Homeward bound: A population study on Chinook Salmon (*Oncorhynchus tshawytscha*) in the Capilano River

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Abstract

The decline of Pacific salmon populations on the west coast of Canada has been observed for decades. Hatcheries are used as one solution to this issue, however the benefits and detriments of releasing hatchery-grown salmon into the wild are widely debated. We investigated the release and return numbers of Chinook salmon, *Oncorhynchus tshawytscha*, at the Capilano River Hatchery in North Vancouver, British Columbia. This study focuses on: (1) establishing whether or not there is a declining trend in the number of returning Chinook salmon over the past seven years, and (2) deciphering the survival rate of a population of salmon. Data was collected by counting the returning Chinook salmon over 10 trials of one hour each. We calculated daily average as well as the use of the release and return data of previous years at the Capilano River Hatchery. The returning rate of Chinook salmon over the past seven years displayed a declining trend until the input of our data, which may be a result of unaccounted environmental factors, such as river height. The return numbers for the 2010 population of Chinook salmon was less than 1.28% in comparison to the amount of salmon released (98.1%). When comparing 2010-2016 return numbers per year, there was no significant effect on returns ($z=0.864$, $df=6$, $p=0.3875$), but there was a significant effect of both Sea Surface Temperature (SST) ($z=2.343$, $df=6$, $p=0.0191$) and an interaction between year and SST ($z=-2.338$, $df=6$, $p=0.0194$) on return numbers. The benefits of these hatcheries remain unclear and should be further studied.

Introduction

Salmon are a critical component of, not only the riparian ecosystem, but the terrestrial and marine ecosystems in British Columbia. They provide a crucial link of nutrient transportation from marine to terrestrial systems (Helfield and Naiman 2006). Salmon spawn in freshwater and the juveniles migrate to marine ecosystems to grow and mature. They then return to the same stream in which they were born in order to spawn (Healey 1991). Many mammal and bird species rely on salmon as a major nutrient source and they obtain these nutrients from the salmon through predation or scavenging of post-spawn carcasses (Helfield and Naiman 2006). It has been demonstrated, by Hilderbrand et al. (1999), that 83-84% of the marine-derived nitrogen in White Spruce (*Picea glauca*) is delivered from salmon to the trees, through bears. Salmon are also a critical food source for First Nations on the Pacific coast of Canada and conservation of the Pacific salmon stocks has become a rising topic of concern (Kerri 2006).

Pacific salmon populations along the west coast of Canada have decreased over the last 30 years due to factors such as disease, changes in nutrient availability, and climate change (Crozier et al. 2008; Noakes, Beamish & Kent 2009). In 2016, an unusually low number of Chinook salmon, *Oncorhynchus tshawytscha,* migrated upstream and created concern about future run numbers (Taylor 2017). A study done by Finney et al. (2000) indicates that climate change can impact the population of returning salmon and influence the abundance of nutrients available for the juvenile Pacific salmon in that ecosystem. As a way of recovering salmon populations, the Department of Fisheries and Oceans (DFO) of Canada operates 23 hatchery facilities and spawning channels, which release hundreds of millions of juvenile salmon every year to supplement wild stocks, as part of their Salmonid Enhancement Program (SEP), (DFO 2015). The DFO insists that this number contributes to 10 to 20 percent of all salmon harvested in BC. As a result, hatcheries are thought to offshoot the amount of salmon lost in the marine system, however there is great debate surrounding the effectiveness of hatcheries and whether they are negatively affecting natural salmon populations (Brannon et al. 2011).

Despite the possible risk of the spread of inferior genes from hatchery salmon to wild Pacific salmon, the benefits of these hatcheries in the maintenance of salmon populations are hard to challenge. Additionally, employees of the SEP claim that the performance of hatcheries is hard to measure due to insufficient data concerning the return numbers of released salmon (DFO 2015).

This study was performed to observe the effects of the current population recovery system on Pacific salmon on the West coast of Canada. In order to do so, we focused on two objectives: (1) establishing whether or not there is a declining trend in the number of returning Chinook salmon through the comparison of return numbers over the past seven years, and (2) deciphering the survival rate of a population of Chinook salmon through the comparison of release and return numbers over a period of four to seven years. This study is based on the finding that salmon return to their original spawning site after spending three to eight years in the ocean (Healey 1991; Yamamoto et al. 2010). This timeframe was adjusted to a period of four to seven years, according to local sources on the tendencies of the Chinook salmon of the area (Uittenbogaard 2017).

Based off of data from previous years, we hypothesize that (1) there will be a declining trend in the number of Chinook salmon returning to the Capilano River Hatchery, and (2) the returning numbers of Chinook salmon will be smaller than the number of salmon released from the hatchery. Chinook salmon were used since the timeframe of the study (October-November) directly coincides with the timing of their run.

Materials and Methods

Study Site

In order to estimate the number of Chinook salmon returning to spawn in the Capilano River, we counted the number of Chinook salmon successfully climbing up the ladder at the Capilano River Hatchery in North Vancouver, BC (49.357, -123.110). The Capilano River empties into the Burrard inlet on the coast of British Columbia and the hatchery is located upstream, in a well-shaded canyon. The establishment consists of salmon rearing ponds, holding tanks, and a fish "ladder" where water is released into the Capilano river with great surge in order to create a waterfall for salmon to "climb" up. The "ladder" is essentially a large rectangular chute connecting the river to the hatchery "spawning ground" at a higher elevation. It is a structure built to create artificial barriers to facilitate salmon's natural migration, and reach their "spawning ground," which, in this case, is the top holding tank at the hatchery. The "ladder" consists of tiered wells that each contain water flowing over the edges, creating "steps" for the salmon to jump over and into the next water well. The hatchery also provides an observation room with multiple windows to the fish ladder. The third window from the left was used for the data collection in this experiment.

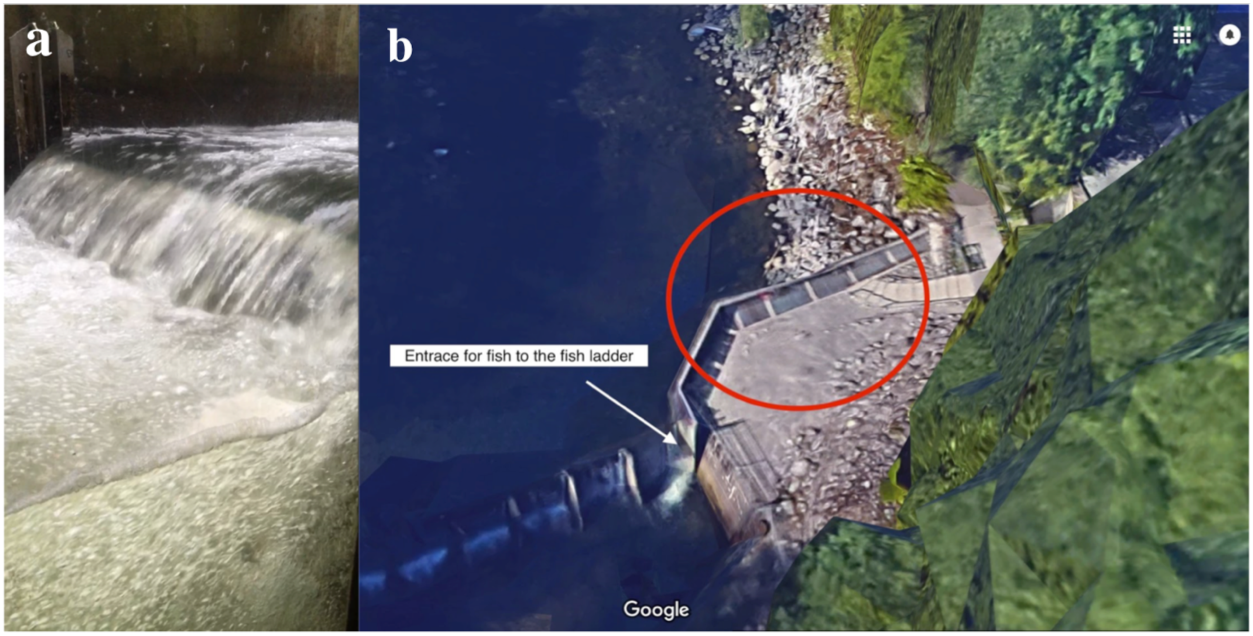

Figure 1. (a) Ladder of third observation window at Capilano River Hatchery. Picture taken by Juhui Lee. (b) Satellite image of Capilano River Hatchery (49.357, -123.110). Circled area represents grills where the fish ladders are located underneath. Observation room is beneath cement platform.

Data Collection

From October 25 to November 10, 2017, we visited the Capilano River Hatchery 10 times to collect data. During each visit, within the hours of 8:30-16:20, we observed the Chinook salmon climbing up the ladder for one hour. The length of time was measured through the use of an iPhone timer. A handheld counter was used to count the amount of Chinook salmon that successfully made it past the designated step as well as those that fell back down the step. We carried out the counting in pairs in order to separately keep track of the amount of salmon climbing up and the amount of salmon falling down. In order to estimate the total number of salmon successfully climbing up to the top of the ladder, we subtracted the total number of salmon that fell back down the step from the total number of salmon that made it past the step.

Data Analysis

The number of salmon successfully making it up the ladder, determined from each of the 10 trials, was averaged in order to obtain an average number of returned salmon per hour. The total return number of the 2017 Chinook salmon population was estimated through the use of the following formula:

Total return number of salmon =

Average number of returned salmon per hour x 9 hours/day x 7 days/week x 8 weeks

Nine hours represents the average amount of daylight during the run period. It was determined that the majority of the Chinook salmon are active during daylight hours (Uittenbogaard 2017), therefore, periods of darkness were disregarded. The average amount of daylight was 10 hours in October and eight in December. Eight weeks represents the estimated duration of the Chinook salmon run based off the hatchery's record from last year's run.

Annual Chinook return and release data from the past four to seven years was obtained from the Capilano River Hatchery (Operations Manager: Ashley Uittenbogaard). Sea Surface Temperature (SST) data was acquired from Government of Canada's Open Government data site (British Columbia Lighthouse Sea-Surface Temperature and Salinity Data (Pacific), 1914-present, Amphitrite Point Lighthouse (48.922, -125.538).) This data was used to compare the average number of Chinook returns in 2017 to previous years, as well as to compare the number of Chinook released in 2010 to the returns of the same population across 2014 to 2017. We also compared the annual return data from previous years to SST to see if there was a correlation.

Statistical Analysis

A Generalized Linear Model with a Poisson distribution was used to compare the number of Chinook returns per year and to compare year and SST to number of Chinook returns. Descriptive plots were created in Excel version 15.36 (2016). All statistical tests were performed using RStudio (R version 3.3.2, 2017). The critical value (alpha) used for each of these statistical tests was $\alpha = 0.05$.

Results

Less than 1.89% of the Chinook released in 2010 successfully returned to the Capilano River Hatchery, while 98.1% never returned (Fig. 2). When looking at four to seven years after a high release number in 2010, we do not see high return numbers of the same Chinook population released. A significant trend can be seen when comparing the return number per year, 2015 to 2017 (GLM, Poisson $z=64.50$, $df=7$, $p<2e-16$; Figure 3.). Observational study of our data demonstrated that 2017 had the largest return numbers compare to the previous seven years. 2015 had the lowest return number of Chinook salmon and there is a general trend of decreasing Chinook returns from 2010 to 2015. 2016 demonstrates a small increase in returns while 2017 demonstrates a major increase in Chinook returns.

The varying size of the return population for each year appears to be driven by SST (Fig. 4). There was no significant effect on returns ($z=0.864$, $df=6$, $p=0.3875$), but there was a significant effect of both SST ($z=2.343$, $df=6$, $p=0.0191$) and an interaction between year and SST ($z=-2.338$, $df=6$, $p=0.0194$). This suggests return number increases with temperature. Highest return numbers were observed in our initial observations while lower numbers were observed in our later observations (Fig. 5).

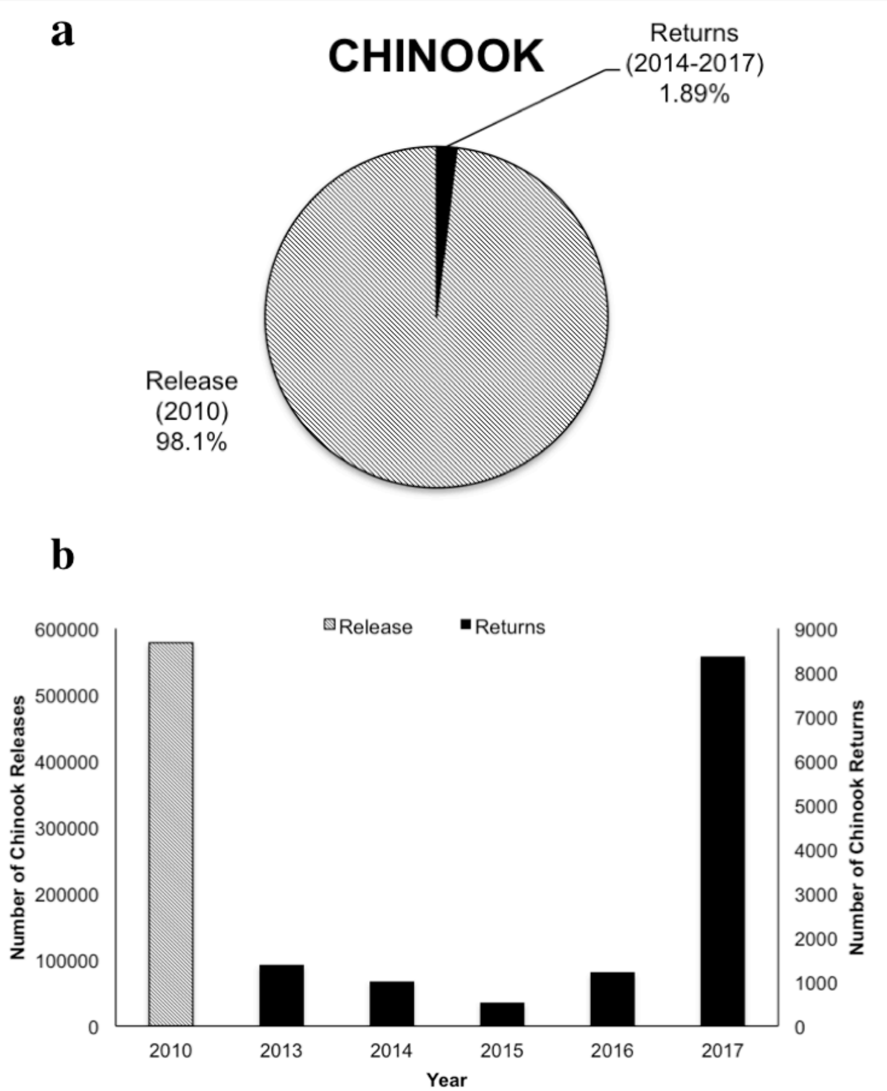

Figure 2. (a) The number of Chinook released in 2010 compared to the number of Chinook returning to Capilano River Hatchery from that population. (b) The number of Chinook released in 2010 compared to the number of Chinook returning from 2013 to 2017. The 2017 return data was gathered from October 25 to November 10th, 2017. The 2010 release data and 2014-2016 return data was obtained from Capilano River Hatchery (Operations Manager: Ashley Uittenbogaard).

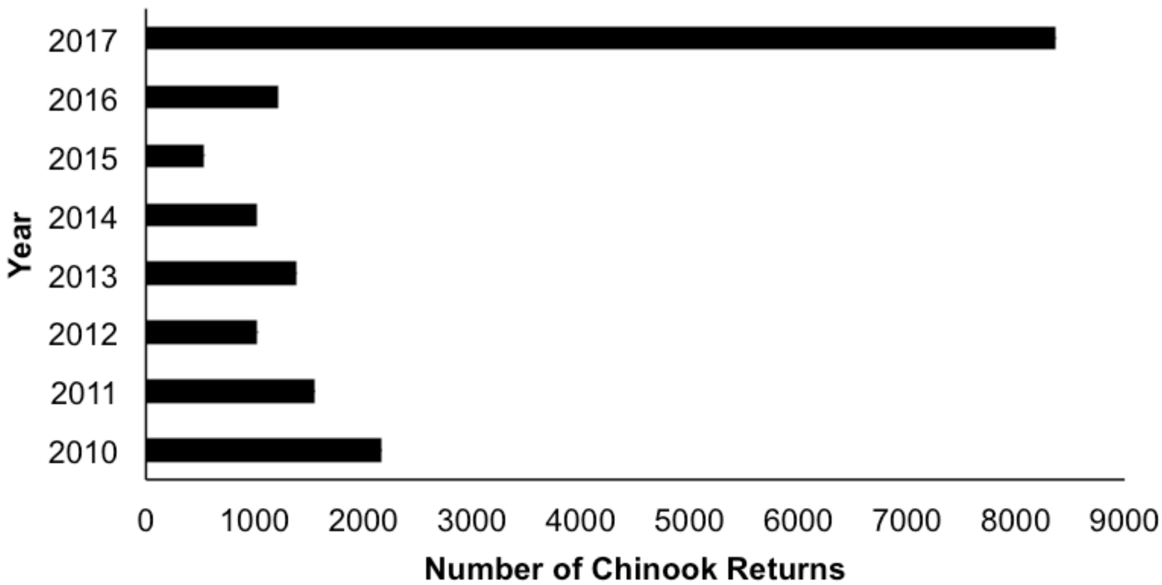

Figure 3. The number of Chinook salmon that returned to Capilano River Hatchery each year from 2010 to 2017. The 2017 return data was gathered from October 25 to Nov 10th, 2017 at Capilano River Hatchery. The 2010 to 2016 release data was obtained from Capilano River Hatchery (Operations Manager: Ashley Uittenbogaard).

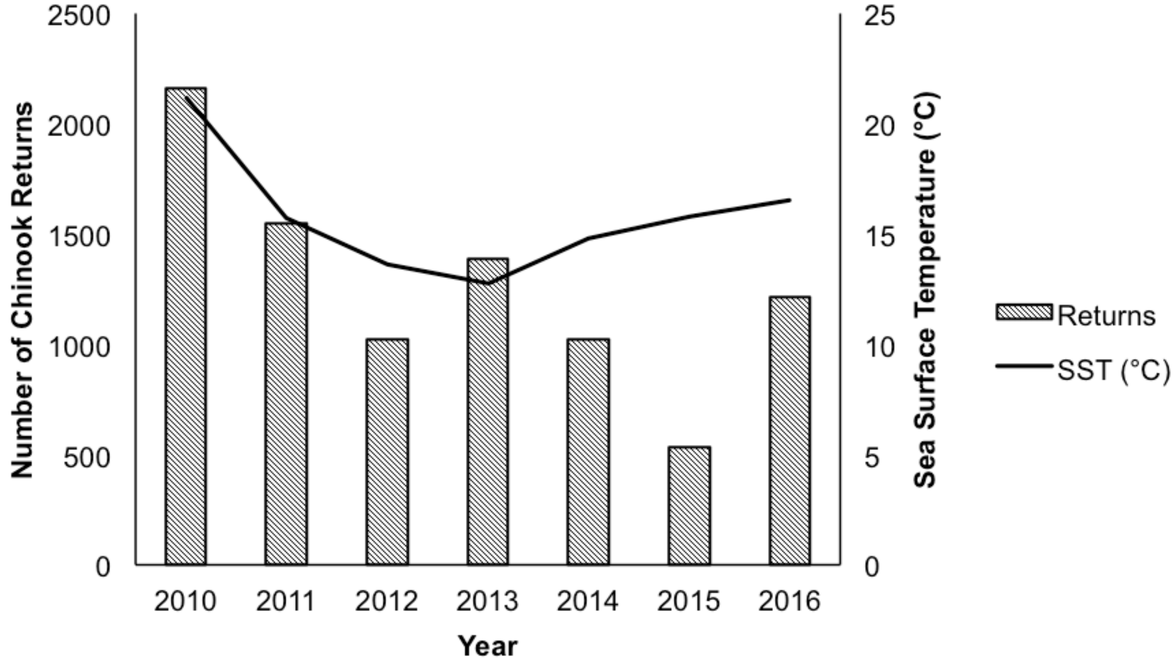

Figure 4. The number of Chinook salmon that returned to Capilano River Hatchery each year from 2010 to 2016 compared to annual Sea Surface Temperature (SST) in degrees Celsius at Amphitrite Lighthouse (48.922, -125.538). The 2010 to 2016 release data was obtained from Capilano River Hatchery (Operations Manager: Ashley Uittenbogaard).

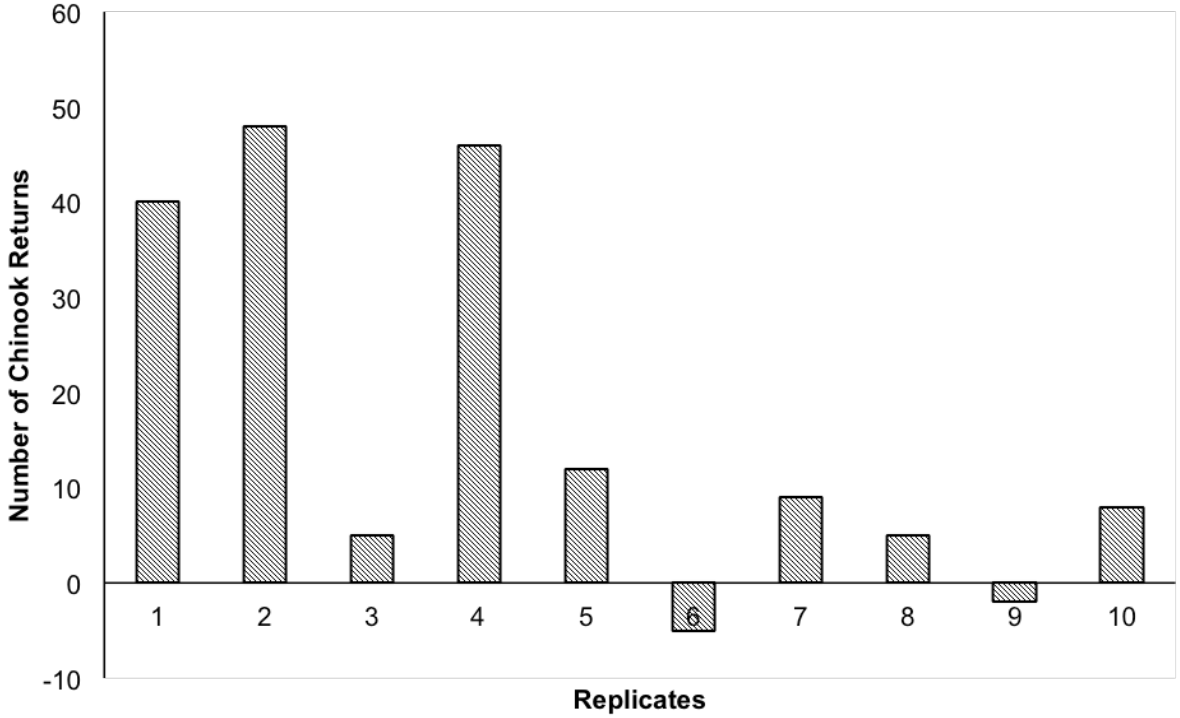

Figure 5. The number of Chinook salmon that returned to Capilano River Hatchery from October 25 to November 10, 2017. Each replicate demonstrates one hour of data collection.

Discussion

Our results do not support our hypothesis for the first objective, while they support that of the second objective. For objective 1, a declining trend in the number of Chinook salmon returning to the Capilano River Hatchery was hypothesized; however, according to the data we collected, salmon return has been increasing since 2015, with an unprecedented increase in 2017. For objective 2, the returning number of Chinook salmon was hypothesized to be significantly smaller than the number of Chinook salmon released from the hatchery, which corresponds accordingly with our results.

The return data calculated from the 2010 population was extremely low (1.89% of the initial population) and even represents an overestimate. Based off of the assumption that Chinook salmon migrate upstream after four to seven years of maturing in the ocean, our return average from the data of past 7 years includes Chinook salmon returns from previous released populations on top of the released population in 2010. In spite of the overestimation, as can be seen in Figure 1, the return data is such a small proportion of the release data that the overall loss of Chinook salmon from the population is clearly seen.

Overall, the data obtained from this experiment is not in consensus with predictions made by salmon experts such as Crozier et al. (2008) and Noakes et al. (2009), who predict salmon returns to be in decline. It is unlikely to see high return numbers due to a variety of factors. Salmon are a keystone species and provide a food source for various inhabitants of marine, freshwater, and terrestrial ecosystems. As a consequence, these salmon are susceptible to a variety of pressures and predation by animals including, but not limited to, humans, bears and killer whales. The intense pressure of predation on these salmon can be observed first-hand directly outside the Capilano hatchery. Many heron, seagulls, and illegal sport fishers can be observed taking advantage of the high number of Chinook salmon headed upstream to their spawning grounds (A. Houweling & D. Nickel, observation, Nov 25, 2017). Chinook salmon are prized catches when it comes to commercial and sport fishing, and many First Nations rely on salmon for sustenance and cultural tradition. Salmon are also susceptible to diseases and parasites encountered during their migration, a factor that could be increasing in severity due to fish farming. Combined, these factors create a great pressure on the survival of Chinook salmon populations.

As shown in Figure 2, when comparing the data obtained from this study to previous return data from the hatchery, the data obtained in this study was a clear outlier. This may have been due to the assumptions of the study: (1) Chinook salmon migrate at the same rate every hour during daylight hours, lending to the use of nine hours per day in the calculations; (2) the Chinook salmon run will end at the same time as it did last year, lending to the use of eight weeks as the timeframe of the run in the calculations; (3) the Chinook salmon that were visibly making it up the ladder at the point of the observation window also made it all the way to the top of the ladder. Due to the fact that this study was conducted between late October to early November only, the study began with the limitation of the inability to capture the trend through observational data collecting at any point in time outside of this set period. This study was finished before the end of this year's Chinook run, therefore, the result obtained for the returning rate of this year is an expectation.

Another unexpected factor influencing the numbers in this study was the water level of the river and the impact it had on the run start date. This year, the water levels of the Capilano river were uncharacteristically low due to minimal rainfall in the month of October. Our belief is that this was cause for the unexpectedly high numbers we observed at the beginning of the run (Fig. 5). We suspect the salmon may have accumulated at the mouth of the river in the Burrard inlet while the water levels of the river were low, resulting in a mass migration once rainfall caused the water levels to rise to a point that allowed the salmon to migrate upstream. As seen in Figure 5, there was a clear decline in our count numbers as the weeks progressed, which was a cause for concern in terms of the average we calculated accurately representing the amount of salmon returning to the hatchery. In order to combat this issue and arrive at a more accurate estimate, a study should be done that includes a greater number of trials spanning over the entire period of the Chinook salmon run. Consequently, our 2017 return numbers may be unreliable. As a result, when comparing returns to SST, only 2010-2016 was analyzed.

An interesting finding was that the amount of salmon returning increased with SST (Fig. 4). This demonstrates that further research is clearly needed to determine what myriad of causes is responsible for salmon decline in BC. Furthermore, it is important to focus on the fact that there was an incredibly small number of returns in comparison to the amount of salmon released from the hatchery in 2010, as seen in Figure 2. If the survivability of the salmon reared in hatcheries is so low, it is curious to think that low survivability may be the main cause of why wild populations, unaided by hatcheries, are dying out. If wild populations spawn in lower numbers than that released from hatcheries, and a similar percentage of returns occurs, then we can expect to observe even lower numbers returning to spawning sites in the wild in comparison to hatcheries. We encourage further studies to compare return rates of Chinook salmon between hatcheries and natural streams to determine if the phenomenon of very small return numbers is being seen in the wild. This could offer greater insight into the conservational benefits of hatcheries and could also lead to further identification of what causes are lending to the small return numbers; whether they are due to natural causes such as predation or due to anthropogenic causes such as overfishing, pollution, disease from fish farms, and the like.

Conclusion

There is no clear trend of decline in salmon return numbers to Capilano River Hatchery over the years as we had predicted. There is however, shocking evidence that only a very small fraction of those released actually return, as was predicted. This demonstrates that salmon research and conservation efforts are very important in saving a key BC species that we cannot afford to lose, whether via hatchery or not.

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Appendix

Run start:	Oct. 21-22			
Date	**Time**	**# Fish Jumped Over**	**# Fish Fell Backward**	**Total # Fish Returned**
10-25	9:35AM - 10:35AM	71	31	40
10-26	15:20PM -16:20PM	73	25	48
10-27	8:13AM - 9:13AM	16	11	5
10-28	12:20PM - 13:20PM	83	37	46
10-29	12:27PM -13:27PM	23	11	12
10-30	9:15AM - 10:15AM	3	8	-5
10-30	12:30PM - 13:30PM	16	7	9
11-2	12:45PM - 13:45PM	13	8	5
11-4	13:30PM - 14:30PM	6	8	-2
11-10	9:00AM - 10:00AM	10	2	8
Average return/hour				16.6
Average return/2017 fall run (8 weeks)				8366.4