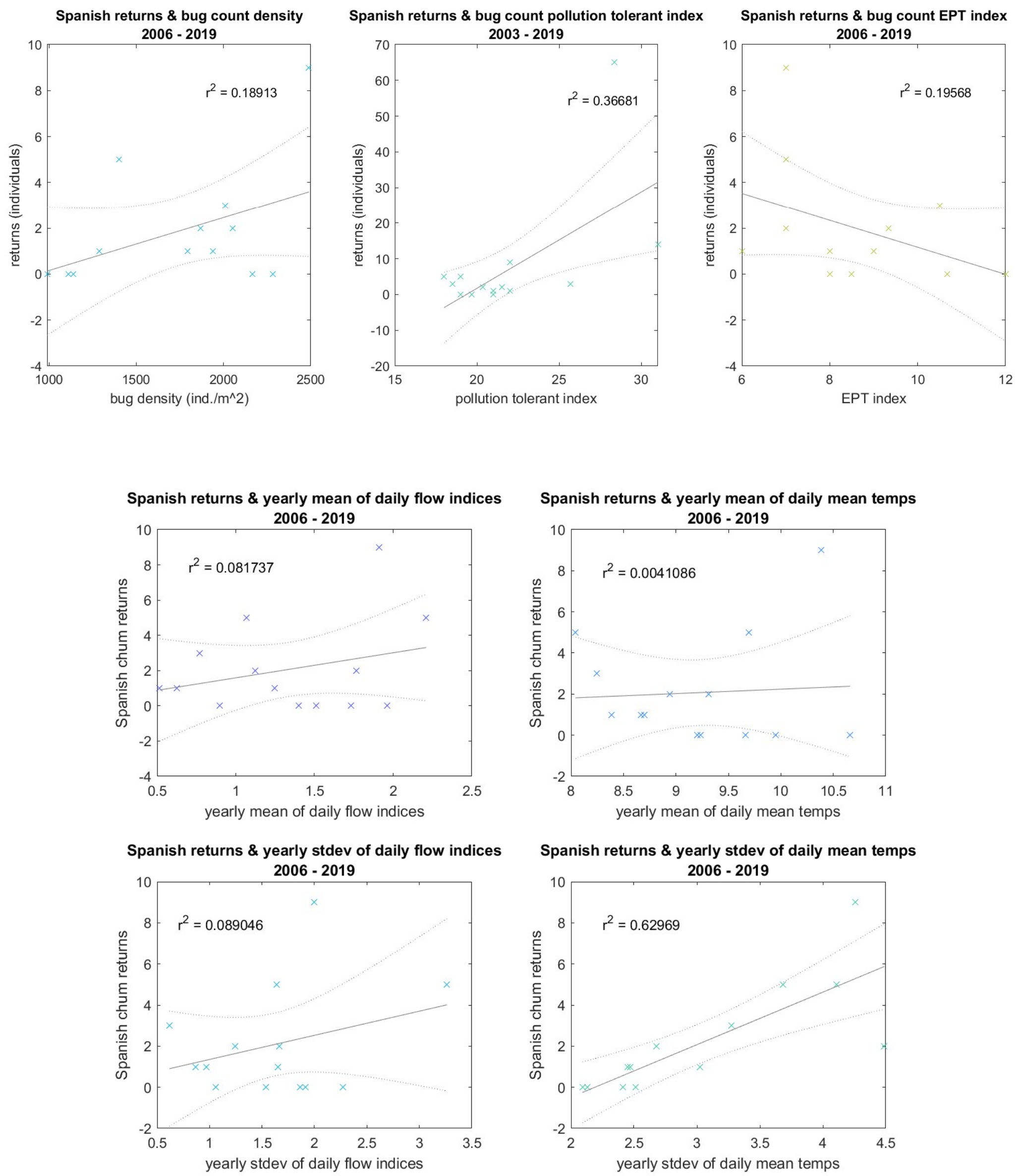


Figure 2: *The three bug count variables that are most closely correlated with Spanish chum returns, followed by four weather summary statistics. Only PTI (a weighted scale of taxon abundance, with pollution-intolerant taxa weighted highest) exhibited even a minimal correlation over the full 17-year period, so it is represented over that period. The other variables are trimmed to the 14-year period from 2006 on to exclude the unusual returns around 2004. EPT index is the ratio of stonefly, mayfly, and caddisfly taxa to total taxa observed, and (like PTI) is intended to serve as a*

Conclusions and Recommendations

Despite being unable to specify the cause of poor returns, we identified several restoration recommendations based on available literature and discussions with experts to support the educational and restoration goals of the Spanish Bank Streamkeepers. The recommendations are:

I. Focus salmon release efforts on establishing artificial salmon redds to increase likelihood of imprinting;
II. Release adult chum into the creek during spawning season to increase the olfactory signal to returning chum thereby increasing the likelihood that returning salmon will choose the creek;
III. Source chum eggs and/or fry from a hatchery in the Burrard inlet (instead of the Fraser river system); and
IV. Consider switching from chum to pink salmon due to the smaller size and short life cycle of pink salmon.

Due to certain limitations and gaps in the data we received, determining the cause for poor chum returns at the Spanish Bank Creek was difficult. Moreover, data collection methodologies and chum release methodologies were inconsistent, leading to difficulties in data analysis. Therefore, in terms of data management, we recommend the following:

I. Permanently install a datalogger in the stream to monitor water temperature, pH, conductivity, salinity, total dissolved solids, and dissolved O2.
II. Manually test for phosphate and nitrate/nitrite/ammonium concentrations at least monthly.
III. Request that DFO test the DNA of any chum that return in the future to try and gain more concrete evidence to support or reject the hypothesis that many returning chum are strays.
IV. Be systematic with any new changes to release and data collection methodologies, so that their success can be assessed with minimal error.
V. Conduct further analysis in 10 – 20 years, once far more data has been accumulated.

Part 1: Introduction and Background Information:

1.1 Who are the Spanish Bank Streamkeepers

In 1995, the Pacific Streamkeepers Federation (PSkF) was formed to provide support to volunteer community groups working on stream health and restoration projects in BC. The Spanish Bank Streamkeepers (SBSk) was founded shortly after and have partnered with government agencies, including Fisheries and Oceans Canada (DFO), to renew and revive the streams of Spanish Bank—in particular, Spanish Bank Creek (Figure 5). This collaboration led to the daylighting of Spanish Bank Creek in 1999 and subsequent reintroduction of *Oncorhynchus keta* (chum salmon; Figure 1) and *Oncorhynchus kisutch* (coho salmon; Figure 2).

Figure 1: An adult *O. keta* - Chum Salmon (Fisheries).

Figure 2: An adult *O. kisutch* - Coho salmon (U.S. Fish and Wildlife Service/Fish and Aquatic Conservation).

Those species were chosen based on anecdotal evidence that they had historically been in the creek. There is no data on coho returns as they are quite small & elusive, spawn in the inaccessible upper reaches of the stream, and enter in the dark; but for several years, coho smolt have been observed leaving the stream in the spring, so it is presumed that they have become adequately naturalized. Chum, however, are tracked, due to their large size & conspicuous spawning location. Unfortunately, chum returns have been low or non-existent since 2005 (figure 3). The SBSk's main objective is to safeguard salmonid species and provide educational experiences to students and local community members regarding the importance of preserving and restoring salmonid habitats. Although the coho returns help meet that objective, chum are much better for educational purposes because of their visibility and life cycle timing. Chum salmon returns to the creek during the daytime, making them easier to count and more visible to the general public. Coho return at night & quickly pass beyond the accessible lower area of the stream, and thus lend themselves poorly to education and community engagement.

Therefore, this report intends to explain why chum are not returning and provide recommendations for the SBSks' future work. It was written in direct collaboration with Richard and Jilian Scarth, two streamkeepers who have dedicated over 20 years to the stream's success and continue to provide their expertise and advice.

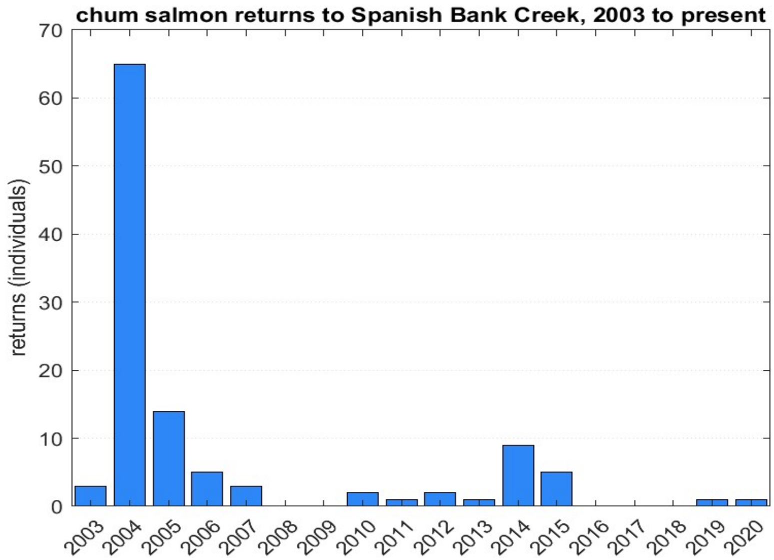


Figure 3. Chum salmon returns to Spanish Bank Creek from 2003 (four years after daylighting) to present. 2004 coincides with the largest Chum salmon run between 2003-2020.

1.2 Relevance of project:

The research conducted for this project will help establish guidelines for potential future modification of the creek, to increase the likelihood of hosting successful chum runs in the future. Chum returns to Spanish Bank Creek will enhance the local biodiversity and terrestrial and aquatic productivity (Hocking & Reynolds, 2011). Salmon are a keystone species in Pacific Northwest ecosystems and increase biodiversity by both providing a food source for predators and fertilizing terrestrial organisms once they die. Due to climate change, small water bodies, including creeks, face changes in their water chemistry, species biodiversity, morphology, and inflow rate, via changes in precipitation (Grant et al., 2019). More particularly to salmon health, climate change can also affect the stream's temperature, sediment concentration, pH, and dissolved oxygen, consequently affecting any restoration efforts. As a result, a more comprehensive knowledge of the systems at play would be of considerable importance for planning around Spanish and other streams, both in 2021 and beyond.

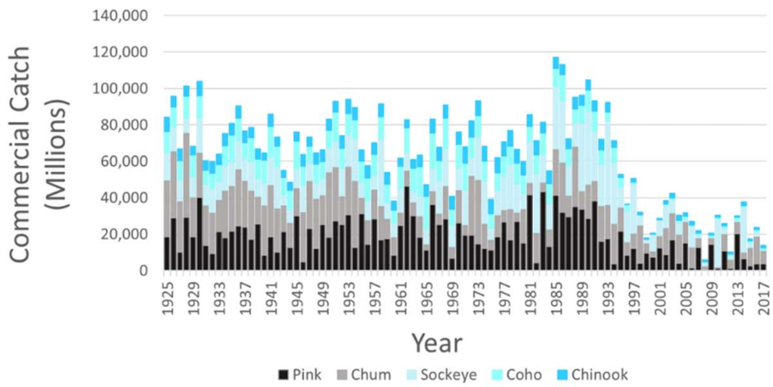
Finally, the most important impetus for this project is its ability to provide an educational experience for future generations. For over 20 years, BC primary school children have raised salmonids in the classroom with the intention of allowing them to observe the full lifecycle of the chum—from the moment the students release the chum fry into the stream until they return as adults for spawning. DFO provides aquariums stocked with salmonid eggs to classrooms where students are learning about the lifecycle of salmon. Students are expected to take care of the salmon for the first 2-3 weeks of their lives before taking a trip to the nearest stream where they release them. Because of the initiative taken by DFO, thousands of children in BC & the Yukon are encouraged to learn about salmonids by participating in a hands-on experience, while witnessing how collective efforts can achieve a sustainable future (*Resources for Educators | Pacific Region | Fisheries and Oceans Canada*, n.d.). Needless to say, actually having the fish they released return to the stream is of great importance to the children, and to the success of the program in general.

1.3 Background Information

1.3.1 Chum returns around North America

The data regarding chum returns to the West Coast of North America is of poor quality, but appears to show abundance generally stable, with results highly variable around Southern BC (Ruggerone et al., 2018; Grant et al., 2019). However, Fraser River stocks are experiencing severe declines, while other streams along the South Coast are flat, or even growing, such as Kanaka Creek (Walters, 2019; R.Davies, personal communication, 2020). The total open-ocean population of Oncorhyncus spp. is dominated by Asian-origin fish—especially Japanese fishery salmon—which have increased in population dramatically over the past half-century. The impact of this increase on wild stocks is unclear; some research on specific areas has found a distinct negative correlation, while other research papers do not reflect such a trend (Ruggerone et al., 2018). Reflecting the generally flat North

American abundance numbers, commercial catches of chum are similarly stable, exhibiting a gradual decline since the highly variable 1960s and '70s (Grant et al., 2019). This may be contrasted with other salmon in the area, especially sockeye, for which commercial catches have plummeted over the past few decades (Grant et al., 2019; Walters et al., 2019).



Canadian commercial catch numbers for Pink, Chum, Sockeye, Coho, and Chinook salmon. Data Source: North Pacific Anadromous Fish Commission (NPAFC). 2018. NPAFC Pacific salmonid catch statistics (updated 31 July 2018). North Pacific Anadromous Fish Commission, Vancouver. Available from www.npafc.org.

Figure 4: A figure by Grant et al., highlighting the numbers of Canadian commercial catch for Pink, Chum. Sockeye, and Chinook.

1.3.2 History and Morphology of Spanish Bank Creek

Spanish Bank Creek flows north from Chancellor Boulevard for approximately one kilometer, then flows under NW Marine Drive, and terminates at a tidal estuary in the Burrard Inlet (figure 5). Logging and urbanization that occurred between the 1860s & 1940s led to ecological disturbances in the watershed of the creek, including a decrease in biodiversity of native species and an increase in water runoff (Reynolds, 2017). Historically, the greater Vancouver region consisted of many streams and creeks covering a distance of 124 km; however, by 1998, only 10km of open streams remained

(Reynolds, 2017). Anecdotal evidence suggests that Spanish Bank Creek supported chum and coho salmon and cutthroat trout in the 1920s (Page & Eymann, 1994).

Figure 5. Satellite & aerial imagery taken using Google Earth showing the location of Spanish Bank creek within the Vancouver area (A), and Spanish Bank Creek (B) (Google Earth, 2021).

Restoration of the creek was initiated in 1999 when a section of the culvert connecting Spanish Bank Creek and Burrard Inlet was daylighted. This culvert was chosen because it was the only location that would have allowed salmon to access the creek. Riparian vegetation was also restored around the lower reaches of the stream (Reynolds, 2017). In 2004, an off-channel habitat (OCH) pond was created to serve as a refuge for coho fry who would have otherwise been washed out to sea by periods of flash flow—frequent in the stream due to its straight, relatively unobstructed course. However, the pond is located higher in the creek than most chum travel and is primarily used by coho (Figure 6).

Figure 6: Left: the OCH pond (left of railroad tie) demonstrating its use as a refuge during a period of extremely high flow in November 2020. The tie is easily surmountable by salmon fry or smolt.

Right: the bulk of the pond, obscured by a thicket. (Pope 2020)

1.3.3 Chum salmon life cycle:

Chum salmon leave their redds (nests made in the gravel where the eggs are laid) in early spring and enter the stream as alevins (Figure 7). They imprint upon the stream for 2-3 weeks after which they become fry and begin migrating down the stream from mid-March to the end of April (Beacham & Murray, 1986). Once the chum fry leave the creek, they stay in the stream's estuary for the summer, becoming acclimated to saltwater, and then leave the Burrard Inlet and head offshore toward the open ocean (Holt et al., 2018). At this point, the fish migrate northwards, arriving at the Alaska current (Debertin et al., 2017). They live, as all Pacific salmon do, in the ocean for their adult lives, until the rising water temperature in their final spring triggers their return to coastal areas (Debertin et al., 2017). Their spawning period spans from September to January—centred on late October & early November—and their death follows (figure 7).

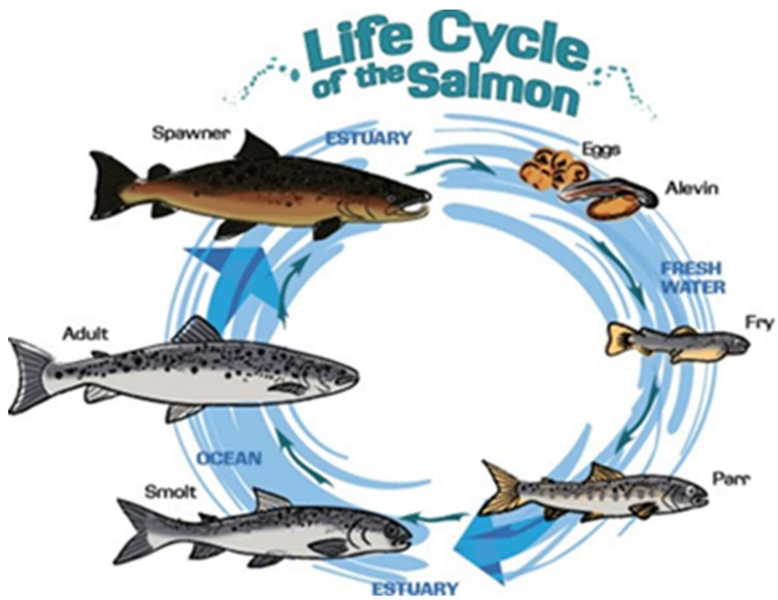


Figure 7. The life cycle of a salmon (Ragan, 2015)

Chum salmon at Spanish Bank Creek were released for the first time in early 2000 (brood year 1999). That year, and in every year since, DFO and the Streamkeepers have released around 30 thousand chum fry from Kanaka creek into the stream between April and May (figure 8). The first chum returns were witnessed in 2003 and 2004, and were highly successful in 2004. However, subsequent years were much less impressive, with several recording no chum returns at all (figure 3). This decrease led to questions regarding the marine and in-stream factors responsible.

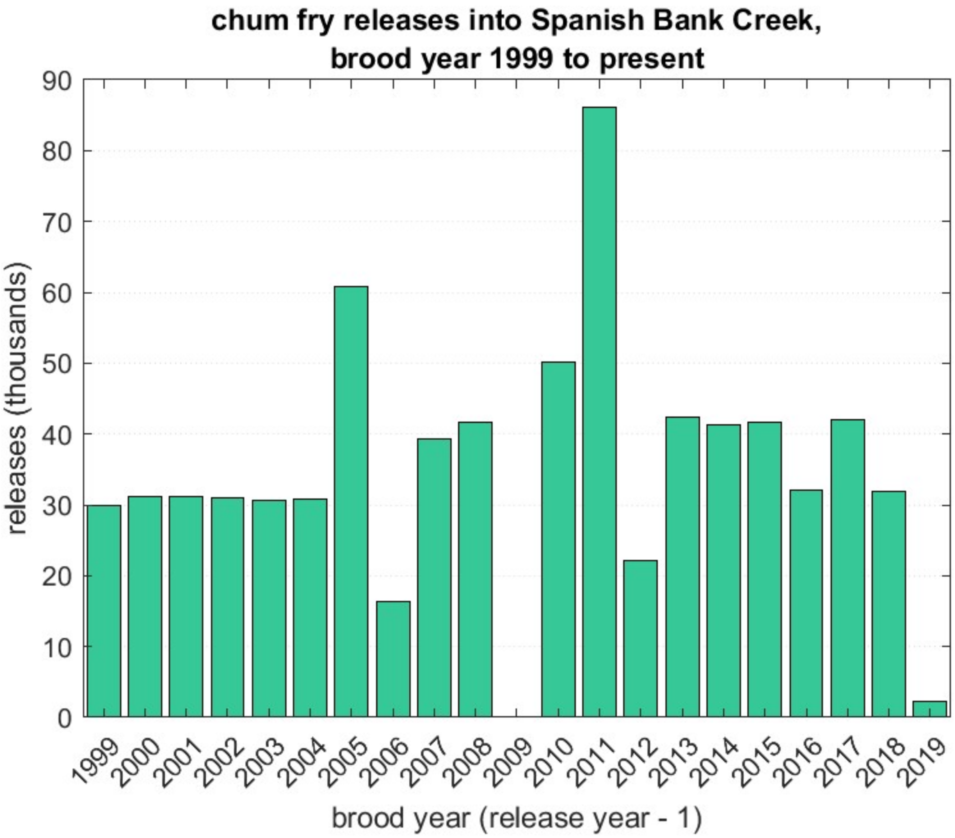


Figure 8. Number of chum fry released in Spanish Bank Creek, brood year 1999 (released spring of 2000) to 2019. Data from SBSK records.

1.4 Research Objectives

This project aims to evaluate factors that could be impacting Spanish Bank Creek's chum returns, to determine if and how the stream environment and fry release process can be modified to improve returns. The factors include estuary conditions, sedimentation, water quality, temperature, stream flow, stream morphology, release methodology, imprinting and marine conditions. Factors were chosen based on literature reviews, availability of data, and expert opinion. Secondary objectives include creating a more comprehensive and digitized database for the historical information collected by the streamkeepers that can be used for future research, as well as presenting the work in a format that is accessible to the public and conducive to education.

Research Questions:

1. Why are Oncorhynchus keta returns to Spanish Bank Creek low? What factors can we eliminate as to the reason of low chum returns? This is our broad scope question which will be answered by the following set of questions:

1A. Is the lack of nutrients, food and shelter normally provided by an estuary causing O. keta to die shortly after leaving the creek?

1B. Is sedimentation preventing O. keta from re-entering the stream as adults?

1C. Is there a decline in the water quality in the past 20 years? If so, is the decline in water quality impeding O. keta returns?

1D. Is the return of O. keta hindered by low and flashy streamflow?

1E. How has the morphology of the stream changed over the past 20 years? Do any of these changes impact the return of O. keta to the creek?

1F. Did increasing or decreasing the number of O. keta fry released into Spanish Bank Creek, or adding artificial redds, result in larger O. keta returns to Spanish Bank Creek?

1G. Are O. keta failing to imprint on Spanish Bank Creek due to their very short residency in it?

1H. Are the O. keta from Spanish Bank Creek dying before they can return to spawn due to competition over food sources with other salmonid and fish species in the Pacific Ocean?

1I. Are the returns of O. keta to Spanish Bank Creek correlated with returns to other streams in the Lower Mainland?

Part 2: Methods

2.1 Data Collection:

Due to the lack of data available on local streams, this project relied heavily on personal communications with local experts. The experts were Dr. Scott Hinch, a professor and lead researcher at the Pacific Salmon Ecology and Conservation Laboratory at UBC; John Barker, the long-standing president of the West Vancouver Streamkeepers; Sandie Hollick-Kenyon and Brian Smith, DFO community advisors to the South Coast region; Hamid Seshadri, the watershed manager at Capilano hatchery; and Ross Davies, the chair of Kanaka Education and Environmental Partnership Society. Summaries of our interviews are included in the appendix. Interviews were conducted over Zoom and involved open ended discussions about the 8 factors we examined in this study. Time constraints resulted in different experts being consulted at different points of the project which impacted the focus of the questions. We also received data from Hamid, Ross, and John relevant to their respective streams and data from Sandie on returns and releases at Spanish and Kanaka. Further details on the data are included in the appendix.

Online data was collected from various sources. Metrological data for Point Atkinson, Vancouver, Canada, was collected from the Environment Canada application programing interface (API). Point Atkinson tidal data was manually downloaded and assembled in Matlab from Fisheries Canada. A screen scraper was written to acquire bug count data from the Pacific Streamkeepers Federation database.

Geospatial data of the creek was collected by walking the creek with a Garmin InReach (GPS), and the Gaia GPS phone app. Tracking intervals were set to 15s and 1s respectively. The map drawn by Bob Seraphim (Appendix) was used as a guide for walking the stream, however, the compressed version of this map was used to analyze the change of the stream's morphology. The map was provided by Sandie Hollick-Kenyon.

2.2 Data Analysis:

The data analysis portion of this project was composed of two overarching correlation analyses, which served to highlight points for further investigation, and a number of supporting analyses of different variables individually or in small groups. These will be broken down in the following sections.

All quantitative analysis was done in Matlab R2020a, with addons:

- Statistics & Machine Learning Toolbox
- Signal Processing Toolbox
- Econometrics Toolbox
- Optimization Toolbox
- Third-party disperse() function

2.2.1 The Multiple Regression:

After much thought, we settled on multiple regression as the primary (though hardly lone, due to the problems detailed in section 3.2) means for evaluating correlation between our predictor variables and response variable (chum returns to Spanish Bank Creek) (Figures 9 and 10). We did this because it is likely that some factors may only map well onto Spanish returns when they are combined; such a correlation would always be missed by a simple matrix of correlation coefficients, (below) but might be caught by a multiple regression. Multiple regression takes in a response vector and a predictor array, and outputs coefficients for each of the predictor variables such that the difference between their sum and the response variable is minimized. It is necessary to include a vector of ones in the predictor array to allow the regression to generate a y-intercept. Thus, the formula for the multiple regression's output is:

$$y = b_1*x_1 + b_2*x_2 + b_3*x_3 + \ldots + b_n*x_n + b_{n+1}*1$$

We z-scaled all variables, input and output, (so as to allow for easy comparison on a single axis) which results in the y-intercept being negligible, but it was included for completeness. The coefficients of the collinearity-passed variables are as follows:

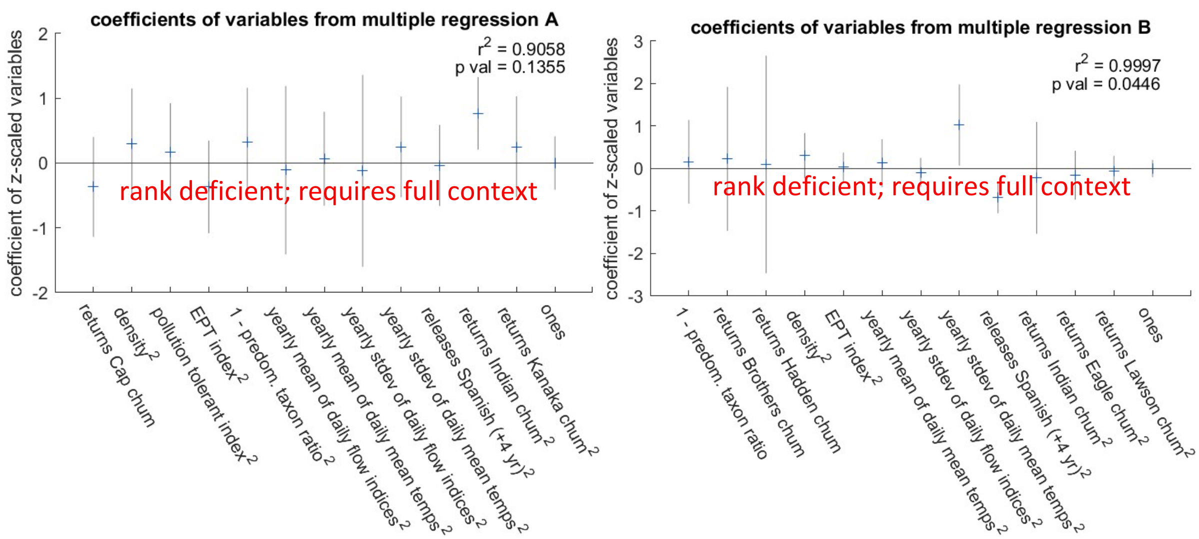


Figure 9. Regression A includes data from 2003 to 2019, but excludes West Van stream returns, while regression B includes only data from 2006 to 2019, but includes West Van returns, which were only recorded from 2006 on. These charts show the coefficients and 95% confidence intervals (using an F-test) returned by multiple regression of all variables collected, (excluding non-chum returns) with exponents of both 1 and 2, after being filtered through a collinearity test. **Both results must be taken with heavy qualification, as detailed in section 3.2: the p-values are lower than they should be.** The fact that the two runs returned opposite-signed coefficients for some variables exemplifies the problems at hand; though it should be noted that the confidence intervals overlap for all variables that exist in both regressions.

And these coefficients, when evaluated, returned the following models of chum returns:

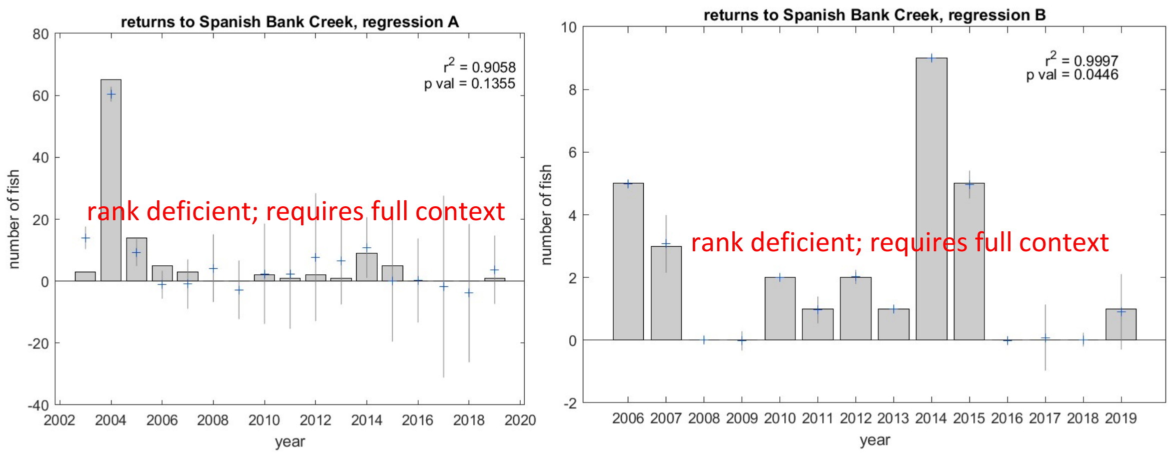
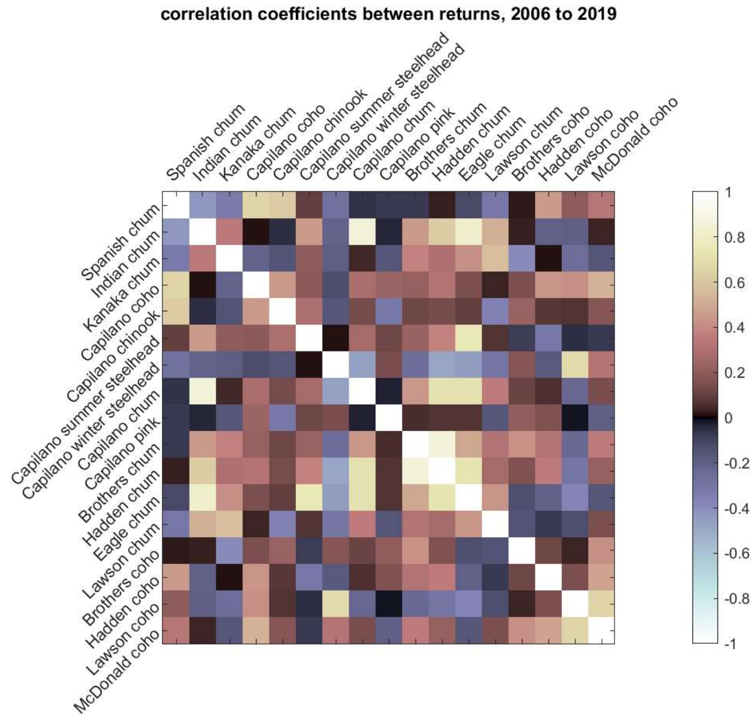


Figure 10. These bar graphs show the actual returns to Spanish (bars) and the predicted values from the multiple regression (crosses, with lines showing confidence intervals). Regression A includes data from 2003 to 2019, but excludes West Van stream returns, while regression B includes only data from 2006 to 2019, but includes West Van returns. The correlation is very strong—especially over time interval B—but again, the rank deficiency & complex dependence of variables complicate matters greatly. **As mentioned in section 3.2: because of the rank deficiency, these regressions (B in particular) must not be taken as a robust conclusion.** It is instead a demonstration of two possible arrangements of variables, which could possibly comprise part of the solution.

The conclusions that can be drawn from the multiple regression are limited in scope, due to the rank deficiency problem, (section 3.2) and are thus excluded from the formal conclusions of the report. Nonetheless, a couple patterns appear to be fairly robust. First, 2004 was a bumper year for the Indian River, and this appears to have resulted in an abundance of strays finding their way into Spanish Bank Creek. This explains the strong positive correlation with Indian returns over time interval A & general lack of correlation through interval B. Second, number of fry released into Spanish exhibits no correlation over interval A & a negative correlation over interval B. This certainly seems odd and might reflect more on the relationship between Spanish returns & the filtered-out variables, which themselves exhibit correlation with releases (returns to most other creeks, for instance). Because of how short the time series is, random variation could easily result in intercorrelated variables being assigned coefficients that do not actually reflect their relation to the response variable. Finally, mean temperatures exhibit a rather robust zero correlation. That is, temperature is almost certainly not a cause of variation in returns. As mentioned above, we did not feel that these conclusions were strong enough to warrant a spot in the formal results portion of the report; as a result, they merely determined which areas would warrant further investigation (Indian returns & West Van returns).

2.2.2 The Matrix of Correlation Coefficients:

This is the second overarching analysis conducted, and it is much, much simpler than the multiple regression. It displays the correlation coefficients from Matlab's corrcoef() function between any pair of variables. It can of course be formatted in any way, with any combination of variables and years. Figure 11 shows the two most useful matrices.



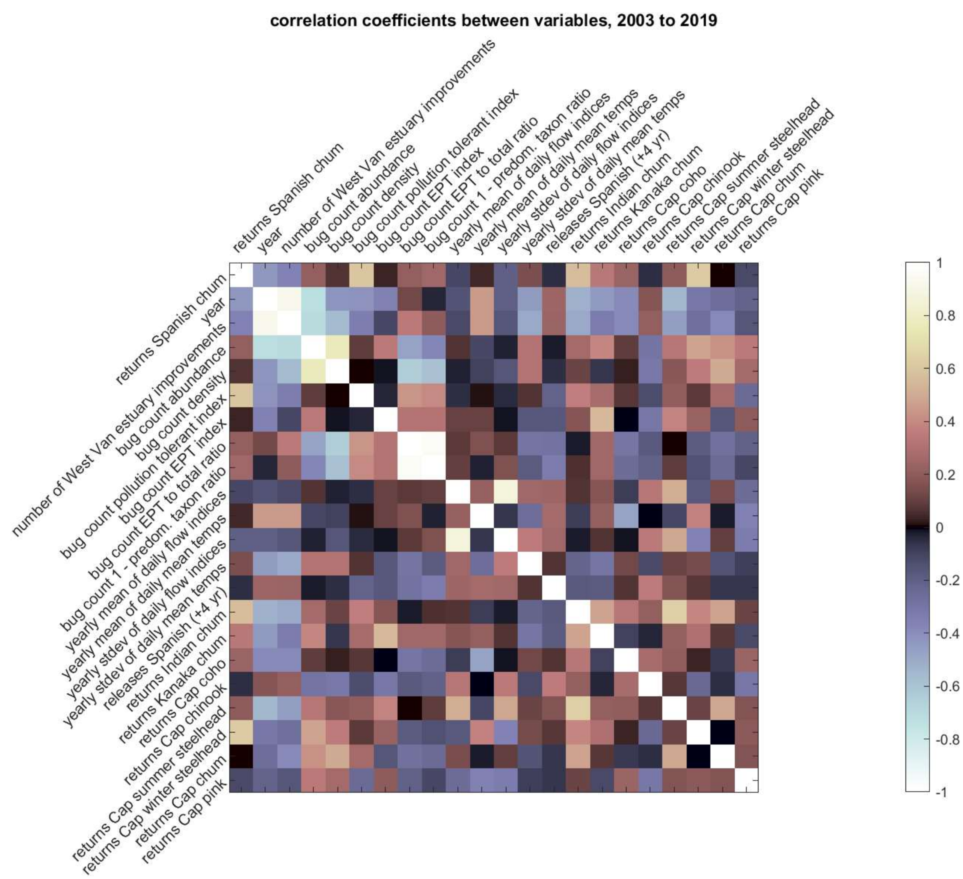


Figure 11. The two most useful matrices indicating the correlation between any two variables.

2.2.3 Water Quality at Spanish Bank Creek

The only measure of water quality available to us over any regular timescale is bug counts, (conducted by the Spanish Bank Streamkeepers & stored in the Pacific Streamkeepers Federation database) and even calling that "regular" is something of a stretch. First, we assessed the bug counts through the multiple regression & correlation matrix, which told us that: first, the 6 bug count variables kept by the Pacific Streamkeepers Federation are not positively correlated with each other to any appreciable extent, barring density & abundance, which are a simple arithmetic modification of each other. Second, of the 6, only EPT index (ratio of mayfly, caddisfly, and stonefly taxa to all taxa observed) consistently exhibited independence, with pollution tolerant index (total count of taxa, scaled by pollution sensitivity) & density (individuals per square metre) being variably independent. Third, only pollution tolerant index exhibited a substantive correlation with returns alone.

Taking these out into individual analyses, we get, as expected, a modest correlation with PTI & no correlation with the other two (Figure 12). Cutting the unusually strong (probably Indian-straying-linked, as discussed in section 3.1.8) 2003 – 2005 bump, where bug counts were thoroughly middling, improves the two weaker correlations somewhat, but not much. It seems safe to say that density & EPT index are not correlated with returns, and if PTI is, it is not solely responsible.

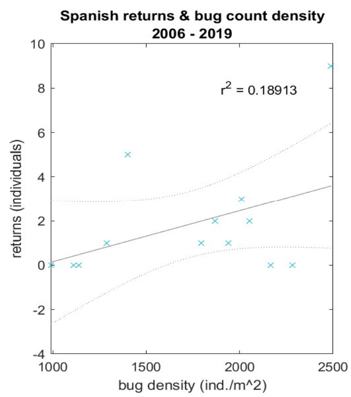


Figure 12. Correlations between bug count variables and Spanish Bank creek chum returns.

2.2.4 Temperatures at Spanish Bank Creek

Data on water temperature is rather incomplete, coming from a datalogger that was not consistently installed over our data collection period. 2006 was the only year of complete data, so we had to use that as a benchmark for modelling. Fortunately, when plotted against air temperature at Point Atkinson, we can see that the two variables are strongly correlated (Figure 13).

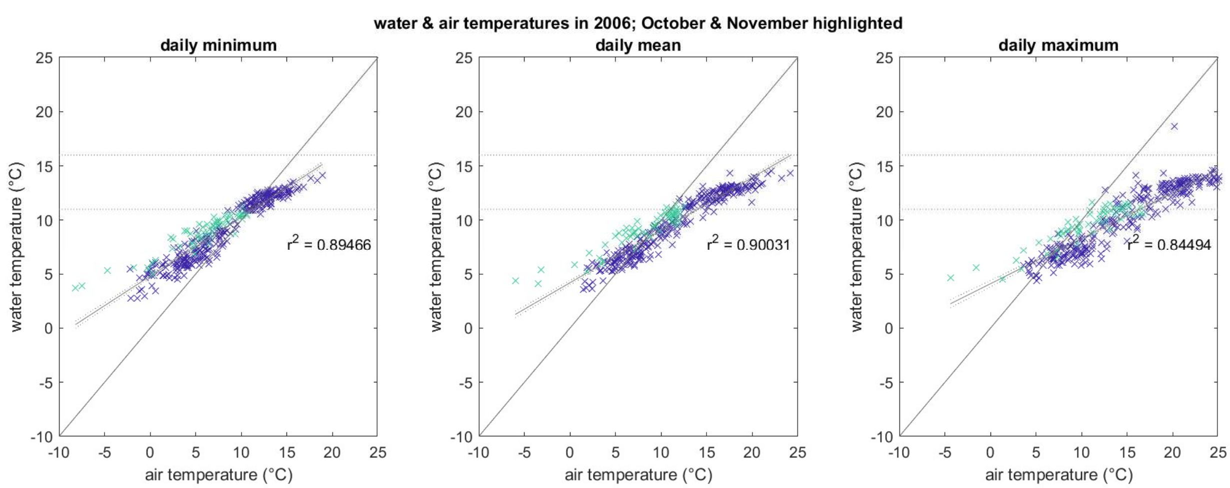


Figure 13. Correlation of Spanish Bank Creek water temperature and Point Atkinson air temperature.

As one would expect, air temperatures exhibit a greater range than water temperatures, so we should hesitate to use air as a direct substitute for water. However, the relationship is unequivocally monotonic, so water : water comparisons could reasonably be replaced with air : air. The lines at 11° and 16° indicate approximate levels for modest & acute heat stress for chum salmon, respectively (Beacham & Murray, 1986; Richter & Kolmes, 2005). Heat stress is clearly not a systemic problem after mid-October (when the chum run begins), so we didn't investigate further beyond the heatmap & mean temperature correlation analysis.

2.2.5 Streamflow at Spanish Bank Creek

Stream accessibility to salmon was modelled by taking the total time (in minutes) in each day during which the tide exceeds the sand bench—which obstructs the stream's mouth most of the time—and multiplying it by the three-day trailing rolling average of precipitation rate, yielding a "flow index" with units of mm. The averaging period of three days comes from an educated estimate of the time over which a rise in precipitation results in a significant rise in streamflow, based on visual observation after storms, the permeability of the Quadra sands, (the primary geologic stratum around the ravine) and the topography of the area.

Both measures were taken from Point Atkinson, as it is the oldest, most reliable, and most-used source of weather & tidal data in the Burrard area. As shown in section 2.2.4, Atkinson's weather tracks quite closely with Spanish Bank's, so using it here shouldn't be a problem.

2.2.6 Spanish Bank Creek Map

Two team members tracked the stream using a Garmin InReach (GPS), the Gaia GPS phone app, and a 19-year-old map drawn by Bob Seraphim as a guide (appendix). Tracking intervals were set to 15s and 1s respectively to collect the geospatial data. ArcGIS was used to create the map and a geodatabase was created that encompasses all Features created in the process of making the map. The stream, off-channel habitat (OCH), and landmarks' coordinates were all isolated into clusters of points using the Select Tool. Landmarks were left as individual points. The cluster of points representing the stream were turned into a line using the Point to Line Tool. The cluster of points representing OCH pond were turned into a line using the Point to Line Tool, and subsequently turned into a polygon using the Line to Polygon Tool. The Smoothing a Feature Tool was used to smooth the stream and OCH pond. The map was overlayed with a topographic map using the add basemap tool in ArcGIS. All these features were projected on a map, and a compass, legend, title, and datum used were all added as map elements. Moreover, two maps were created, the first one is a close-up version of the map without the topographic layer (Appendix). The second map included the topographic layer.

To compare the accuracy of the GPS and hand-surveying methods, we overlaid the close-up map (Appendix) on the hand drawn map (Seraphim, 2003; Appendix). To align the maps, the points "footbridge" & "two stumps" were fixed, and the maps scaled and rotated to align them. Footbridge was chosen because it is the lowest and most permanent feature of the stream (being a large block of concrete). Originally, chum release was chosen as the second point, but that resulted in a track that did not line up whatsoever. Thus, two stumps was used instead, as it is the most conspicuous feature of the upper portion of the stream (being two rather large stumps, under which the stream becomes subterranean for about 5m). This resulted in a better match, (Figure 20A) but with two remaining issues. First, the stretch of stream from the chum release platform to around the middle of Marine Drive appears to be at an entirely different scale from the rest of the track. Second, at the southern end, while the GPS track slowly curves east, the hand-drawn map does not. And third, the very conspicuous 90-degree bend between tire & two stumps appears to be rotated between the two maps.

By cutting and realigning the hand-drawn map in two places, we were able to resolve some of these issues. The conspicuous 90-degree bend matches up perfectly, as do several of the meanders on the upper reaches. However, the scaling issue around chum release remains, and a major error (a 90-degree bend that doesn't exist) has been introduced at cut 2.

Finally, a file (Spanish Bank Creek Map) was created and includes the following:

1. A geodatabase for Spanish Bank Creek
2. A glossary in the format of an Excel spreadsheet. It will include a description of all the Features (points, lines, and polygons) found in the geodatabase
3. A PDF version of the maps

The file will be sent to our community partners. This allows for the recreation and further modifications of the map in the future if needed.

2.2.7 Spanish, Indian and Kanaka Creek Returns

These bar graphs are fairly self-explanatory, but they simply line up returns to the three streams, with the portion above the interannual mean over the years assessed highlighted. Indian and Kanaka returns were chosen for more explicit visualization for several reasons. For both, correlations were observed with Spanish returns in the multiple regressions and correlation coefficient matrices, which warranted more explicit comparison. For Indian in particular, the most certain expert opinion we received was that Indian straying was responsible for at least some of the chum returns to Spanish in 2004 (S. Hinch, personal communication, 2021; Appendix). And because we were examining where the salmon appeared to actually be originating, (Indian) we thought it prudent to examine the source of the fry that should be returning—Kanaka, offset 4 years because we are comparing fry to (mostly) 4-year-old adults.

Beyond the basic visualization, some derivative analysis was done, and it was found that the second derivatives (i.e. concavity or acceleration) of each dataset correlated somewhat more strongly with each other than zeroth derivatives do. However, the difference was marginal, and there is no immediately obvious explanation for a second-derivative correlation, (our requests for expert comment went unanswered) so the results were not included here. They can be seen in derivativeAnalaysis.m.

As can be seen in the multiple regressions and matrices of correlation coefficients, returns to the Capilano River & West Van streams are not significantly correlated with Spanish returns, and so were not included in this comparison.

Part 3: Results and Discussion:

3.1. Why are chum returns in Spanish Bank Creek low? What factors can we eliminate as to the reason of low chum returns?

3.1.1 Is the lack of nutrients, food and shelter normally provided by an estuary causing Oncorhynchus keta to die shortly after leaving the creek?

After leaving the freshwater stream, the second part of the salmon's life cycle takes place in the estuary. Chum salmon spend 3-4 months in their estuary after leaving their natal stream, so the conditions they experience in the estuary are significant. One study conducted in various estuaries along the coast of British Columbia found that food abundance is an indicator of salmon population abundance in estuaries (Healey, 1982). The study adds that the estuary's carrying capacity for juvenile salmon is influenced by the estuary's morphology, food availability, secondary river channels, and streamflow. For the estuary to retain high carrying capacities of juvenile chum salmon, optimal conditions in the estuary must be maintained (Healey, 1982). The estuary of Spanish Bank Creek has not been restored, or even closely monitored, since the stream's daylighting in 1999 (Figure 14). This raises questions concerning the estuary's condition: food availability, temperature, morphology, pH, dissolved oxygen, etc., and those factors' impacts on juvenile chum.

Figure 14. the unrestored estuary at mid-tide + low flow (A); and perigean spring tide + high flow (B) (Pope, 2020)

Although optimal estuarine conditions increase survival rates, they are not necessary. With the exception of tributaries to the lower Fraser River, such as Kanaka, most streams on the South Coast of BC have poor estuarine conditions, while several have perfectly adequate salmon returns (Healy, 1982). For example, the Capilano River estuary is directly under a bridge, dominated by boulders with minimal sea grass and surrounded by human development, and yet has substantial (and, in some cases, growing) runs of several salmon species (H. Seshadri, personal communication, 2020; Appendix). The West Vancouver Streamkeepers have also struggled with poor estuarine conditions at their streams and have successfully improved conditions at three of their streams through estuary restoration projects; however, there has been no particular effort to establish chum in those streams, so the implications for Spanish are limited. A fourth project was attempted but has not yet been successful. Estuary restoration projects generally involve using heavy machinery to dig down and install large boulders to prevent wave scouring, followed by planting native aquatic plants such as Leymus mollis (dunegrass), Rosa nutkana, (Nootka rose) and Lathyrus japonicus (beach pea). This process is rather involved, and requires considerable financial investment—in the case of Spanish Bank, from DFO, which has made quite clear that it has no interest in undertaking such a project (S. Hollick-Kenyon, personal communication, 2021; Appendix). Furthermore, even if the project is successful in the short term, it would degrade over time as the macro-scale conditions that resulted in the current morphology will not have changed (S. Hinch, personal communication, 2021’ Appendix). Because of this, though the lack of an estuary at Spanish Bank Creek may be contributing to the poor chum returns, an estuary restoration project is not advised.

3.1.2 Is sedimentation preventing Oncorhynchus keta from re-entering the stream as adults?

The area surrounding Spanish Bank Creek is predominantly composed of the highly erodible Quadra sands, has been logged extensively, and continues to undergo development. These land use changes in such a fragile soil have allowed for higher rates of erosion than would be desired (Reynolds, 2017). Some of this sediment is deposited in the creek, causing blockages and an overall shallowing of the channel—a condition that is exacerbated by the low flow of the stream. This results in spawning habitat that is less than optimal as it makes it harder for the females to bury their eggs (Reynolds, 2017). Additionally, a study conducted by Birtwell (1999) revealed that salmonid species exhibit an avoidance response to highly turbid waters. The deposition of large amounts of sediment into the creek can also lead to lower levels of dissolved oxygen, consequently reducing the survival of eggs, embryos, and alevins (Birtwell, 1999). Near the mouth of the creek, there is a low footbridge, which would create a severe blockage if the channel were allowed to fill with sediment (Figure 15). Gravel cleaning is a technique that could improve these issues in the short term, but it would likely have to be carried out frequently as the issues causing sedimentation would remain unchanged. Fortunately, sedimentation levels have not worsened over the past 20 years, and blockages are cleared by DFO and the SBSk, so none of the issues associated with sedimentation have been allowed to become critical. Although negative impacts due to sedimentation are possible, action beyond the status quo is not recommended.

Figure 15. The very low footbridge at Spanish Bank Creek (Pope, 2020)

3.1.3 Is there a decline in the water quality in the past 20 years? If so, is the decline in water quality impeding Oncorhynchus keta returns?

Uncontaminated water is essential for the development of juvenile chum salmon, as well as for homing & spawning of adult chum. Temperature, dissolved oxygen, and pH are three water quality indicators that can affect chum salmon mortality. The ideal temperature range for adult chum is between 7 – 11°C, with eggs and alevin preferring temperatures less than 12°C and juveniles preferring a slightly warmer range of 11 – 14°C (Beacham & Murray, 1986; Richter & Kolmes, 2005). Cooler temperatures delay development, while higher temperatures can inhibit seaward migration, exacerbate the spread of disease, and cause premature death. However, spawning can occur at a larger range of 9 – 16°C, and acute lethality typically does not occur until 20°C. In one study in the Fraser River, the emergence and survival of chum alevins dropped from 90-99% when the water temperature was 8° to a low of 60% when the temperature was 12° (Beacham & Murray, 1986). Another study on various salmonids revealed that temperatures over 12 – 17° (depending on species) inhibit gill ATPase necessary for osmoregulation in seawater. This inhibition is associated with the loss of migratory behaviour in juvenile salmonids (Richter & Kolmes, 2005).

A study that examined the relationship between ten stream habitat characteristics and spawning chum and pink salmon density in 44 streams in British Columbia found that pH was the most positive predictor of spawning densities for chum Salmon. Low pH suppresses reproductive behavior and increases egg and fry mortality in various salmon species, with negative effects beginning at a pH of about 6.0. Newly hatched chum fry are particularly sensitive to this effect (Harding et al., 2015). Another study showed that spawning salmonids could exhibit an avoidance response when dissolved oxygen levels in a stream are insufficient (Carter, 2005). To this point, survival at many stages of life was greatly diminished when dissolved oxygen was below 3 mg/L (Koski, 1981).

There does not appear to be a systemic decline in water quality at Spanish Bank Creek, but the data was not collected every year and is based solely on bug counts (Figure 16) and temperature (Figure 17). There is also no dissolved O2 or pH data, so those areas remain unknown. There is little correlation between most of the bug count factors (and even less of the full suite) and chum returns. There has been no systemic change in mean air temperatures despite several exceptional years, and water temperature has been shown to track air temperature closely (section 2.2.4). Of the water temperature data that has been collected, daily highs during spawning approach the point of modest physiological stress, but are still within the bounds of acceptability.

We recommend that water quality data be collected far more systematically moving forward. A datalogger should be permanently installed in the stream to monitor water temperature, pH, conductivity, salinity, total dissolved solids, and dissolved O2, and should be downloaded & cleared monthly to avoid data overwriting. Manual testing should be performed at least monthly to monitor phosphate and nitrate/nitrite/ammonium concentrations.

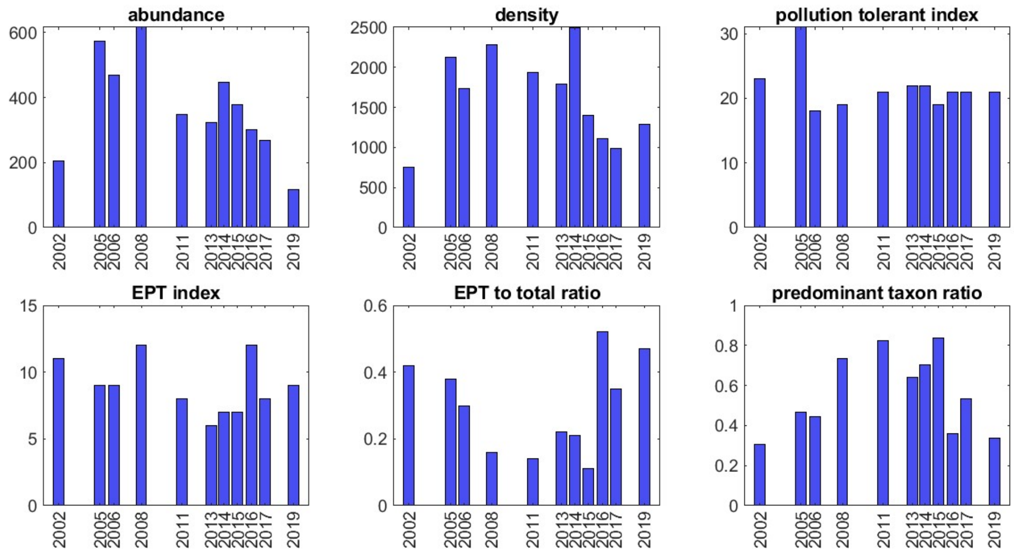


Figure 16. Six "bug count" statistics used by the Pacific Streamkeepers Federation to quantify stream health, as measured in Spanish Bank Creek in the summers since its daylighting. *Abundance* is simple count of invertebrates in water; *density* is abundance per square metre assessed; *pollution tolerant index* is number of taxa present, weighted by pollution tolerance of taxa; *EPT index* is the number of Ephemoptera, Plecoptera, & Trichoptera taxa present; *EPT to total ratio* is EPT index divided by the total number of taxa observed; and *predominant taxon ratio* is the portion of abundance accounted for by the most prevalent taxon (blackfly larva up to 2017, then mayfly larva in 2019)

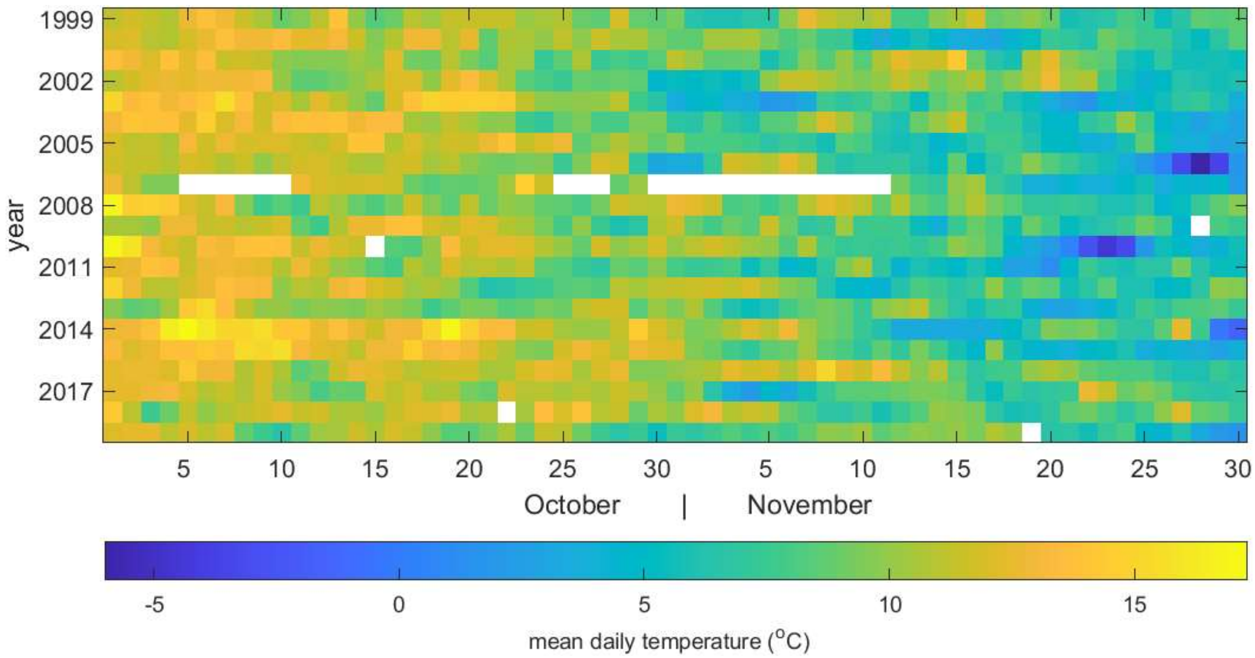


Figure 17. A heatmap of mean daily air temperature in October & November (the period over which chum return to the stream) at Point Atkinson from 1999 to 2019. Little change due to climate change can be observed over such a short timeframe, though the heatwaves of 2014 & 2015 are noteworthy, as are the cold snaps of 2006 & 2010.

3.1.4 Is the return of Oncorhynchus keta hindered by low and flashy streamflow?

Rate of flow impacts a number of elements of stream quality, including gas concentrations, pollutant levels, quality of spawning beds, and ease of access to spawning locations (Hunter 1996). Because flow rates are not monitored in most small streams, there is little information on correlations between flow and chum returns. However, the three consistent chum runs we were able to acquire data for (Indian River, Capilano River, and Kanaka Creek) all take place in channels with flow rates at least an order of magnitude larger than that of Spanish Bank Creek. And even then, chum have been observed waiting outside of the Capilano River for flow to increase before entering the stream (H. Seshadri, personal communication, 2020; Appendix).

At Spanish Bank, this problem is even more pronounced, as chum are not even capable of accessing the stream unless a particularly high tide is combined with high streamflow (Figure 18). This indicates that the stream is less than ideal for chum. However, there are several windows in every year when the salmon can enter the stream, and there is no significant correlation between flow rates and returns. We can conclude that, though streamflow may be dissuading chum returns in all years, it fails to explain the interannual variation.

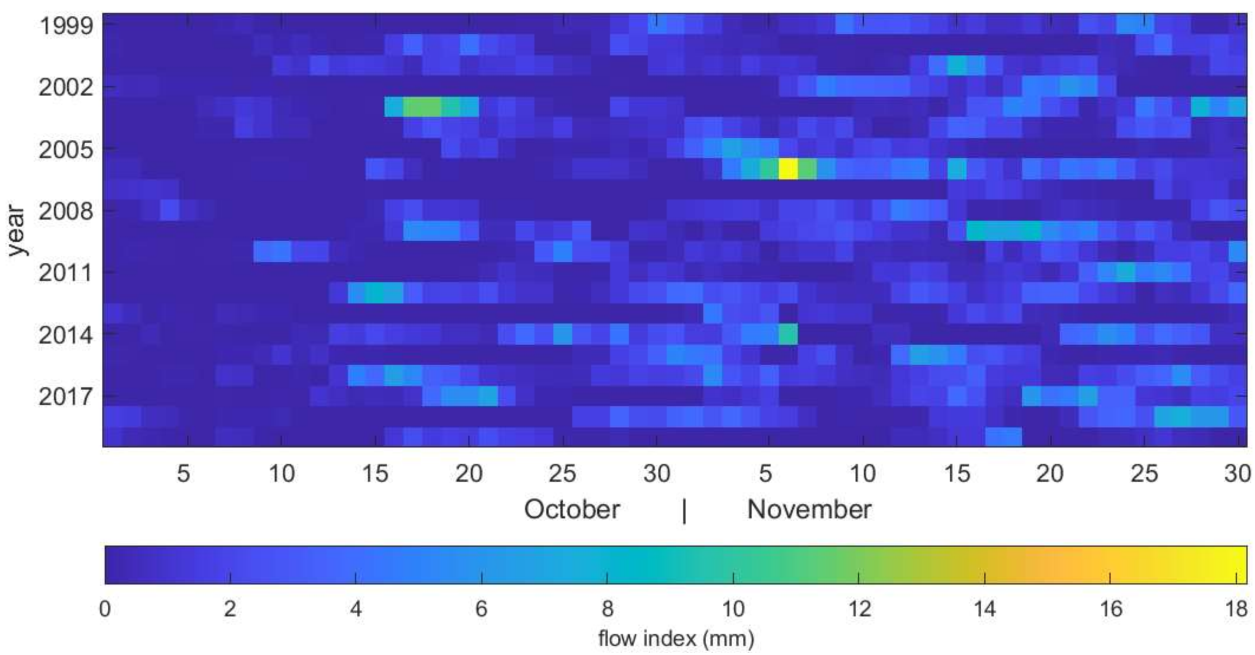


Figure 18. A heatmap of daily flow index in October & November, using tidal and precipitation data from Point Atkinson, from 1999 to 2019. Flow index is calculated by multiplying the amount of time in which sea height is over the "bench," (a sand bar that usually obstructs access to the creek from the ocean) in each day by the 3-day running mean of precipitation rate (3 days being a reasonable estimate of transit time to the stream, given its highly flashy response to rainfall). This is designed to operate as a reasonable estimate of stream entry opportunities for salmon.

3.1.5 How has the morphology of the stream changed over the past 20 years? Do any of these changes impact the return of Oncorhynchus keta to the creek?

Based on a visual inspection of the creek, a detailed 18-year-old map of the creek (appendix) that includes prominent landmarks, and a new GPS track of the creek (Figures 19 and 20) we can conclude that there have been some changes to stream morphology. All small falls and rock jumbles have disappeared—save the one directly above chum release (map in Appendix)—and the off channel (OCH) pond has been created (Figures 19 and 20). However, these changes are higher in the creek than chum travel, and have not even negatively impacted the coho that spawn in that portion of the creek, so morphology seems unlikely to be the cause of worsening chum returns.

Trees appear to fall fairly often in the bottom of the ravine. In our survey, we noticed many older fallen logs over the stream, as well as one truly enormous Alnus rubra, which had fallen just a few months prior. However, these all occur well above the chum spawning area, which is mostly surrounded by Rubus and Ribes shrubs.

Figure 19. A 2021 Topographic map of Spanish Bank Creek in Vancouver, BC, Canada.

To compare the accuracy of GPS and manual surveying methods, we overlaid the GPS track (appendix) on the hand-drawn map, (Seraphim, 2003; Appendix) using footbridge and two stumps as the fixed points (Figure 20A). This yielded a fairly close match across the middle of the stream, but there is a severe scaling discrepancy roughly between the chum release and the centre of Marine Drive, and while the GPS track curves gradually east at the southern end, the hand-drawn map does not. These suggest that, while the hand-drawn map captures the precise details of the stream's meanders much better than the GPS does, it lacks accuracy in some larger-scale features, such as gradual curves. It is possible that it was the GPS that erred in these respects, but that is unlikely, given the persistence of the features through two GPS tracks, and general nature of GPS error (random jitter on the order of one or two metres, rather than persistent trends on the order of tens of metres).

It should be noted that the hand-drawn map was made in two parts: north and south of what is now the OCH pond. This could explain the fact that the angles on the two segments don't seem to align. When the hand-drawn map is cut & realigned to correct for some of these large-scale discrepancies, another issue is created: a 90-degree bend that does not exist (Figure 20B). This could be an error stemming from the fact that the 2003 map was created in two parts. If the Spanish Bank Streamkeepers require a high-precision map, we would recommend physically resurveying the stream while recording a GPS track at the same time. However, for general use, we believe that any of the maps in figures 19, 20, or the appendix would suffice.

Figure 20A: The GPS track from 2021 overlaid on the hand-drawn map from 2002 (Seraphim, 2003). Footbridge and two stumps were used as the fixed points.

Figure 20B: The GPS track overlaid on the hand-drawn map (Seraphim, 2003), but with two cuts made in the hand-drawn map to align it more closely with the GPS track. Two major discrepancies remain, but the form of several meanders aligns very closely.

3.1.6 Did increasing or decreasing the number of Oncorhynchus keta fry released into Spanish Bank Creek, or adding artificial redds (2015,2017,2019) result in larger Oncorhynchus keta returns to Spanish Bank Creek?

Approximately 30,000 chum fry are released in Spanish Bank creek every year, but the exact number, timing, and strategies have differed from year to year.

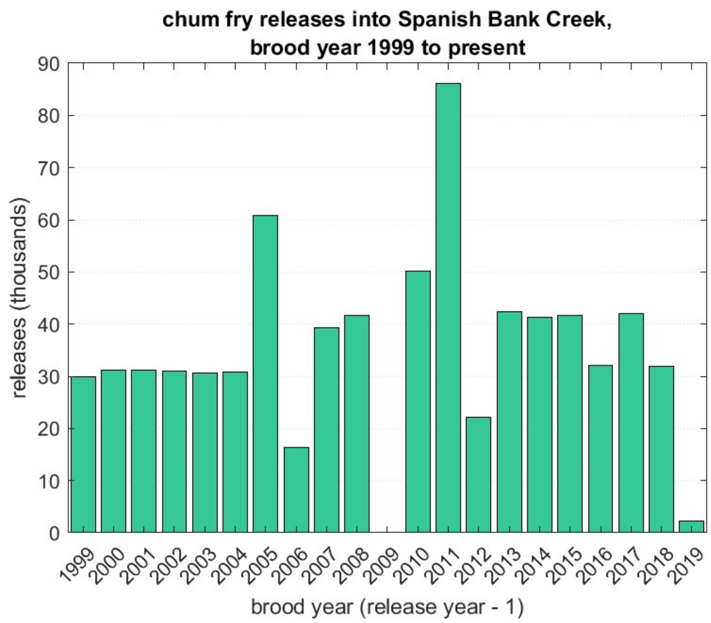


Figure 7. Number of chum fry released in Spanish Bank Creek, brood year 1999 (released spring of 2000) to 2019. Data from SBSK records.

The data for release strategies is very coarse, and no significant conclusions can be drawn from it. However, there was enough data to examine the impacts of fry size at release and the number of fry released. We found that neither of these were significantly correlated with returns (Figure 21). There were three years (2015, 2017, 2019) where eggs were placed in artificial redds, but too few years have passed to know whether this was successful.

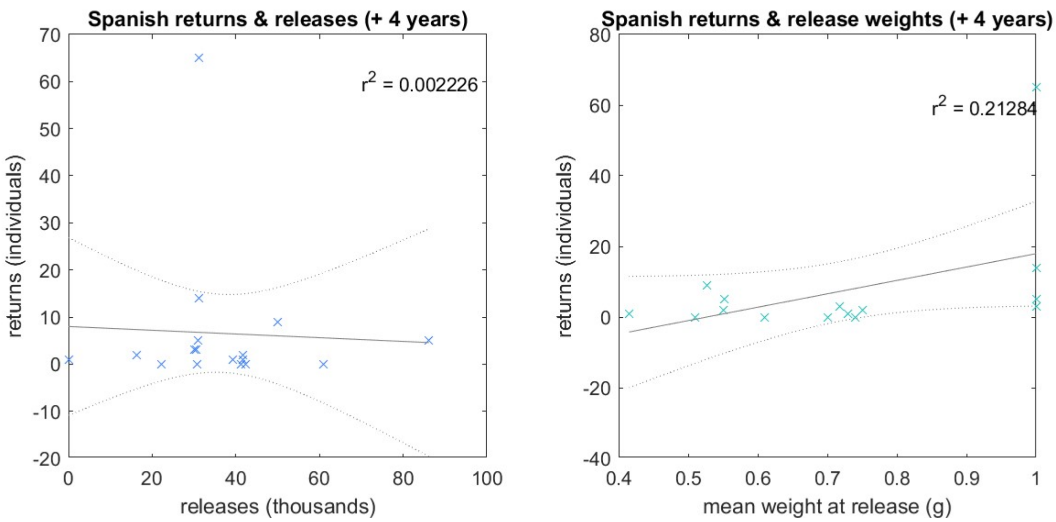


Figure 21. Number of returning salmon four years after release was not significantly correlated with the size of fry at release or the number released per year. The SBSKs also varied the dates of release, the length of time the fry were released over, and the number of fry released at once, but the variations were not systematic, and the data is too coarse to draw conclusions.

3.1.7 Are Oncorhynchus keta failing to imprint on Spanish Bank Creek due to their short residency in it?

Chum salmon imprint as juveniles in their natal stream. The fish use olfaction to imprint and, as adults, can identify their natal streams when their spawning time approaches. SNAP 25 is a protein responsible for pre-synaptic functions, imprinting, and memory in the brain of chum salmon, and amino acids constitute many of the odorants used in the imprinting-homing process (Abe et al., 2018; Yamamoto et al., 2013). The development of olfactory receptor neurons in the lifecycle controls the process of imprinting. Chum salmon spend very little time in fresh water, so they only develop 5 of their 18 olfactory membranes as fry before they imprint and begin migrating seaward (Kudo et al., 2009). This means they do not imprint as strongly as other salmon species, and straying from their natal stream is common. There is a hierarchy of olfaction used in homing; location is the most important, but a lack of other chum, overcrowding, or unfavorable spawning habitats can convince returning chum to stray and choose a different stream (S. Hinch, personal communication, 2021; Appendix).

The 2–3-week-old chum fry released every spring arrive from a hatchery located at Kanaka Creek, then spend only 2 to 3 days imprinting on Spanish Bank Creek before entering the ocean. This raises questions about whether the chum are returning to Kanaka Creek, where they were hatched, instead of Spanish Bank Creek. In addition, the species' tendency to stray and colonize new streams could mean the chum that have returned were not born in Spanish Bank creek (S.Hinch, personal communication, 2021; Appendix).

Of the streams we were able to acquire data from, none of them are comparable to Spanish Bank in imprinting. All either possess strong natural runs, (Indian, Capilano, Kanaka) and/or receive salmon reared in a local hatchery (West Vancouver streams). Of these, most receive considerably more chum returns than Spanish, although some West Vancouver streams do not (Nelson and McDonald) (J. Barker, personal communication, 2021; see data link in appendix). Because there is no other example of a stream receiving fry from as far away as Spanish & Kanaka, we cannot draw any robust conclusions about the success of different fry sources. Because of the lack of information on the matter, we would recommend experimenting with adding fry of various origins as part of a more systematic data collection scheme over the next few decades. If the Capilano hatchery's chum run grows to the point where it can begin exporting fry, that would be an ideal candidate for experimentation on the impact of origin proximity (H. Seshadri, personal communication, 2020; Appendix).

3.1.8 Are the Oncorhynchus keta from Spanish Bank Creek dying in the Pacific Ocean due to competition over food sources with other salmonid and fish species?

Climate change has caused the ranges of zooplankton, which are salmon's primary food source, to shift northward (Grant et al., 2019). This has resulted in changes in the food type and quality available throughout the Pacific system, and conditions for salmon in southern regions—the Salish Sea and the outer coast of BC, for instance—have rapidly declined (S. Hinch, personal communication, 2021; Appendix). Large salmon populations in the open ocean—driven by wild and hatchery stocks from Alaska, Russia, and Japan—have increased competition and caused the ocean to reach carrying capacity (Conners et al., 2019; Oke et al, 2020; Ruggerone & Irvine, 2018). The high abundance of salmon, combined with worsening marine conditions, has increased competition. The increased competition is delaying maturity, and is causing the size of mature salmon to decrease (Debertin et al., 2017). This is concerning, as numerous studies and expert opinions indicate that larger females are more fecund and better at finding spawning locations and protecting their eggs (by digging deeper egg pockets) than smaller females are. Moreover, increased mortality in salmon is associated with a reduction in size-at-age. A study conducted on chum in Alaska also confirmed that faster juvenile growth and larger body size are positively correlated with survival (Kohan et al., 2019).

Over the past 30 to 40 years, marine survival rates for all Pacific salmon species (including chum) have fallen by two orders of magnitude, from roughly 10% to 0.1% (S. Hinch, Personal Communication, 2021; Appendix). Poor marine survival is likely to be the primary cause for systemic low chum returns at Spanish Bank Creek. All salmon are faring poorly in the southern parts of their range, so it is hardly surprising that a less-than-optimal stream like Spanish Bank Creek is receiving barely any returns.

3.1.9 Are Oncorhynchus returns to Spanish Bank Creek correlated with returns to other streams in the Lower Mainland?

The conclusions of the correlation coefficient matrices and multiple regressions, along with expert opinion, led us to pull out Indian and Kanaka for explicit comparison (figure 22).

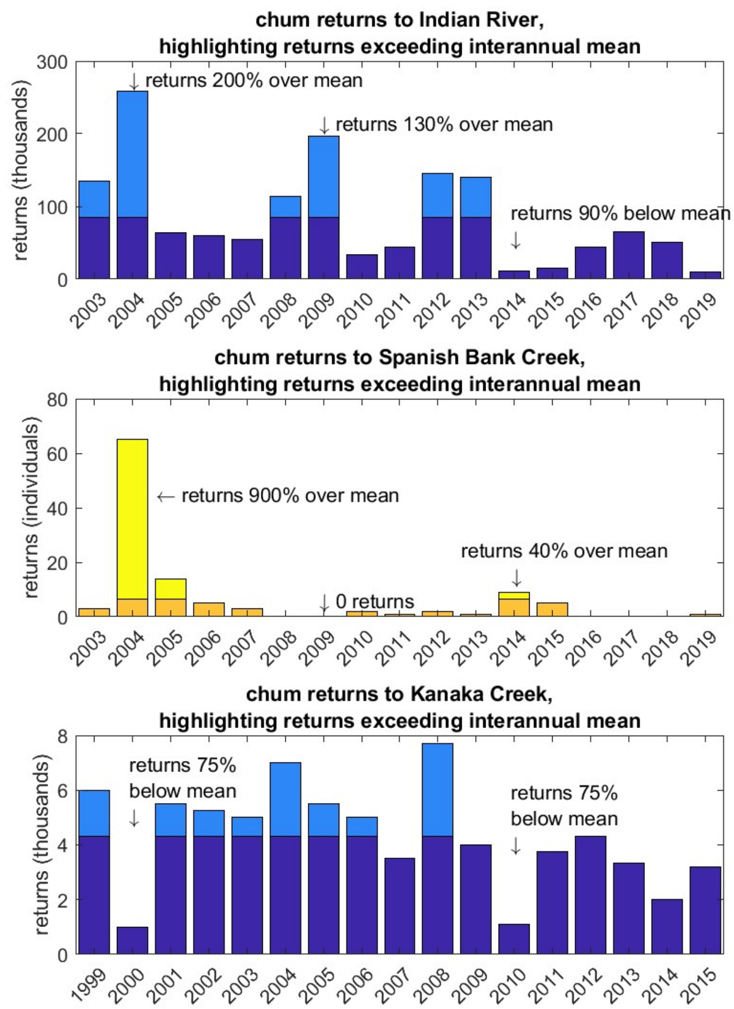


Figure 22. Chum returns at Spanish Bank creek in comparison to chum returns in the Indian River and Kanaka Creek (for which dates are offset by 4 years, to compare fry to adults). Particularly noteworthy years are annotated.

As has been demonstrated elsewhere, the 2004 bumper return to Spanish Bank was almost certainly due to straying from the bumper return to Indian River. This result is supported by the opinion of every expert we asked about the matter, including Scott Hinch. However, there are several other points of comparison that are much less clear-cut. First, returns to Indian in 2014 were quite low, while they were fairly high for Spanish. One hypothesis for this behaviour was that something was amiss in the Indian River in 2014, which forced a substantial return of 5-year adults from 2009 to stray to regional streams, including Spanish. However, 5-year returns are uncommon for chum, and Sandie Hollick-Kenyon does not recall any issue in the river in 2014, so this is unlikely (personal communication, 2021; Appendix).

A second hypothesis focusses on a different interpretation of the Spanish returns. Chum salmon return according to a roughly gaussian distribution, with most adults returning at 4 years old, and considerably fewer at 3 and 5. The Spanish returns can be viewed as two such gaussian distributions superimposed on a 0–3-fish baseline, with a large curve centred on 2004 & a smaller one on 2014. Interestingly, these happen to align perfectly with the two years of extraordinarily poor returns to Kanaka Creek, minus four years, (2000 and 2010) almost as though poor performance at Kanaka leads to fry that are more likely to return to Spanish. None of us are salmon experts, and none of the experts we asked about the matter were able to respond, so we cannot draw any firm conclusions here, but we feel that this certainly warrants further investigation.

3.2 Challenges:

Going into our analysis, we had 22 to 30 variables (West Vancouver Streamkeepers' eight return variables only begin in 2006, while the remaining 22 begin in 2003 or earlier) and only 14 to 17 data points (one per year) at best. However, several datapoints needed to be linearly interpolated (such as the bug counts, which only occurred every couple years) in order to include them at all. We made a judgment that the loss of accuracy from interpolation was worth the increased breadth of the search, as breadth of data was sorely lacking not only in the Spanish Bank Streamkeepers' records, but in the records of every other agency we contacted—Fisheries Canada included—as well. The missing data points are as follows:

variable	missing year(s)	notes
returns Indian chum:	2006	
returns Capilano chum:	2003	
releases Spanish weight:	*2014, '17, '18, '19*	*omitted from full analysis*
bug counts at Spanish:	2003, '04, '07, '09, '10, '12, '18	

Bug counts & release weights were the most problematic variables. Release weights were simply struck from the full analysis & assessed individually, but as bug counts are the only available indicator of any in-stream factors at all, (results from a temperature datalogger were even less complete) we decided that we had to include them in the analysis, poor quality and all.

The ratio of variables to datapoints caused another problem as well: rank deficiency. Rank deficiency refers to a state of affairs in which the number of variables roughly equals or exceeds the number of datapoints. It is associated with negative degrees of freedom and tends to break a number of analysis algorithms (such as the F-test used to evaluate the multiple regression, section 2.2.1). 22 variables to 17 datapoints is not too bad—that could be remedied by just removing some lower-quality variables; but 30 variables to 14 datapoints is considerably worse, and both of these were dramatically worsened by our decision to evaluate squares of the variables as well, wholly doubling the number of variables. In a strict statistical sense, we should have abandoned our attempt to conduct a multiple regression here. Such a large number of predictor variables all but guarantees that some combination of them will yield a very close approximation of the response variable: that's why rank deficiency halts the F-test. However, that seemed unsuitable to us; many of these variables were not even independent (several bug count variables are simple arithmetic modifications of each other), so surely, we could cut them down in a way that doesn't unduly select for correlations with Spanish chum returns. Our purpose in this stage of the evaluation was to cast as broad a net as possible & simply see what turns up; that's why we collected so many variables in the first place. So, rather than plugging the 44 – 60 variables directly into the multiple regression, we first sent them through a collinearity filter. This filter used Matlab's collintest() function to assess the collinearity between each pair of variables, then trim off the least-unique variables with a progressively more stringent filter until all remaining variables passed the test of collinearity to a confidence of 95%. See file collinFilter.m for details. In every case, the number of variables remaining was less than the number of datapoints, so although the rank deficiency had only been circumvented rather than resolved, we were willing to accept the risk of type 1 error in exchange for actually being able to observe what conclusions the multiple regression returns. And it was important that we made this decision, as the multiple regression gave us the impetus to further investigate Indian River returns, which wound up being our most substantive quantitative correlation.

Part 4: Conclusions

4.1 Next Steps and Recommendations

4.1.1 Recommendations to improve returns at Spanish Bank creek

The strongest predictors of *O. Keta* returns to Spanish Bank Creek are out-of-stream factors—particularly ocean survival rates and Indian River chum returns. These are out of the Spanish Bank Streamkeepers' control, and so are not strictly within the scope of our prescription. But should this report find its way to someone with the ability to impact these out-of-stream factors, we hope that it should prove a strong justification for doing so.

In-stream conditions at Spanish Bank Creek are similarly less than optimal. Estuary restoration and gravel cleaning might help to remedy the morphology and sedimentation issues, but we advise against them due to the high cost and low chance of sustained success (Roni et al., 2008; S. Hinch, personal communication, 2021; Appendix). Establishing a hatchery at Spanish Bank Creek was deemed unfeasible due to lack of DFO support and complications with electricity, and modifications to the OCH pond could risk worsening the stream by diverting the already meagre flow, so those are not recommended either. However, based on what we know about chum's olfactory hierarchy, feasible options that could improve chum returns include continuing placing eyed eggs in artificial redds, putting mature chum in the stream, and switching to a different fry stock located on the Burrard Inlet. Capilano would be very convenient, should they feel comfortable exporting fry; and Indian chum appear to already have an affinity for Spanish.

An alternative approach, as suggested by Scott Hinch, would be to switch to *Oncorhynchus gorbuscha* (pink salmon) as they are smaller and may be better suited to the small stream. They are comparable in ease of rearing to chum and have a similar life cycle timing. In addition, they return after only two years, which may be a more useful turnaround time for educational and scientific purposes. It is not possible to release both pink and chum as the larger chum will be too aggressive for the smaller pink when they return as adults. There are several pink salmon streams around the Burrard Inlet, including the Capilano River and a couple streams in West Vancouver.

4.1.2 Recommendations for Future Data Management and Collection

Due to limitations and gaps in the data we received, determining the cause for poor chum returns at Spanish Bank Creek was difficult. Moreover, data collection methodologies and chum release methodologies were inconsistent, which dramatically reduces the already-limited capacity for statistical analysis of the various methods. Therefore, we recommend the following:

1. Permanently install a datalogger in the stream to monitor water temperature, pH, conductivity, salinity, total dissolved solids, and dissolved O_2.
2. Manually test for phosphate and nitrate/nitrite/ammonium concentrations at least monthly.
3. Request that DFO tests the DNA of any chum that return in the future to try and gain more concrete evidence to support or reject the hypothesis that many returning chum are strays.
4. Be systematic with any new changes to release and data collection methodologies, so that their success can be assessed with minimal error.
5. Conduct further analysis in 10 – 20 years, once far more data has been accumulated.

If no changes yield improvements in returns, it is recommended that work be done to improve viewing opportunities of coho in the off-channel pond to continue the educational experience for both children and adults.

4.1.3 Recommendations for Future Education Programs

1. Utilize the new website as an educational tool:

   The website Weebly.com has been used to create an upgraded version of the Spanish Bank Streamkeepers' website. This platform can be easily operated, decreasing the chances of technical issues. Creating the website is free of charge making it feasible for an organization supported by volunteers. A Gmail account for the Spanish Bank Streamkeepers was created (SbkStreamkeepers@gmail.com), and was used for signing up on Weebly. The username and password for both accounts were given to our community partners to be used at their discretion. Furthermore, the website combines elements from the old site and our research. The following is the website's link:

spanishbankstreamkeepers.weebly.com

2. Use the artificial redd program as an educational tool.
3. Advertise about the SBSK in the local community to increase general engagement.

Authors' Biographies

Sara Alshanteer is a fourth year double major student. Sara's first major is Environmental Sciences with a concentration in land, air, ocean, and freshwater systems, whereas her second is English Literature. She has a background in ArcGIS, freshwater hydrology, and marine biology and microbiology. Sara is currently enrolled in a marine pollution course and aqueous environmental chemistry course.

Jessica Brown is in her fourth year of Environmental Sciences with a concentration on land, air, ocean, and freshwater systems. She has a background in data science with experience using ArcGIS, Python, R and Excel. She has also taken several courses on freshwater hydrology and an introductory oceanography course.

Mark Pope is a fourth year Environmental Sciences student with a concentration in land, air, ocean, and freshwater systems. Mark has worked as a nurseryman, stream water quality tester, and data aggregator for various projects. He is especially capable in MATLAB & Excel, and has taken enough hydrology (freshwater, marine, and sub-surface) courses to have a functional understanding of most processes at play in streams such as Spanish Bank Creek.

Joshua Shepherd is a fourth year Environmental Sciences student concentrating on ecology and conservation. Additionally, Josh is pursuing a minor in First Nations and Indigenous studies. Josh has developed his understanding of ecology, including Pacific salmon ecology, through relevant coursework and professional work.

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Appendix

All Data, Analysis, and Figures:

https://github.com/mark-pope0/Spanish_Bank_Chum

New Website:

spanishbankstreamkeepers.weebly.com

Communication with Experts:

Ross Davies – Kanaka Creek:

According to Ross Davies, Kanaka Creek provides 250,00 chum fry to 10 different streams in Burnaby and Vancouver, with the remaining 25,000 released into Kanaka. Overall, returns have been stable in Kanaka with some decrease in returns over the past 4-5 years. Strong chum returns were witnessed in 2020, with at least 6000-7000 adults returning. He noted that Kanaka's stream morphology is good, and no issues were reported regarding temperature and pH. Furthermore, it is worth noting that Kanaka is a flashy, unpredictable stream due to its large catchment area and geographic position, meaning it usually takes the brunt of atmospheric rivers in fall and winter. This can cause some floods, killing or damaging chum stocks.

When discussing Spanish Bank Creek, Davies noted that chum prefers larger streams and tends to stray. He stated that chum usually returns to the stream they were born in, however because of their tendency of colonizing other streams, chum's return to their natal stream is not exclusive. Even at Kanaka, chum rarely enters the tributaries and chooses to stay in the main channel. He emphasized the importance of flow on chum returns and encouraged analyzing Spanish Bank Creek's streamflow. As for 2020, he noted that no fry transfers to other streams occurred due to Covid-19 and its restrictions on volunteer activities.

Hamid Seshadri – Capilano River Hatchery:

According to Hamid Seshadri, chum returns are highly variable at Capilano and have decreased over the past years. However, 2020 proved to be surprising with larger chum returns than was expected. Hamid noted that they only count returns to the hatchery, disregarding any other fish entering Capilano River without making it to the hatchery. Furthermore, around 40% of salmon species are taken by First Nation weir fishing, indicating that the number of returns at Capilano is an underestimate. Furthermore, marking the salmon allows them to track which salmon is returning to their natal stream and which is straying. Salmon species at the Capilano estuary have coded-wire tags inserted in their nose. Their adipose fin is cut off as a method of marking them as well.

When discussing the estuary at Capilano, he stated that the estuary there is not ideal due to ongoing development. Like Ross Davies, he noted the importance of streamflow – again emphasizing the need for an analysis at Spanish Bank Creek. He also noted that Kanaka creek's water is composed mostly by surface water, unlike at Spanish Bank Creek, where groundwater gradient exists. He saw the difference is water sources as a reason that can affect imprinting. Hamid believes that adding fry from the correct water system is important and suggested trying Burrard fry rather than Fraser fry.

Files received:

1. Release data of chinook, chum, coho, cutthroat, pink, sockeye, and steelhead in most of hatcheries and streams located in British Columbia - excel sheet
2. Return data of chum, coho, and chinook at Brothers Creek for 2018 and 2019 - excel sheet
3. Capilano chum fecundity and survival (2010-2019) - excel sheet
4. Capilano water discharge (2009-2019)- excel sheet

5. Capilano chum, pink, coho, and chinook releases (2000-2018) - excel sheet
6. Capilano chum, pink, coho, chinook, and steelhead returns (1972-2019) - excel sheet
7. Map of Brothers and Hadden creeks - PDF
8. Nelson Hatchery Synopsis 2005 - PDF

Sandie Hollick-Kenyon and Brian Smith – Department of Fisheries and Oceans Canada (DFO)

The potential for creating a small hatchery at Spanish Bank Creek by diverting some water to the off-channel (OCH) pond was discussed in this meeting. The idea was rejected due to strict guidelines implemented by DFO. Furthermore, seeing that electricity supply is limited in that area and the minimal amount of chum returns, the stream is unfit for building a hatchery. The purpose of this creek is stewardship and education. Therefore, in the future, Sandie recommends that we continue with chum and coho releases since it supports the creek's purpose. Building an estuary was also deemed concerning and challenging. The concern stems from the need to receive approval for building or fixing the estuary at Spanish Bank Creek – an unlikely endeavor. As for inserting a camera to monitor chum returns at the creek, it was deemed extremely labor-intensive since it requires reviewing all footage manually.

Files received:

1. Chum returns to Kanaka Creek (1980-2020) - excel sheet
2. Hand-drawn map of Spanish Bank Creek - PDF
3. Original Spanish Bank Creek restoration proposal written in 1996 - PDF
4. Report by Nick Page and Markus Eyman (1994): Recommendations for the Reestablishment of Salmonids in Spanish Bank Creek - PDF
5. Spanish Bank Creek Average Daily Temperature (2003-2004, 2006-2007) - excel sheet

John Barker – West Vancouver Streamkeepers

Fourteen creeks in West Vancouver are suitable for salmonid species. John notes that salmon species exhibit a 10% straying rate. This was confirmed when they saw chum returns marked with a clipped fin – a tagging method used by other streams, including Capilano, to mark the salmon released from their hatcheries. When discussing the creeks West Vancouver Streamkeepers took responsibility for, John noted that Eagle Creek went from receiving 60 chum returns to zero returns in the past few years – speculating that a damaged culvert might have induced this decrease. However, even after fixing the culvert, returns have not recovered. John noted that three out of four of the estuary restoration projects were deemed successful; however, he emphasized that it is a large undertaking, requiring the need for big machinery to dig down and put in large rock to prevent wave scouring. The purpose of the estuary enhancement at Lawson creek was to create defined pathways that allow fish to come in on an 8-ft tide instead of a 16-ft tide. Similar projects were done at McDonald's and Rodger's creeks, and both were successful. One final thing discussed was the location of burying eggs or releasing chum fry in the creek. John deemed it unwise to put eggs/fry in a side-channel, seeing that the survival rate will decrease due to limited food and oxygen levels.

Files received:

1. Chum, coho, and chinook returns to 15 creeks under the jurisdiction of West Vancouver stream keepers (2006-2020) - 3 separate PDFs

Scott Hinch – Professor at the University of British Columbia (UBC)

Professor Scott Hinch discussed Pacific salmon runs in British Columbia. He stated that chum salmon are doing poorly due to climate change. Most BC salmon populations have a survival rate of 0.1% in the ocean – a vast decline from the 10% survival rate recorded 30-40 years ago. Moreover, all species are facing a decline in marine survival by one to two orders of magnitude, decreasing the amount of food available and increasing competition. Competition is also amplified in the marine environment by the enormous populations of salmon in the open ocean driven by hatchery stocks from Japan, Russia, and Alaska. Overall, ocean conditions have deteriorated rapidly both in the Georgia strait and the open Pacific.

When it comes to Spanish Bank Creek's conditions, Hinch stated that chum and pink salmon tend to stray more than other salmonid species because of the limited time they spend in the stream before heading out to the ocean – decreasing their imprinting period. He noted that straying chum from the Indian River is likely the cause of 2004's large chum returns at Spanish Bank Creek. This can be attributed to overcrowding seeing that overcrowding a stream can cause salmon to stray. It is also possible that Kanaka fry was never imprinted – raising the hypothesis that all chum returns to Spanish were the result of salmon straying. Furthermore, chum salmon follow the smell of other chum when choosing a creek to spawn at. Therefore, if an adult chum does not smell other chum in the stream, they tend to enter and then leave the stream. Hinch also commented on Spanish Bank Creek's spawning habitat, stating that it is not great and eggs might die there because of natural processes. The presence of erodible soils at the creek causes the accumulation of fine sediments. Due to low flow, fine particles cannot be flushed out easily. Fine sediments decrease oxygen levels in the creek's bank – the location at which adult chum bury their eggs.

When discussing restoration efforts at Spanish Bank Creek, Hinch thought cleaning the gravel might be helpful. He also suggested adding adult chum into the stream and having them spawn there. He was supportive of adding the artificial redds or changing the focus from chum to pink salmon. pink salmon are three times more abundant than chum with an average life-cycle of 2 years; however, their survival rates are no better than chum. As for estuary restoration, he believed their success rate is low. Moreover, the restoration will be temporary, seeing that it does not solve any underlying problems. He believed that walking away and allowing nature to take its course can be the most successful restorative method.

Ron Gruber's field notes:

We received a combination of hand-written and printed field notes written by Ron Gruber, a former Spanish Bank stream keeper. They were documented over the span of 14 years (2000 – 2014). Once digitized, these notes discussed the following:

1. The first and last date of arrival for chum and coho.
2. The total number of adult chum returns.
3. The dates and numbers of chum fry released annually.
4. Documentation of any salmon predators near the stream.
5. Any observed morphological changes to the stream.
6. Dates and numbers of bug count.
7. Dates documenting periods of heavy rain and stream floods.

→ A sample of Ron Gruber's field notes:

June 19 2002

d) Water sampling at Chancellor Blvd: Bob reported on the results of water samples, collected by Sandie and Ron, that he had analysed. The results did not disclose anything unusual other than a higher than normal iron content, probably coming from the culvert pipe and fill under Chancellor Blvd.

e) Fry trapping: May 28-29/02 six 1/8" mesh net traps were used. 111 coho fry were captured with an average size of 5.2cm to 5.6cm. As a number of fry were captured above, what was thought to be an impassible cascade, there was discussion/speculation that one or more adult pairs had spawned above the cascade.

3) The third order of business was the treasurer's report: As Maurice had only just been appointed, he advised that the bank account had been set up and that he was working on budgetary matters, such as source and application of funds.

Account balance: $260.96 @ June 19/02

4) The fourth order of business was a review of proposed In-Stream work projects for the Aug/Sept work window:

a) Ron reported on his on-site consultations with Scott Ducharme in regards to 5 spots needing habitat improvement/enhancement:

i) Pool immediately below the bridge: Action, dig out silt from around existing habitat log.

ii) Pool above the bridge: Action, dig out silt to deepen existing channels.

MEETING OF THE SPANISH BANK STREAMKEEPERS GROUP
Held at Aberthau on Jan.20/04 at 1 pm.

Present: Dick and Jilian Scarth, Maurice LeGallais, Ron Gruber, Sandie Hollick-Kenyon, Cal Easter, ZoAnn Marten, Ken Fowler; arriving later: Kathy Chambers, Bob Seraphim. Dick chaired the meeting.

1. The first order of business was a review of events, by Dick, since the last meeting Nov.22/02.
   a) Trapping for fish presence: Ron reported trapping 51 pre-smolt (7.5 to 10.5 cm) over Mar. 11-12/03. Six traps were used with 32 Coho caught in one trap.
   b) Chum drop: On Apr.15 & 22, & May 5, 32000 Chum fry provided by Federal Fisheries were released by several volunteers. Sandie reported that the same program will be done in 2004. Around Apr.4-5 Dick and Norm were involved with the set up of the Chum Drop Platform for Chum release by the school classes. The platform was taken out in June and stored at the GVRD Works yard.
   c) In May/03 there was trapping for emergent Coho fry from the natural spawn from Fall 2002. Result: 3 Coho, 3 large sculpins.
   d) On Aug.14/03 2000 Coho, with adipose fin clipped, were released below Belmont. Sandie advised that they came from Capilano hatchery.
   e) Catching the Spirit kids worked on two projects: Firstly, on July 19/03, under the direction of Ron in-stream habitat improvements were made. Secondly, on Aug.20/03 a fence was constructed blocking off the illegal trail that runs parallel to the stream south of the Chum drop area. (see Fig.1) Dick reported that the GVRD had closed off the top end of that trail. There was some discussion as to whether further closure of the trail was needed. Decided not to do more at this time.
2. Maurice gave the Treasurer's report: He reported that there is $205 in the bank account and very little activity over the past year. Under budget for 2004. Money for Streamkeeper courses, making copies of Bob" map, and signage/art design for information posters are to be included in the 2004 Budget request.

3. Ron gave a chronological report on the Lower Watershed:
   a) Dec.28/02 Ron saw one adult Coho carcass.
   b) Mar./03 through Aug./03 reported under 1 (a) to 1 (e) above.
   c) Sep.30/03 Ron observed that most of the Coho fry from the Aug.14/03 drop had moved downstream above and below the road.
   d) Oct.15-16/03 Extreme high water flow. Ron believes all the Coho fry were blown out of the stream.
   e) Oct. 23/03 One dead Coho adult approx 5 pounds observed.
   f) Oct. 24/03 Two dead Chum adults observed.
   g) Oct. 26/03 One dead Chum adult male observed in the Creek near the bridge, approx. 11-12 pounds. (see Fig.2)
   h) Nov.25/03 One live Jack Coho observed.
   i) Nov. 28/03 A big flood resulting in a lot of silting.

Last Meeting → June 20/08 ATT "B"

June 28/08 Norm Walker + R Gruber went to "Ugly Bug Ball" in Surrey

Met many interesting People including Eric Olsen from Noons Creek - (end of Burrard Inlet) Fish Hatchery - Took Carvings of Salmon - Coho - smolt Trout

July 17/08 I Met Prof. Barry Bond + His UBC. Science Class @ Spanish Bank Creek Gave 45 min. Talk on Hist. of Stream & our endeavours to Re-establish Run of Salmon (4th year?) - Talks

July 18/08 Spoke To Rob Knight - "Dept of The Environment - Re Cutthroat Trout + Our Stream - had positive view on Transfer of Trout from Possibly Noons Creek - as" is in Burrard Inlet

July 28th/08 Met Mel Lehan - Tara Cullis + 2 others Susuki Foundation members @ Spanish Bank Creek - Had Walkabout - Told them of our History - They're interest in Possibilities of Tatlow Creek Restoration

SPANISH BANK STREAMKEEPERS SPRING 2010 MEETING

AGENDA

Date: Wednesday, February 3rd, 2010
Time: 1:00 p.m. – 3:00 p.m.

Place: Library at Aberthau, WPGCA, cnr. 2nd Ave & Trimble

1.0 Treasurer's Report (Maurice) $629.50 in bank.

2.0 Field Reports

a) Department of Fisheries & Oceans (Sandie) → no RN's [illegible] on CK.; service awards to Directors
b) Upper Watershed (Maurice) [illegible] survey.
c) Lower Watershed (Ron)* → Beaver rectified

3.0 Business Arising from Fall '08 Meeting (Nov.25th)

a) Membership in Musqueam Creek Ecosystem Society

4.0 New Business

UBC program (

a) Salish Creek feasibility study → Ron:
b) Trap Coho Pre-Smolts (Sandie) → march
c) Chum & Coho Drops (Sandie) → 2 x 20,000 Chum
d) Invertebrate Count (Richard) Sandie
e) Ivy pull with CtS (Dick) ok
f) Stream rehabilitation with CtS (Ron) ok.

5.0 Next Meeting

Ron's LW Rep. * from Nov 25/08

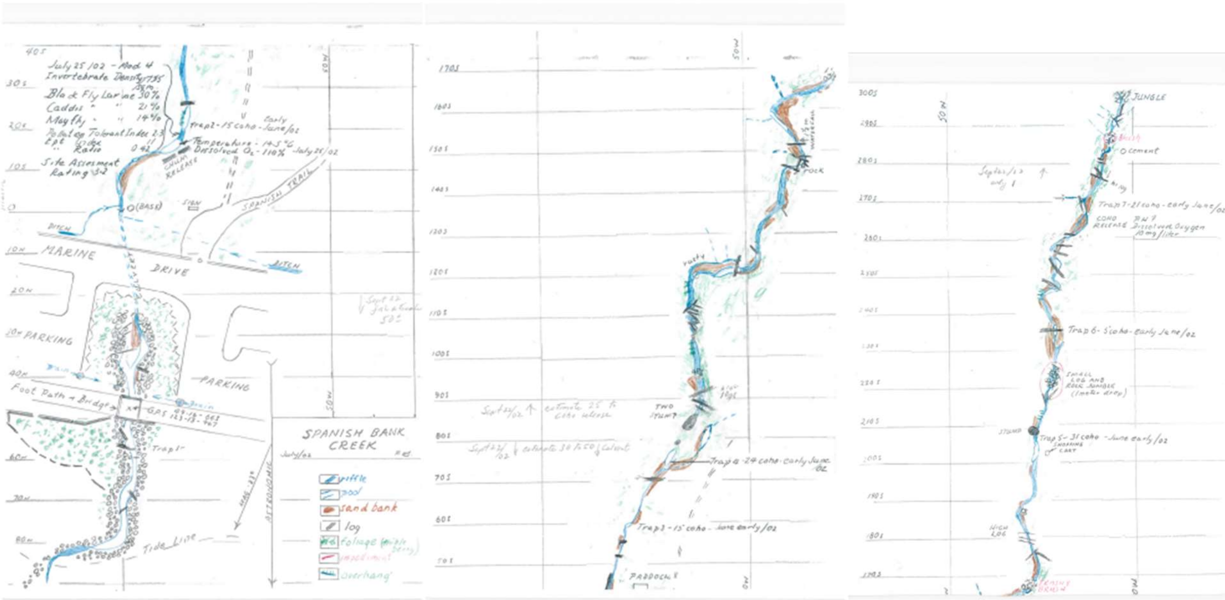
(1) Small salmon off-shore fall → spring
(2) swiss lecturer: climate change re brown trout > water temp glacier retreat. climate ch. start. '87-'88.
(3) Conference in [illegible]/09: emphasis on wild salmon - must be preserved "ranch" salmon vs farm salmon; salmon moving North because of warm water, withdrawing [illegible] from southern rivers (in US).

→ A sample of Ron Gruber's field notes (digitized):

20	Year	Month	Day	Occurrences
21	2004	October	18	First chum arrived
22	2004	November	14	Last chum arrived; 59 chum in stream, 6 dieg on beach, total 65
23	2004	November	18	First coho arrived
24	2004	November	21	Second coho arrived
25	2004	November	25	2 more coho seen
26	2004	November	26	Large female seen
27	2004	November	30	Last coho arrived (male, 6 lb); joined [hg]? female
28	2004	December	2	Large female spawned at culvert mouth; eaten by otters
29	2005	January	16	Heavy rains for 48 hours, record-breaking; creek in flood for 4 days; temp 5 - 5.5 degrees
30	2005	January	18	Washouts on Marine Drive, closed for 9 days
31	2005	February	8	Saw first chum fry at bridge
32	2005	February	14	Saw 4 chum fry below culvert
33	2005	February	16	Heavy silt in stream from west ditch on Marine
34	2005	February	17	1 chum fry
35	2005	March	4	8 chum fry at culvert
36	2005	March	7	Chum release platform installed
37	2005	March	10	Dug out sand bar cutting off OCH pond
38	2005	March	12	Replanted salmonberries & assorted evergreens salvaged from OC Habitat dig in Sept 2004
39	2005	March	18-19	Set traps in OCH & adjoining creek; caught 9 pre-smolt cohos, 2 salamanders in OCH, 2 chum fry in creek
40	2005	March	23	Saw 6 coho fry below rock pool 100 m above twin stumps; total of 50+ chum fry
41	2005	March	23	Took photos of mink sleeping in the sun on stump near the bridge
42	2005	April	5	Beaver arrived (witnessed by neighbour whose dog got into a "fracas" with same)
43	2005	April	21	Planted 10,000 chum fry
44	2005	April	21	Beaver cuttings stopped; believed to have moved on
45	2005	April	26	Planted 10,000 chum fry
46	2005	May	5	Planted 10,000 chum fry; found dead "oolichan" (eulachan?) at OCH pond
47	2005	May	7	Eulachons being fed on by birds near anchor

	A	B	C
1	Year	Chum returns	
2	2003	3	
3	2004	65	
4	2005	14	
5	2006	5	
6	2007	3	
7	2008	0	
8	2009	0	
9	2010	2	
10	2011	1	
11	2012	2	
12	2013	1	
13	2014	9	
14	2015	5	
15	2016	0	
16	2017	0	
17	2018	0	
18	2019	1	
19	2020	1	

Hand-Drawn Map by Bob Seraphim:



New (2021) Map of Spanish Bank Creek