

Factors Influencing Run Strength of Upper
Yukon River Chinook Salmon (*Oncorhynchus
tshawytscha*)

By

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ABSTRACT

Pacific salmon (*Oncorhynchus spp.*) are anadromous fish distributed around the Pacific Ocean. Pacific salmon generate numerous ecosystem services including those that directly benefit humans related to nutrition, livelihoods and culture. Extensive research effort has been devoted to discerning what governs the life history of these fish. Widespread declines in this vital resource over the past century and specifically the last few decades have prompted efforts to identify the drivers of Pacific salmon decline in an attempt to reverse it. In this study, I used quasi-Poisson Generalized Linear Models (GLMs) to quantify the influence of multiple environmental (e.g. sea surface temperature, overland precipitation, and river temperature) and anthropogenic (e.g. fishing and hatchery operations) factors on the run size of Chinook Salmon (*Oncorhynchus tshawytscha*) from the Yukon River that spawn upstream of Whitehorse, Yukon, Canada. I found no evidence of a discernable growth trend in this population, even though the main predictor of run strength variation was found to be sea surface temperature. It is plausible that actions of the Whitehorse Rapids Fish Hatchery are acting to bolster this population against effectors of global Pacific salmon decline. However, with Whitehorse Chinook Salmon being small in number and on the edge of their distributional range, my findings suggest that this population may experience exacerbated effects of future perturbations to North Pacific and global climate compared to other populations of the same species.

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1. INTRODUCTION

Pacific salmon (*Oncorhynchus spp.*) are an anadromous genus of fish, generally meaning they hatch in freshwater, migrate out to sea for the majority of their life, and return to their natal streams to breed and die. In North America, Pacific salmon have native ranges extending from southern California to northern Alaska. There also are populations in Russia and Japan and the genus has been widely introduced to other regions such as the Laurentian Great Lakes and New Zealand. Pacific salmon generate a number of ecosystem services. For example, commercial landings of salmon in British Columbia alone are upwards of 25,000 metric tonnes valued at hundreds of millions of dollars per year (Agriservice B.C. 2017). Salmon are also an important resource for subsistence fishers, making up a significant portion of the diet in smaller, more isolated rural communities during the adult migration season (Wein et al. 2005; Lambden et al. 2007; Shuster et al. 2011). Beyond economic value, salmon are revered by Indigenous peoples across the Pacific Northwest not only for the sustenance they provide to the people but also for cultural, spiritual and ceremonial purposes. Moreover, the marine-derived nutrients brought in from the ocean during spawning migrations provide substantial ecological value, fueling freshwater and riparian ecosystems. Some consider Pacific salmon a keystone species (Bilby et al. 1998; Wipfli et al. 1998; Moore et al. 2011).

Many Pacific Northwest salmon fisheries have experienced a decline in population size over the past century and more specifically over the past few decades. Gresh et al. (2000) estimated that, based on historical records from the early 1900s, only

around 10% of salmon biomass remains in the Pacific Northwest. More recently at the end of the 1970s, salmon populations in the lower Northwest (Oregon, Washington, and British Columbia) began to see reductions in population size and body size (Mantua et al. 1997; Zabel et al. 2006; Cross et al. 2009; Species at Risk Public Registry 2019). Declines became more extreme at the beginning of the 1990s into the turn of the century when fisheries in the lower Northwest saw ubiquitous, rapid declines in population numbers (Cohen 2012; Species at Risk Public Registry 2019); however, Alaskan populations did not share this pattern of decline. An increase in production among Alaskan salmon species occurred from the late 1970s until the 1990s when these populations began to mirror the lower Northwest populations in decline (Mantua et al. 1997; Ruggerone et al. 2009; Seigel et al. 2017). Since then, declines have become so drastic that both the US and Canadian governments have launched extensive inquiries, invoked emergency powers, and imposed fishing moratoriums in an effort to understand the causes of and control the rapid declines of Pacific salmon (Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative 2006; Cohen 2012; NOAA 2012).

A great deal of effort has been devoted to understanding the causes of observed declines in Pacific salmon. One of the most notable and successful tools in fisheries science has been modeling (Mantua et al. 1997; Litzow et al. 2014; Siegel et al. 2017). Starting from the institution of the Ricker stock/recruit (S/R) model (Ricker 1954), helped by advancements in computer technology, mathematics, and data gathering (Rogan and Chen 2004; Giorgi 2005), modeling has become a powerful tool in helping to understand what factors influence growth and survival at key life stages of Pacific

salmon. Numerous studies have sought to discern the underlying causes for salmon run strength fluctuation and decline. Investigated causes range from climate change affecting growth (e.g., Ruggerone et al. 2009) and phenology (e.g., Mundy and Evenson 2011), to riverine thermal hydrology (Dugdale et al. 2013) and nutrient cycling (Moore et al. 2011), as well as migration delays and disease (Jonsson and Jonsson 2004; Fenkes et al. 2016). As much as migration (both smoltification and spawning migration) is considered a key point in salmon life history, one other area has come to the forefront in research on salmon survival and production: the early ocean feeding stage (Healey 1991). Specifically, during this stage, ocean temperature has been shown to be the largest predictor of marine growth and, consequently, survival across a number of studies and species (Holtby et al 1990; Ruggerone 2009; Seo et al 2011).

Chinook Salmon (*Oncorhynchus tshawytscha*) are the largest species of salmon and possess defining characteristics that set it far apart from even Coho Salmon (*Oncorhynchus kisutch*), its closest relative. Under the right conditions, Chinook Salmon can grow to over a meter long and weigh upwards of 50 kilograms. Even on average they are many times larger than any other species of Pacific salmon. Chinook Salmon also have the oldest age at maturity of Pacific salmon, historically returning anywhere between 4 and 6 years old on average. These characteristics, combined with low redd density and populations rarely over a one or two thousand, make Chinook Salmon far more K-selected than any of its taxonomical counterparts (Healey 1991). This not only makes them specifically prized and revered, but also vulnerable to rapid changes in their environment.

In this study, we focused on an upper Yukon River Chinook Salmon population (defined for the purpose of this study as fish that terminate in the mainstem Yukon River or its tributaries above the confluence with the Teslin River), specifically the population spawning above the Whitehorse Hydro Plant (WHP), dubbed here as Whitehorse Chinook Salmon (WCS)(Figure 1). The Michie Creek - M'Clintock River system lies just upriver of Whitehorse, Yukon and is a spawning ground for a population of Chinook Salmon. Since the 1970's Yukon River Chinook Salmon populations have declined by roughly 50% in yearly abundance (Figure 2). Even after the cessation of a large portion of direct fishing pressure after the turn of the century (indirect harvest via bycatch during marine residence still occurs at about 50,000 fish a year. This may seem high, but that number is out of the entirety of Yukon Chinook Salmon currently in the Bering Sea), Chinook Salmon populations in the Yukon did not recover and even continue to decline in some areas (Yukon River Panel Joint Technical Committee 2017). Traditional Ecological Knowledge and historical accounts from the early 1900s indicate that ~10,000 Chinook Salmon were harvested annually in the Michie Creek - M'Clintock River system (Cox 1997; Herkes 2015); however, returns counted at the Whitehorse Rapids Fish Ladder have averaged only ~1200 since the ladder was constructed in 1959. In the half century between these accounts, it is unclear what may have caused the apparent disparity in population size. Also of note is the shift in age classes of Yukon Chinook Salmon. Over the past 40 years, the number of 8-year-old fish dropped from about 5% of the population to 0, while the mean age shifted from 6 to 5 (Figure 2).

Because size increases with age, individuals in current typical returning populations are smaller.

This Upper Yukon Chinook Salmon population has experienced large fluctuations in population cycles similar to other Yukon River populations in the past half-century, even with the construction of a hatchery in the mid 1980's (Figure 1). The Whitehorse Rapids Fish Hatchery was founded in 1985 as part of an agreement with the Canadian Department of Fisheries and Oceans for installing a fourth turbine in the WHP. The hatchery was created to provide supplemental Chinook Salmon fry to the population above the WHP to account for additional juvenile mortality during outmigration through the WHP and its now four turbines.

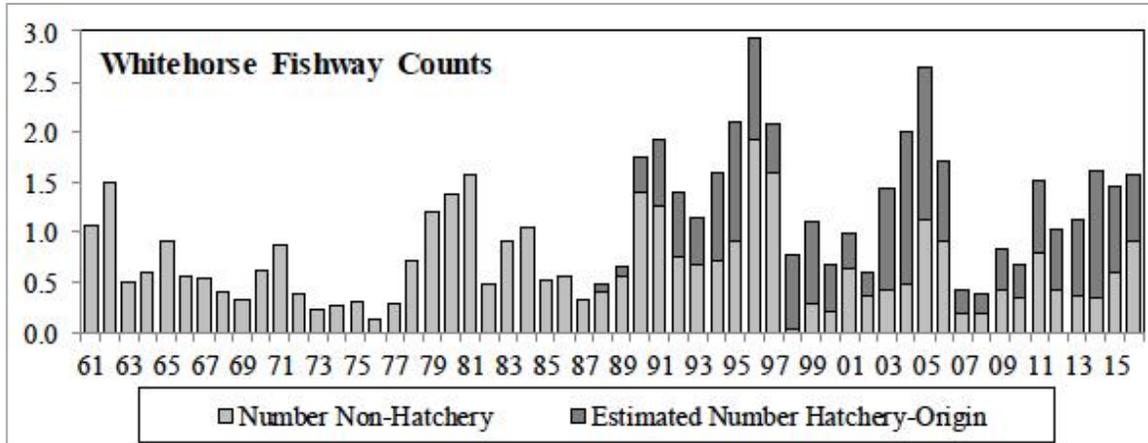


Figure 1: Whitehorse Rapids Fish Ladder Counts *Counts of Chinook Salmon passing through the Whitehorse Rapids Fish Ladder per year (x-axis) in thousands of fish (y-axis). Sourced from the Yukon River Salmon 2017 Season Summary and 2018 Season Outlook prepared by The United States and Canada Yukon River Joint Technical Committee.*

Table 1: Canadian-Origin Chinook Salmon Brood Year Run Totals *Table A9 from the Yukon River Chinook Salmon 2017 Season Summary and 2018 Season Outlook prepared by The United States and Canada Yukon River Joint Technical Committee. This table details Yukon River Canadian-origin Chinook Salmon total run by brood year and escapement by year (Yukon River Panel Joint Technical Committee 2017).*

Brood Year	Age						Return	Spawners	R/S
	3	4	5	6	7	8			
75					33,080	175			
76				88,405	22,026	40			
77			19,491	111,771	19,734	801	151,797		
78		4,443	22,845	63,235	29,424	1,493	121,439		
79	1,534	3,388	21,422	100,503	48,253	1,175	176,274		
80	15	6,604	13,510	70,415	33,978	4,240	128,763		
81	0	1,122	33,220	114,180	54,845	1,841	205,208		
82	0	5,141	17,169	37,883	27,763	376	88,330	43,538 2.03	
83	560	7,558	35,117	89,449	16,408	162	149,253	44,475 3.36	
84	69	13,368	34,379	75,041	13,782	138	136,778	50,005 2.74	
85	223	10,738	38,956	62,142	4,756	91	116,906	40,435 2.89	
86	347	20,408	45,928	109,067	15,843	138	191,731	41,425 4.63	
87	0	2,368	33,542	67,697	11,700	18	115,325	41,307 2.79	
88	0	6,641	34,323	75,396	8,937	68	125,366	39,699 3.16	
89	75	13,517	78,826	128,851	25,841	0	247,109	60,299 4.10	
90	56	6,343	24,873	71,641	10,816	9	113,737	59,212 1.92	
91	501	7,107	82,332	121,590	10,182	0	221,712	42,728 5.19	
92	6	2,608	23,981	41,677	1,831	0	70,103	39,155 1.79	
93	14	5,313	36,363	86,880	5,880	0	134,450	36,244 3.71	
94	0	755	19,932	30,683	6,175	0	57,545	56,449 1.02	
95	34	1,784	15,989	52,720	7,026	10	77,562	50,673 1.53	
96	20	276	23,201	44,462	14,610	2	82,571	74,060 1.11	
97	14	3,567	26,386	94,406	7,828	14	132,216	53,821 2.46	
98	0	3,478	39,260	76,502	4,357	0	123,598	35,497 3.48	
99	134	1,692	30,110	76,649	2,870	0	111,455	37,184 3.00	
00	0	2,798	40,704	63,414	1,509	0	108,424	25,870 4.19	
01	8	1,813	50,877	51,785	2,205	0	106,688	52,564 2.03	
02	75	2,262	28,704	20,725	227	9	52,003	42,359 1.23	
03	63	5,898	37,236	52,339	2,261	2	97,798	80,594 1.21	
04	3	2,462	26,833	21,936	4,777	1	56,012	48,469 1.16	
05	9	8,268	29,475	38,857	1,754	0	78,362	67,985 1.15	
06	15	6,009	25,248	25,683	1,568	0	58,522	62,630 0.93	
07	47	2,858	17,746	22,193	1,694	1	44,539	34,904 1.28	
08	1	3,138	11,092	25,750	1,853	0	41,834	33,883 1.23	
09	173	2,324	32,868	44,943	456	0	80,763	65,278 1.24	
10	1	4,379	29,627	19,598	844		54,450	32,014 1.70	
11	194	10,645	52,670	41,975			105,484	46,307 2.28	
12	255	9,885	44,598					32,656	
13	92	5,095						28,669	
14	110							63,331	
15								82,674	
16								68,798	
17								68,315	
Average 1982–2010							106,041	48,026 2.21	
							Contrast =	3.12	

Reliance on salmon as a natural resource continues under the constant looming threat of climate change and global warming (Wrona et al. 2006). As our predictive ability increases, climate predictions continue to be dire under the assumption of no radical change in human behaviour (Eyring et al. 2019). Because the WCS population is small and has one of the longest spawning migrations in the world, this population is specifically vulnerable to any perturbations. In the effort to assess how environmental changes affect salmon on a large scale, it is imperative to look at individual populations, especially those with confounding factors that may put them at a higher risk of decline. My goal in this study is to provide insight into the degree and cause of the fluctuation in run strength in WCS as a whole, as well as both fish of wild origin and hatchery origin separately. Using statistical modeling, specifically generalized linear models, I compare the number of WCS migrating through the WHP per year to a number of potentially predictive environmental and anthropogenic factors during multiple life stages. My objective is to provide information to aid in managing this population and further contribute to our understanding of how Pacific salmon will fare in a changing future.

2. METHODS

2.1 Study Site and Population

Whitehorse Chinook Salmon (WCS) migrate over 3000 kilometers up the Yukon River to reach their spawning grounds. As Chinook Salmon pass by the Whitehorse Hydro Plant (WHP) via the Whitehorse Rapids Fish Ladder, they are counted, and basic demographic information is recorded. These fish then proceed roughly 100 km

upstream, branching off into the M'Clintock River, and subsequently their main spawning grounds in Michie Creek (Figure 3) (de Graff 2015). Some other streams above the WHP and areas in the Michie Creek – M'Clintock River system are thought to be spawning sites for this population, though confirmation is currently lacking. Once they reach their spawning grounds, Chinook Salmon construct redds, lay their eggs, and die. Upon hatching later in the fall, these Chinook Salmon fry spend an entire year growing in the Yukon River. They then migrate out to the Bering Sea the following spring. During their time at sea, most juvenile Chinook Salmon stay close to the land, not leaving the continental shelf (Farley et al. 2004; Farley et al. 2009). Coded Wire Tags on more mature fish from the Whitehorse Rapids Fish Hatchery have been found near and to the North of the tip of the Aleutian Island chain (Myers et al. 2009). This suggests that individuals from this population spend more of their time in the open ocean rather than on the continental shelf if they survive to mature past the juvenile stage. Since observations reported in Meyers' et al. (2009) were in summer, it is also possible that these distributions were indicative of seasonal migrations, rather than static distribution (Larson et al. 2013).

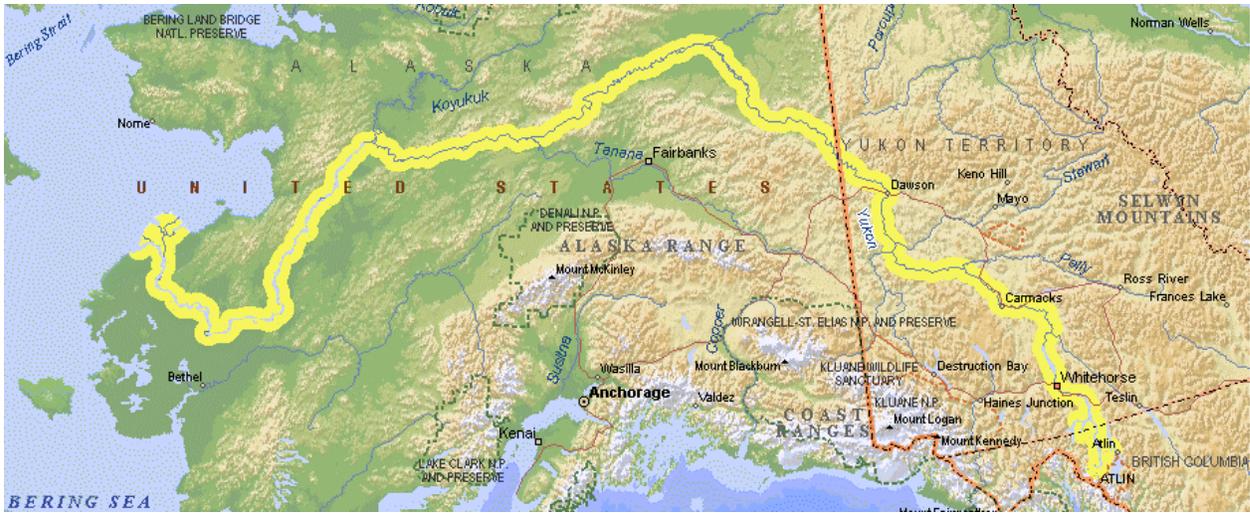


Figure 2: Map of the Yukon River Above, the Yukon River highlighted in yellow. Below, a zoom-in on Whitehorse in relation to the Michie Creek Spawning Grounds.

2.2 The Models

Five separate models were created to explore different permutations of origin-based population breakdowns and time periods (Table 2). Given that response variables are integer counts, I initially fit generalized linear models (GLMs) with a Poisson family log-link function. This log-link approach prevents negative estimations of the response variable by assuming that the natural log of the predictor variables are linearly related to the response variable. However, in all cases, residual deviance exceeded null deviance, suggesting that the models were over-dispersed, which can lead to biased parameter estimates and assessment of significance. To account for over-dispersion, I refit each model using QuasiPoisson family (Zuur, 2007).

2.3 Variable Selection and Data Manipulation

Variables for Model Series 1 (Table 1) were selected in accordance with previous studies and established literature. Sea surface temperature was used as the metric of ocean climate in this study to mirror many other studies regarding salmon population fluctuation (Holtby et al 1990; Mantua et al. 1997; Ruggerone 2009; Seo et al 2011; Litzow et al. 2014; Siegel et al. 2017). Three factors were included as indicators of in-river conditions linked to migration and spawning success: Yukon River flow rate; air temperature; and precipitation in the surrounding area (Fenkes et al. 2016; Dugdale et al. 2013; Neuswanger et al 2015). Dawson City, Yukon was chosen as the location of temperature and precipitation because Dawson lies at a location in the migration route that would provide biologically relevant insight as to how conditions at that location

affect migrating Canadian Chinook Salmon in the last, and most difficult, leg of their journey. In a similar vein of logic to choosing Dawson as a location for data, Eagle Point, the point where the Yukon River passes from the USA to Canada, was chosen to provide biologically relevant data for Canadian Chinook Salmon. Dawson City was not used, since flow data was not available for that area. The number of spawners and past stocking efforts that contributed to the current run were included in the models as a necessity to any stock assessment study. Where possible, returns were corrected for harvest pressure .

Year: The year is included in each model as a nominal variable to track change over time in the dependent variable.

SST: Data provided by the NOAA Bering Climate database is in the form of average temperature anomalies from January to April of each year at M2 mooring, just north of the middle of the Aleutian Island chain. Anomalies are calculated based on the 60-year mean from 1940 to 2000 and were provided in the form of a single number per year.

DawsonPrecipitation: Data were retrieved in the form of monthly (for 1959-2006) and daily (for 2007-2013) centimeters of rainfall in Dawson, Yukon. Daily values were summed within a month barring any lack of daily data, in which case the month was not used. A number of months in the most recent decade of the study did lack significant data. To correct for this, long-term average monthly values were calculated and anomalies off that mean were also established. Missing months were filled in with the

long-term average anomaly for that month. Once missing values were filled in, monthly average precipitation for each precipitation year was calculated. A precipitation year was calculated from November to October rather than January to December to focus around the freeze-up date in order to more closely represent the precipitation that would influence flow during salmon migration. Given that I included Yukon River flow in the form of the EagleFlow variable as well, precipitation has been included to serve as a proxy for flow in the years prior to 1988, as data did not extend far enough back to use in the 1959 models. A regression between DawsonPrecipitation and EagleFlow provides decent support for the proxy ($df = 24$; $R^2 = .405$; $p = 2.83E-4$).

DawsonTemp: Data were retrieved in the form of monthly (for 1959-2006) and daily (for 2007-2013) average air temperatures in Dawson, Yukon. Average daily values were calculated by month barring gross lack of daily data. A number of months in the most recent decade of the study did lack significant data. In order to correct for this, long-term average monthly values were calculated and anomalies off that mean were also established. Missing months were filled in with the longer-term average anomaly for that month. Once missing values were filled in, monthly average temperature for each year was calculated. Air temperature was used in these models as a proxy for Yukon River water temperature. Data on Yukon River water temperature was not available for any time period relevant to this study.

Table 2: Short Reference of Variables Used in This Study

Variable	Short Description	Source
SST	Sea Surface Temperature of the Bering Sea at M2 Mooring. Used during the year fish migrate back upriver to spawn. (Degrees Celsius)	NOAA "Bering Climate"
Year	Year span of the model.	N/A
EagleFlow	Yukon River flow rate at Eagle Point. (m ³ /s)	Government of Canada "Historical Data"
DawsonPrecip	Monthly precipitation average by year at Dawson City. (mm)	Government of Canada "Historical Data"
DawsonTemp	Monthly air temperature average by year at Dawson City. (Degrees Celsius)	Government of Canada "Historical Data"
TemponEntry	Sea Surface Temperature of the Bering Sea at M2 Mooring. Used in the year fish enter the ocean. (Degrees Celsius)	NOAA "Bering Climate"
Spawners	Number of past spawning Chinook Salmon that contributed to a run.	Yukon River Panel Joint Technical Committee 2017)
Stocking	Number of past stocked Chinook Salmon fry that contributed to a run.	Yukon River Panel Joint Technical Committee 2017)
Wild	Number of only wild-origin Chinook Salmon that pass though the Whitehorse Rapids Fish Ladder in a year.	Yukon River Panel Joint Technical Committee 2017)
Total	Number total Chinook Salmon that pass though the Whitehorse Rapids Fish Ladder in a year.	Yukon River Panel Joint Technical Committee 2017)
PreHarvWild	Number of only wild-origin Chinook Salmon that pass though the Whitehorse Rapids Fish Ladder in a year corrected for harvest before that point.	Yukon River Panel Joint Technical Committee 2017)

PreHarvHatch	Number of only hatchery-origin Chinook Salmon that pass through the Whitehorse Rapids Fish Ladder in a year corrected for harvest before that point.	Yukon River Panel Joint Technical Committee 2017)
PreHarvTotal	Number of total Chinook Salmon that pass through the Whitehorse Rapids Fish Ladder in a year corrected for harvest before that point.	Yukon River Panel Joint Technical Committee 2017)

EagleFlow: Data were retrieved in the form of monthly average flow rate in cubic meters per second. Average annual values were calculated from monthly averages.

TemponEntry: To calculate temperature experienced on marine entry, I began with the percentage of fish of each age within a run year (i.e., return adults) for total brood year returns of Canadian-origin Chinook Salmon. I then used those brood year returns to calculate age percentage breakdowns by run year (steps detailed in section 2-2: Pre-Harvest Returns). I then used the average temperature that each age group of fish in a run year experienced on marine entry, weighted by the relative representation of each age within that run year. The resulting average temperature was then used in the models.

Spawners: The number of spawners contributing to a run year was calculated using yearly returns through the WHP and Upper Yukon River run year age distributions as determined in the Pre-Harvest Returns section. I used the percentage representation of each age within a run year, and calculated the total based on corresponding past years:

$$Sp_y = \sum_{x=3}^8 \%x_y * R_{y-x}$$

“*Sp*” represents the number of spawners that contributed to the current run.

“%*x*” represents the percentage of fish of age “*x*”. “*R*” represents the total WCS abundance in a year. “*y*” represents year in question.

I acknowledge that this relationship may not be completely accurate as it assumes consistent mortality across ages of returning fish and in all the factors that contribute to that consistent mortality. However, I believe that the model is more complete and informative with the inclusion rather than the omission of this variable in a sub-optimal state. A population model without any consideration of the biological contribution of spawners to the next generation would be insufficient.

Stocking: Data on stocked fry was taken from the YRPJTC Report (Yukon River Panel Joint Technical Committee 2017). Stocking efforts above the WHP were totaled by year and manipulated in the same manner as Spawners in order to calculate the number of stocked fry that contributed to the current run.

$$St_y = \sum_{x=3}^8 \%x_y * s_{y-x}$$

“St” represents the number of past stocked Chinook Salmon fry that contributed to one year’s abundance. “s” represents the total stocked Chinook Salmon fry in a year.

The same caveats apply here as they did to Spawners. Again, I accept the sub-optimal variable in order to have representation of purely biological contributions to run strength.

Pre-Harvest Returns: Data were retrieved in the form of total Yukon River Chinook Salmon harvest, percentage of harvested fish that were of Canadian origin, Canadian-origin total brood year returns, and number of fish of each age within a brood year for Canadian-origin Chinook Salmon returns. Using the number of fish of each age within a brood year, I calculated the number of fish of each age within a run year and run year total returns:

$$R_y = \sum_{x=3}^8 \%x * B_y$$

“*B*” represents the brood year total abundance of WCS. Using total Yukon River Chinook Salmon harvest and the percentage of harvested fish that were of Canadian origin, I calculated the number of Canadian-origin Chinook Salmon harvested each year. I divided that number into Canadian-origin Chinook Salmon run year total returns, generating the percentage of Canadian-origin Chinook Salmon that are harvested each year. This percentage was used to correct returns of WCS for harvest that the population encountered prior to being counted at the Whitehorse Rapids Fish Ladder. Whitehorse Rapids Fish Ladder count data were retrieved and used in their original form, detailing the number Chinook Salmon of each origin passing through the Whitehorse Fish Ladder.

Table 3: Details of the Five Models *Initial models include all variables available for the designated timeframe. Final models represent the lowest AIC combination of variables in their respective initial models.*

Model Description and (Code)	Initial Model	Final Model
Wild Return 1959-2013 (1)	Wild ~ SST + Year + DawsonPrecip+ DawsonTemp+	Wild~ SST + DawsonPrecip
Pre-harvest Wild Return 1988-2013 (2)	PreHarvWild ~ SST + Year+ EagleFlow+ DawsonPrecip + DawsonTemp+ TemponEntry+ Spawners+ Stocking	Wild ~ SST
Pre-harvest Hatchery Return 1988-2013 (3)	PreHarvHatch ~ SST + Year + EagleFlow + DawsonPrecip + DawsonTemp + TemponEntry + Stocking	Hatch ~ SST +
Total Return 1959-2013 (4)	Total ~ SST + Year + DawsonPrecip + DawsonTemp + Stocking	Total ~ SST + Stocking
Pre-harvest Total Return 1988 – 2013 (5)	Total ~ SST + Year + EagleFlow + DawsonPrecip + DawsonTemp + TemponEntry+ Spawn+ Stocking	Total ~ SST + EagleFlow + TemponEntry

2.4 Model Output Analysis: Deviance Explained

The R-package “rsq” was used to calculate the deviance explained by each model. Deviance explained by full models were compared to variance explained by models with a single independent variable removed. The gap in variance explained between these two models is the variance explained by the variable that was removed. In a large number of cases, the cumulative deviance explained by individual variables within a model exceeded the variance explained by the full model. This is likely due to collinearity. For example, if one built a model variable by variable, one would not most likely not see an increase in variance explained equal to the objective variance explained by the variable added. This is likely because two correlated variables trend similarly and overlap in a portion of what they explain in the dependent variable. To rectify this issue, variance explained by individual variables was scaled to the deviance explained of the full model.

2.5 Akaike Information Criterion Usage

The final models (Table 2) were generated from the initial models by minimizing the individual Akaike information criterion (AIC) of each model. AIC is a measure of information loss between one data set (the dependent variable) and other data sets (the independent variable(s)) attempting to mimic, or predict, the original data. Generally, when comparing data with the same degrees of freedom, AIC is identical to maximum-likelihood estimation (Ciannelli et al. 2012). Using the R package MuMIn’s

“dredge” function, I calculated all variable inclusion iterations of each model and selected the one with the lowest AIC to be the final model.

3. RESULTS

Model 3 explained the greatest amount of variance in the dependent variable, with independent variables explaining 55.4% of the variation in pre-harvest hatchery-origin WCS. Model 5 explained 39.2% of variance in the dependent variable. Model explanatory power dropped off consistently through model 4, 1, and 2, with 12.2% variance explained in the latter (Table 3).

Model 1 had half of the initial variables selected during AIC selection while only one variable was selected for Model 2. Yet, both have relatively little power overall in predicting the fluctuations of wild-origin WCS. Though not included in any other model, DawsonPrecip explained just under half of Model 1’s explained variance with a positive relationship. Yet neither DawsonPrecip nor EagleFlow (note that DawsonPrecip proxies for EagleFlow prior to 1988 where flow data is not available) were included in Model 2. For both models concerning wild origin WCS, there were two common traits: a positive relationship between returns and SST as well as a lack of the nominal Year variable.

Model 3 shows the continued the domination of SST as a predictive term. Cut down heavily by AIC selection, SST remains the sole variable, just as in Model 2. Here however, it provides substantially more explanation of variance.

In models 4 and 5, SST continues its presence and relative predictive power along with additional unique predictors (Figure 4C and 4D). Model 4 had a variable

unique to itself: Stocking including years with no stocking before the institution of the hatchery (Figure 4B). Previous iterations of this model without stocking resulted in Year being kept through AIC selection. Yet when Stocking was included as well, Year was not. Though SST was included, it was not the dominant predictor. Model 5 included negative relationships with both EagleFlow and TemponEntry (Table 4A), which did not pass AIC selection in any other model, yet were still predictively relevant in this model.

SST was ubiquitously selected in AIC selection and was the driving predictive force in the majority of models. It also invariably has a positive relationship to returns, adding to its consistency as a predictor. Beyond SST, no predictor is included in more than one model, each model secondarily (primarily in the case of Model 4) tracing unique predictor variables. SST is the predictive bedrock of this model series.

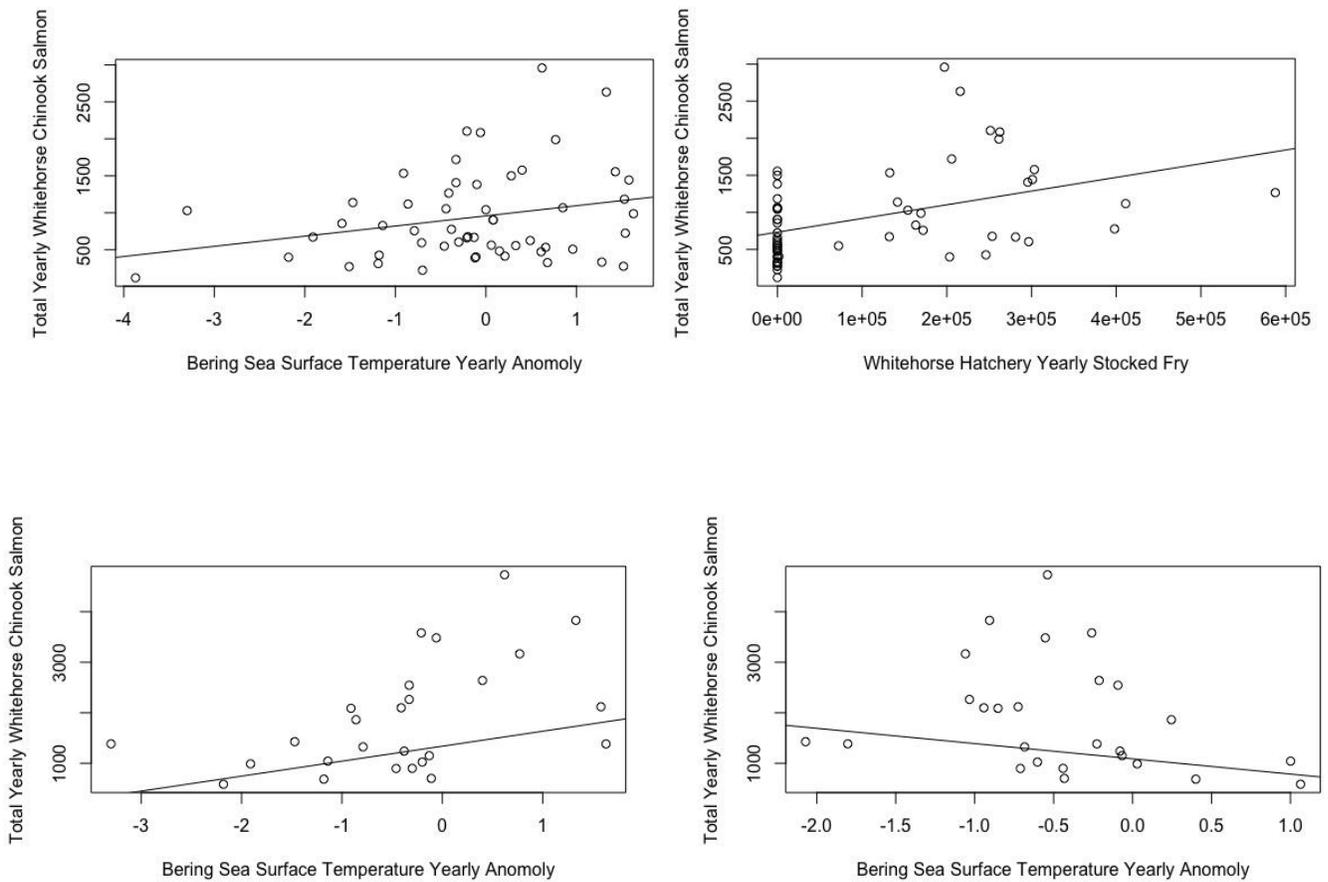


Figure 3: Whitehorse Chinook Salmon Yearly Returns From top left to bottom right –
 A) WCS total yearly returns from 1959-2013 as a function of Bering Sea SST during spawning migration; B) WCS total yearly returns from 1959-2013 as a function of Whitehorse Rapids Fish Hatchery Yearly Stocked Chinook Salmon Fry; C) Pre-Harvest WCS total yearly returns from 1988-2013 as a function of Bering Sea SST during spawning migration; D) Pre-Harvest WCS total yearly returns from 1988-2013 as a function of Bering Sea SST during outmigration and marine entry.

Table 4: Model Output - Independent variables are listed below the model number and dependent variable.

Model and Variables	Estimate	Standard Error	t-value	p-value	Variance Explained
1: Wild Returns 1959-2013					.195
SST	0.215	0.082	2.204	0.012	.108
DawsonPrecipitation	0.031	0.015	2.044	0.046	.088
2: Pre-Harvest Wild Returns 1988-2013					.122
SST	0.284	0.136	2.066	0.050	.122
3: Pre-Harvest Hatchery Returns 1988-2013					.207
SST	0.380	0.091	4.161	4.08E-4	.207
4: Total Returns 1959-2013					.257
SST	.197	.007	2.692	0.010	.100
Stocking	1.9E-6	4.7E-7	4.069	1.6E-4	.157
5: Pre-Harvest Total Returns 1988-2013					.392
SST	0.221	0.083	2.661	0.014	.182
EagleFlow	-5.9E-4	2.8E-4	-2.140	0.043	.115
TemponEntry	-0.341	0.157	-2.169	0.041	.094

4. DISCUSSION

It is difficult to say how well these quasi-Poisson generalized linear models performed in explaining the variation in the WCS population. Few if any studies exist that have used similar statistical methods and data. Even in relatively similar studies, methodological differences bar objective comparisons of results (Neuswanger et al. 2015; Seigel et al. 2017). In one sufficiently similar study, Kim et al. (2017) uses a cross-correlation function analysis to compare chum salmon returns to a number of biotic and abiotic variables. Even considering statistical differences, they found that sea surface temperature during the entry of fry to the ocean was over four times as correlated than my results would suggest. Given this discrepancy in results and the paucity of comparable studies in general, a tempered approach to interpretations of my results is warranted. Additionally, many models were ineffective at providing a holistic perspective on the interplay between different factors affecting this population with many variables being removed from final models. Rather than the lack of variables that improved the AIC of the models indicating that these variables do not affect WCS population numbers, I find it more likely that the variables were inadequate in representing the desired factors. Much of the data on factors we desired - most notably water temperature and flow rate of the Yukon River - were unavailable for the desired timeframe of this study, if available at all. Proxies were made and blanks were filled in with averages that could have been cruder than reality, resulting in the appearance of certain variables being non-predictive in many models. Not all possible relevant factors

were addressed here; also adding additional factors may improve future model predictiveness.

As an additional note to this effect, any statements hereafter regarding variables making or not making it past AIC selection are inherently subjective. Not improving the AIC of a model does not mean that the variable in question does not contribute in some way to explaining the variance of the dependent variable. Conjectures of this nature are just that and should be interpreted cautiously.

Fortunately, Model 5, concerning the entire population of WCS from 1988-2013, accounted for almost 40% of observed variation. This is roughly 80% more than the next-best model in this study. The variables that proved relevant to this model provide us with the context to compare environmental effects between marine entry, marine exit, and spawning migration.

4.1 Harvest Considerations and Effects

As a means to regulate harvest of Yukon salmon, The Yukon River Panel Joint Technical Committee (YRPJCT) sets harvest limits based on run estimates. Using initial salmon returns, the YRPJTC produces a total run estimate for that year. The YRPJCT then sets a harvest limit based on the size of the estimated run. This process makes for sustainable harvests; more harvest in years with larger predicted returns and limited harvest in years with smaller runs (Yukon River Panel Joint Technical Committee 2017). My initial models suggested that harvest rate has little to no predictive relationship to WCS returns. This lack of relationship is most likely a testament to the YRPJTC's success

in their harvest management strategy of estimating abundance and allowing a sustainable harvest. However, any adequate fisheries model must control for fishing. Adjusting our response variable for harvest allows harvest to be accounted for without it cluttering the model, or risk getting removed by AIC selection, as a predictor variable. However, this adjustment does not rule out the possibility of some undetected effect due to the difficulties of quantifying the impact of harvest *per se* separately from other possible confounding factors based on the structure of harvest strategies and the statistics used to account for error (Frisman et al. 2005; Ellner and Feiberg 2003). Nevertheless, it is highly plausible that harvest affects the composition of the WCS population if not the strength of the population. Size-selective fishing gear has been shown to produce changes in the size and age at maturity of a number of stocks. Additionally, fishing tendencies can shift a population towards smaller, younger fish by removing larger, older fish from the pool of potential spawners year after year (Ricker 1981). The Yukon Chinook Salmon overall population has sustained decreases in average age (Figure 2). These shifts are indicative of harvest effects; however, other possible reasons for this shift exist, such as ocean temperature affecting growth rates and age at maturity (Lewis et al. 2015; Yukon River Panel Joint Technical Committee 2017;).

4.2 Population Dynamics: Growth Trajectories and Hatchery Operations

The models provide no evidence of change in the WCS population throughout the study period since the nominal Year variable did not make it through AIC based selection in any model. However, this lack of the Year variable does not imply stability

throughout this time period. Since 1959, WCS have experienced many swings in their population (Figure 1). Oscillation in population strength is natural in Pacific salmon. Populations of Pink Salmon have been known to oscillate roughly year-to-year, with large populations cycling by over 50% abundance between on and off years (Ruggerone et al. 2009; Amoroso et al. 2017). Chinook Salmon are older at maturity and thereby cycle somewhat less often (Healey 1991). Nevertheless, the cycles can still be loosely observed, even in a population as small as WCS. Unfortunately, with a small population comes a higher risk of collapse (Purvis et al. 2000; Matthies et al. 2004). Although the minimum viable population for WCS is not known, this population has dipped below 125 individual spawners before and has had multiple stretches of consecutive years where the population has not exceeded 500, even after the formation of the hatchery. With such a small average population number, fluctuations in percentage population strength that are common in other species or populations may prove catastrophic to the WCS population, especially if combined with some other confounding factor(s) that the salmon may experience in their environment. In short, a lack of evidence of change in the WCS population strength is hiding a lot of irregularity and should not be taken as the primary metric of stability.

Whether or not hatchery-based stock enhancement is a viable strategy for maintaining salmon populations has been debated for over a century (Maynard and Trial 2013). Factors influencing hatchery program success vary from system to system, and decision-making around specific operations can be challenging (Solomon 1985; Travis et al 1988; Moloney et al. 2003). Even quantifying the impact of a hatchery once

one has been established can be as difficult as the assessment process leading to a decision to build a hatchery. (Morita et al. 2006).

In Model 4, the Stocking variable included zero values all the way back from 1959 to 1988 specifically to explore the effect of having any fish stocked into the system at all on overall population size; a sort of all-or-nothing comparison of stocking versus no stocking (Figure 4B). Stocking was selected in Model 4 but was not selected in Model 5. Although not being selected does not mean Stocking has no effect in Model 5, we can say it has a small enough effect to not be selected whereas Stocking in Model 4 had a large enough effect to be selected. The way I interpret this is that the presence of stocking at all has, at least, a larger effect on WCS than any variation in amount of stocking since 1988. This seems to provide evidence to suggest that hatchery operations are providing at least a baseline boost to the population strength.

4.3 Sea Surface Temperature and Consideration of Other Relevant Variables During Spawning Migration

The variable SST rises to the forefront of predictors in this study, with SST included and accounting for most or all of the variance explained in every model. This study showed a general positive correlation of WCS returns and Bering Sea surface temperature during the time this population of Chinook Salmon approach the coast and begin their spawning migration. This correlation, generally shared by both wild and hatchery origin WCS, is a significant finding of this modeling effort and provides evidence to ocean condition effects dominating the in-river condition effects during

marine exit and spawning migration. Yet, even considering that SST dominated the models, both oceanic and in-river conditions combined to make more predictive models than models with just SST in Model 5. The concept of combining ocean and river effects to make more predictive models has been previously exemplified (Keefer et al. 2008) and lends itself to the continued debate as to where there may be a possible bottleneck for salmon production, in the complexity of salmon life history.

On that note, one is not to say that I have found definitive, objective proof of ocean effect dominance over in-river effects. Primarily, one must consider that the objective variance explained by the factors in Model 5 is low and that no one factor, or even combination thereof, can be said to be a driving force on the WCS population. Considering that, factors affecting SST may also affect conditions overland or in-river that impact migrating salmon. Although not as predictive as SST, Model 5 showed that Yukon River flow rate plays a part in governing migration success of WCS. This model exemplified evidence of higher migration success for WCS in lower Yukon River flows. This finding is in corroboration with Neuswanger et al. (2015) who found that the addition of river flow to their stock/recruit model improved its accuracy. Biologically, high flow rates make for more difficult migrations by increasing the needed energy expenditure for swimming against the current (Cooke et al. 2006; Burnett et al. 2014; Neuswanger et al. 2015). Because salmon do not eat during migration, they must ration energy output and any stronger than expected current may result in premature expiration during migration (Healey 1991).

The timing of approach to and ascent of the Yukon River may also play a part in explaining the predictiveness of SST. Marine exit timing and its effects are highly multifactorial and continue to be under heavy study, lacking definitive effects and mechanisms (Robards and Quinn 2002; Cooke et al. 2004; Katinić et al. 2017). It is possible that higher SST during this migration period may be standing in for effects of migration timing, which is governed at least in part by temperature (Jonsson et al. 2006; Mundy and Evenson 2011). Higher ocean temperatures may correlate with and encourage favorable migration timings for this population, rather than having some direct physiological effect during their up-river migration.

It is additionally possible that the variables selected did not adequately encompass or represent in-river conditions, resulting in the observed relative overshadowing by SST. Yukon River temperature was proxied for by air temperature in Dawson, Yukon, as water temperature was not available for a sufficient number of years from a number of sources. If river temperature does correlate with salmon survival during migration, possible lack of correlation between air and water temperature in Dawson may have caused this air temperature variable to be rejected in model selection. Another possibility is that the proxy was a success, but Dawson is not as important, in terms of temperature, as another geographic point in these salmon's migration. DawsonPrecip may be plagued by similar issues in being a proxy for EagleFlow. DawsonPrecip was included in the final iteration of Model 1, yet EagleFlow was not included in Model 2. Similarly, EagleFlow was present in Model 5 but was not selected for Model 4. Although inclusion or non-inclusion of a variable after AIC

selection is not a definitive measure of correlation, the regression between DawsonPrecip and EagleFlow would lead me to believe that there should have been more representation of the variables together in the relevant models. It is possible that precipitation in Dawson City, Yukon, specifically, could be unrepresentative of overall Yukon River flow as the river heads into the USA and another geographic location could be more relevant. I believe that it is, however, unlikely that river flow and precipitation are so wholly unrelated that using precipitation as a proxy for flow would be altogether incorrect, in contrast to the relationship between air and river temperature in the Yukon. Regardless, a highly predictive SST may be indirectly pointing at favorable in-river conditions that occur during favorable migration timing windows but are conditions that may not be adequately accounted for in the models.

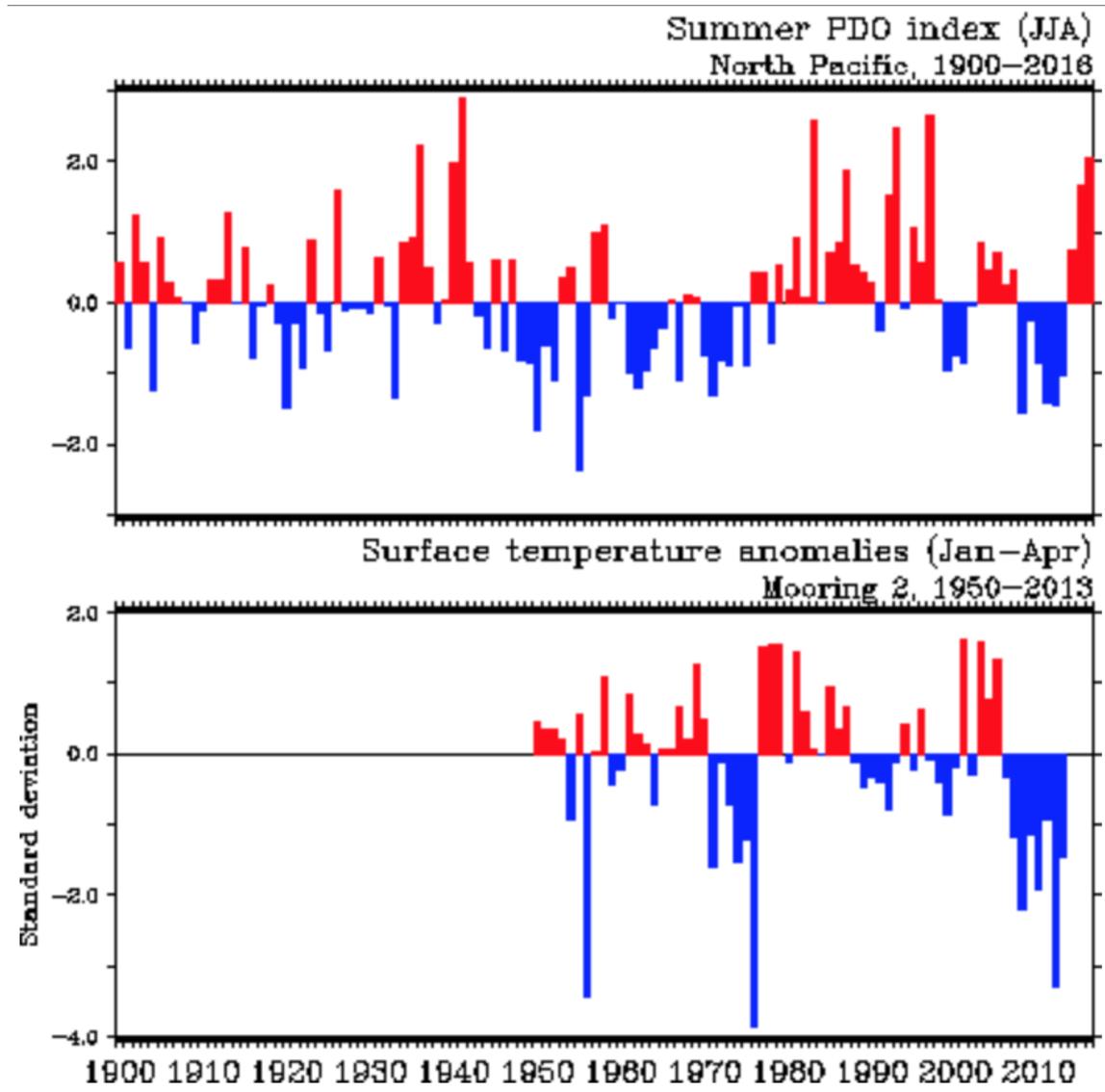


Figure 4: Temperature Anomaly Data - Top – Summer Pacific Decadal Oscillation index. Anomalies based on the 60-year mean from 1940-2000. Bottom – Bering Sea Surface Temperature Anomaly on the 60-year mean from 1940-2000. Temperatures taken from M2 mooring off the north coast of the central Aleutian Islands. Figure reproduced from the NOAA Bering Climate database (Bering Climate 2019).

4.4 Oceanic Conditions During Growth at Sea

I have found evidence in Model 5, with the predictiveness of the TemponEntry variable, to suggest that temperature during their first spring and summer at sea is a

notable predictor of survival. Studies have found that the growth during a salmon's first year at sea overshadows any other biological metric - during any period in a salmon's life - in terms of predicting survival and that this growth is contingent upon ocean temperature (Holtby et al. 1990; Cross et al. 2009; Ruggerone et al. 2009). Although I have found evidence that salmon run strength varies with temperature during this established critical growth period, cooler waters seem to favor the WCS population (Figure 4D).

This finding is contrary to previous studies that found that growth and subsequent survival was linked to warmer ocean temperatures. The vast majority of studies have found that positive phase PDO "regimes" and warmer SST correlate with higher growth and survival in this region of the North Pacific (Seigel et al. 2017). Shifts in Pacific Ocean climate indices such as the PDO, and related sea surface temperature, have also been strongly linked to larger salmon population size (Mantua et al. 1997; Seo et al. 2017; Hare and Francis 1994). Historically, the PDO has shifted regimes every few decades, alternating between warm and cool phases. The two major shifts in recent history have been in 1977 and again in the early-to-mid 1990's (Figure 5). The 1977 regime change to a warm phase generally favored more northern stocks while mildly negatively affecting southern stocks. In the mid-90's however, a shift to a cool phase coincided with more precipitous declines across the West Coast of North America.

Since the 1990s regime shift, the PDO and other indices have become irregular. It would seem that this semi-consistent alternation between warm and cool phases has largely broken down. More recently, oscillations have consisted of minor shifts back and

forth over the course of a decade or less in some cases with no major regime changes as would be expected based on the past. Additionally, we do not see as much connectivity between climate indices and temperature in the North Pacific (Overland and Stabeno 2004). We also no longer see salmon populations tracking these shifts in climate; it would seem that populations are unable to track the now rapid changes in climate. It is highly possible that this growing inconsistency itself is the cause of continued salmon decline. The findings of Reed et al. (2011) suggest that, at least in Fraser River Sockeye Salmon, populations are being given enough time to adjust to overall temperature increases associated with climate change. This, however, does not encompass the smaller time scale shifts in PDO that we are beginning to observe. We must also take into account the higher age at maturity of Chinook Salmon over Sockeye Salmon. Without a stable oscillation, Chinook Salmon populations specifically are more vulnerable to being continually exposed to new temperature regimes every few generations, or possibly every generation for longer lived Chinook Salmon. This rapid regime oscillation would not allowing populations to slowly adjust and cycle along with changes in regimes or general climate change, resulting in general decline. With the potential cool temperature preference of WCS (coinciding with below-average Bering Sea SST for the past decade, yet high PDO; a nod to the aforementioned inconsistency), WCS may specifically face additional challenges in the face of a sudden irregular North Pacific climate shift as well as the global increase in temperature.

Although there are many possible reasons for finding that WCS are more successful with cool rather than warm ocean entry temperatures, it is possible that at

least for this population of Chinook Salmon, temperature may not be having a direct effect. Beauchamp et al. (2007) found that temperature effects on growth were only of note outside of a relatively large comfort range. They also found that changes in food quality and availability affected salmon growth regardless of temperature. This may indicate that temperature only has an indirect effect on salmon growth, proxying for the effects of temperature on salmon food sources, which are much more complex and poorly understood (Sugimoto and Tadokoro 1997; Batten et al 2018). During their first year at sea, salmon smolt generally feed on zooplankton such as euphasids, amphipods, and krill. As they grow in size, salmon diets include increasing amounts of filter-feeding or low-food-chain predatory fish (Hertz et al 2015). Integral to ocean life, phytoplankton is the ubiquitous base of most oceanic ecosystems. Because of phytoplankton's basal position in the food web as primary producers, even small perturbations in phytoplankton communities can have much more drastic, scaled-up effects on organisms higher in the web (Mackas et al 2007; Farley et al. 2009). Of all Pacific salmon species, Chinook Salmon may be affected the most by food web changes due to their size and relatively high trophic level (Adyin et al. 2002). Cultivating a greater understanding of the intricacies of the North Pacific plankton populations' own relationship to ocean temperature and their relationship to salmon food sources may be a promising way forward in understanding this population's trajectory.

5. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This study's findings provide evidence for marine temperature governing Whitehorse Chinook Salmon production and survival. This proposed relationship was exemplified during both marine entry and exit. Although I found that SST was more predictive of run strength than in-river factors during these life stages, I do not propose that this is definitive evidence of ocean effects dominating this population's life history. It is entirely possible that, because of shortage of environmental data or considered variables that this study inadequately encompassed in-river effects. It is also possible that the predictiveness of SST is standing in for those unassessed environmental effects, taking into consideration of the interconnectedness of weather and climate. Regardless, I see this study as lending support to an intricate and multifaceted life history rather than supporting the existence of a single bottleneck in salmon production.

North Pacific Climate is, as much of climatology, convoluted and multifactorial. Relating the interactions of large-scale climate indices to year-to-year micro-climate can be even more mired than relating indices to each other. More extensive exploration of North Pacific climate indices and observed micro-climate relevant to this study is necessary for any continuation of this study. Fine tuning the quantification of how interdecadal trends and climate indices translate to experiences of migrating salmon may provide more insight as to how this population varies with environmental conditions.

Specifically salient in this study is evidence for WCS being positively affected by colder ocean temperature on marine entry. I found no possible cause in other studies for this apparent departure from the norm of warmer ocean temperature benefiting early growth. Additionally, a number of models failed to provide insight into more than 10 or 20 percent of observed variation in single-origin run strength. Even my most successful model did not crest 50% variance explained. This study thereby lends itself to exemplifying the need for more data on this system, specifically finer scale climate data, not just continued study of what data exists. Consequently, it is even more important that precautions be taken in management, as major causes for observed population fluctuation remain unclear not only for WCS but for Pacific salmon in general.

WCS are the only population of Yukon Chinook to have direct contact with a hatchery and in that may lie a cause for their apparent deviance from the ocean temperature effect norm. Differences between hatchery and wild fish within the same population is not uncommon generally, but the degree of difference between these groups of fish, the underlying mechanism, and the effect of that difference vary widely across studies (Satterthwaite and Carlson 2015; Dittman et al. 2010; Kallio-Nyberg et al. 2014). It is possible that specific hatchery functions are influencing the optimal temperature range of these fish (Unwin and Glova 1996). The Whitehorse Rapids Fish Hatchery rears their Chinook fry at a static, cold temperature rather than mimicking the shifting warm to cold temperature of the natural spawning creek over the course of incubation. This may be causing the observed success of this population in colder temperatures (Alderice and Velsen 1978; Nathanailides et al. 1994; Ricks and DNA 1996;

Crichigno et al. 2017; Harstad et al. 2018; de Graff, pers. comm.). The topic of hatchery effects is, however, unexplored and possible cause(s) of the observed ocean temperature effects are likely many and multifaceted, especially given the relatively low percentage of variance explained by TemponEntry in Model 5. Yet, this observed effect specific to this population which has a hatchery may provide an accessible area of research that year-to-year adaptive management could assess.

Food sources and environmental impact on food sources is something commonly left out of the discussion on Pacific salmon production. Filling in knowledge gaps in the understudied and complex interactions between Pacific salmon life history, the North Pacific food web, and phytoplankton-temperature dynamics may prove invaluable in discerning a major mechanism driving production. Although research has been done in regard to all three of these topics, that research has mostly been on a single topic independent of the other two. Gaining a more complete understanding of factors affecting Pacific salmon production will require a more holistic approach, quantifying how plankton-temperature interactions scale up the food web. Hunt et al. (2002) provides a premier example of this approach, creating a causal chain that links ocean temperature and sea ice cover to Pollock (*Gadus chalcogrammus*) production via plankton. Although Hunt's study is extremely well argued with a plethora of data and evidence, it is still largely conceptual, and contains little concrete statistical correlation. Considering Hunt's study was done in 2002, a similar approach combined with modern modeling techniques as exemplified in Cunningham et al. (2018) would enhance our knowledge base of Pacific salmon life-history. Discerning concrete linkages between

various bottom-up effects, and how the North Pacific ecosystem as a whole governs production, may be vital in our ongoing efforts to maintain a future with healthy Pacific salmon populations.

With Pacific salmon being a key natural resource for humans in multiple facets, we must find further ways to mitigate and account for the effects of both North Pacific and global climate change. We cannot afford continued declines in salmon stocks; in the face of contemporary declines, focusing on populations with have the propensity to be first affected by changes to their habitat should be a main objective. This study provides a unique look at a small, fringe population of Chinook Salmon and has shown that they may be affected by a changing environment differently than the average population. Cultivation of a mechanistic understanding of what drives this and other similar, edge populations' fluctuations could provide further novel insights into environmental effects on Pacific salmon and to piecing together a solution to rapid declines.

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Appendix 1: Detailed Data Used in This Study

This appendix presents a data table that consists of rows per year 1959-2013, and 19 columns of data per year. The table data is presented in segments A-D, each indexed by year and showing 4 or 5 of the 19 columns. Some columns contain empty cells, in cases where the data did not include a value for the year of the row.

Segment A

Year	M2 SST Anomaly	Whitehorse Wild	Whitehorse Rapids Fish Hatchery	Whitehorse Total	Preharv Wild
1959	-0.44	1054	0	1054	
1960	-0.21	660	0	660	
1961	0.85	1068	0	1068	
1962	0.28	1500	0	1500	
1963	0.15	483	0	483	
1964	-0.71	595	0	595	
1965	0.08	903	0	903	
1966	0.06	563	0	563	
1967	0.66	533	0	533	
1968	0.21	414	0	414	
1969	1.28	334	0	334	
1970	0.49	625	0	625	
1971	-1.59	856	0	856	
1972	-0.12	391	0	391	
1973	-0.7	224	0	224	
1974	-1.51	273	0	273	
1975	-1.19	313	0	313	
1976	-3.87	121	0	121	
1977	1.52	277	0	277	
1978	1.54	724	0	725	
1979	1.53	1184	0	1184	
1980	-0.1	1383	0	1383	
1981	1.43	1555	0	1555	
1982	0.61	473	0	473	
1983	0.08	905	0	905	
1984	0	1042	0	1042	
1985	0.96	508	0	508	
1986	0.33	557	0	557	
1987	0.68	327	0	327	
1988	-0.11	340.2	64.8	405	588
1989	-0.46	444.69	104.31	549	727
1990	-0.33	1069.32	337.68	1407	1721
1991	-0.41	620.34	645.66	1266	1028

1992	-0.79	121.28	636.72	758	212
1993	-0.13	180.36	487.64	668	311
1994	0.4	725.42	851.58	1577	1214
1995	-0.21	904.29	1198.71	2103	1540
1996	0.62	1922.7	1035.3	2958	3074
1997	-0.06	1583.84	500.16	2084	2646
1998	-0.38	38.85	738.15	777	62
1999	-0.86	290.68	827.32	1118	484
2000	-0.2	209.87	467.13	677	318
2001	1.63	632.32	355.68	988	885
2002	-0.3	369.05	235.95	605	549
2003	1.58	432.9	1010.1	1443	636
2004	0.77	477.36	1511.64	1989	760
2005	1.33	1131.76	1500.24	2632	1646
2006	-0.33	911.6	808.4	1720	1349
2007	-1.18	187.88	239.12	427	302
2008	-2.18	183.54	215.46	399	269
2009	-1.14	438.84	389.16	828	553
2010	-1.91	342.72	329.28	672	504
2011	-0.91	797.68	736.32	1534	1086
2012	-3.3	422.3	607.7	1030	568
2013	-1.47	375.87	763.13	1139	471

Segment B

Year	Preharv Hatchery	Preharv Total	DawsonPrecip anomaly (mm)	DawsonTemp anomaly (Degrees C)
1959			-3.22594697	-1.768181818
1960			2.682386364	-0.068181818
1961			7.107386364	-0.508181818
1962			3.582386364	-0.388181818
1963			3.540719697	-0.288181818
1964			-0.792613636	-1.848181818
1965			11.45738636	-0.708181818
1966			-6.359280303	-0.748181818
1967			1.907386364	-0.208181818
1968			-2.342613636	0.251818182
1969			-10.9842803	0.191818182
1970			3.32405303	-0.408181818
1971			-0.417613636	-0.228181818
1972			-2.017613636	-1.268181818
1973			-1.25094697	0.011818182
1974			-1.934280303	-0.568181818
1975			-2.817613636	0.791818182
1976			-10.6342803	0.591818182
1977			-5.142613636	0.151818182
1978			-7.109280303	0.091818182

1979			6.490719697	-0.128181818
1980			3.440719697	0.751818182
1981			7.19905303	-0.928181818
1982			-3.642613636	-0.788181818
1983			8.240719697	0.411818182
1984			-5.484280303	-0.088181818
1985			10.5657197	-2.108181818
1986			-8.817613636	-1.548181818
1987			1.140719697	-0.168181818
1988	112	701	3.815719697	0.631818182
1989	171	898	-7.42594697	1.651818182
1990	543	2264	10.53238636	1.391818182
1991	1070	2098	3.040719697	0.471818182
1992	1113	1325	3.182386364	-0.388181818
1993	840	1151	-3.459280303	1.271818182
1994	1425	2639	-0.22594697	1.431818182
1995	2041	3581	0.42405303	1.731818182
1996	1655	4730	-7.992613636	-0.328181818
1997	836	3482	3.465719697	0.571818182
1998	1179	1241	-7.609280303	1.391818182
1999	1378	1862	-1.942613636	0.831818182
2000	707	1025	7.19905303	-0.648181818
2001	498	1383	-2.534280303	0.411818182
2002	351	900	2.211480461	-1.176722801
2003	1484	2119	-2.976820821	-0.108181818
2004	2406	3166	-4.85719697	1.708342013
2005	2182	3828	1.44905303	1.091818182
2006	1196	2545	-0.259280303	0.131818182
2007	384	686	-3.908403428	1.201087842
2008	316	586	4.54104021	-0.370001753
2009	490	1043	-4.752870047	0.755001332
2010	485	989	-4.787785496	8.763843353
2011	1002	2088	-0.778288728	0.210203401
2012	817	1385	-3.030654702	0.802392894
2013	957	1428	0.326427917	-0.356595611

Segment C

Year	Yukon at Eagle Flow (m/s ³)	Wild Temp on Entry	Hatch Temp on entry	Total Temp on entry
1959				
1960				
1961				
1962				
1963				
1964				
1965				

1966				
1967				
1968				
1969				
1970				
1971				
1972				
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980				
1981				
1982				
1983	2519			
1984	2158			
1985	2560			
1986	2622			
1987	2411			
1988	2699	-0.624383564	0.57532737	-0.432429814
1989	2041	-0.838496873	-0.164935174	-0.71052015
1990	2601	-1.050359947	-0.978929287	-1.033216589
1991	2721	-0.622901545	-1.248797897	-0.942108685
1992	2945	0.195218423	-0.851302823	-0.683859423
1993	2643	-0.182293065	-0.023893269	-0.066661214
1994	2331	-0.245965796	-0.182387278	-0.211633397
1995	2146	-0.366373092	-0.177735936	-0.258849913
1996	1860	-0.622096009	-0.384453217	-0.538921032
1997	2388	-0.570903711	-0.49618757	-0.552971837
1998	1739	0.049747135	-0.086794428	-0.07996735
1999	1955	-0.714466667	0.583121588	0.245748641
2000	2970	-0.562600204	-0.62052515	-0.602568417
2001	2697	-0.007428645	-0.614385557	-0.225933133
2002	2439	-0.659369715	-0.097932431	-0.440409174
2003	2039	-0.982529821	-0.614445222	-0.724870602
2004	2282	-1.320904074	-0.97550351	-1.058399645
2005	2589	-0.406692554	-1.282496279	-0.905900677
2006	2287	0.12367067	-0.33715956	-0.092919538
2007	2471	0.696445807	0.167984277	0.40050735
2008	2766	1.166442837	0.976494245	1.063870597
2009	2473	0.766411578	1.264824251	1.000665535
2010	2099	-0.626526506	0.711705361	0.029207109
2011	2692	-1.538949893	-0.108930374	-0.852540524
2012	2646	-2.039627583	-1.639590465	-1.803605683
2013	2857	-2.25985179	-1.97791753	-2.070955836

Segment D

Year	Wild Spawners	Hatchery Spawners	Total Spawners	Stocking
1959				0
1960				0
1961				0
1962				0
1963				0
1964				0
1965				0
1966				0
1967				0
1968				0
1969				0
1970				0
1971				0
1972				0
1973				0
1974				0
1975				0
1976				0
1977				0
1978				0
1979				0
1980				0
1981				0
1982				0
1983				0
1984				0
1985				0
1986				0
1987				0
1988	1063	0	1063	1689
1989	841	0	841	72195
1990	823	0	823	295628
1991	582	0	582	587771
1992	497	3	499	172026
1993	371	28	398	281215
1994	415	90	505	303355
1995	538	159	697	251391
1996	764	448	1212	197200
1997	562	619	1180	262612
1998	208	579	787	398060
1999	290	567	857	411124
2000	725	917	1642	253587
2001	1196	1100	2296	169392
2002	1642	863	2505	296685
2003	1198	618	1816	301137

2004	211	739	950	261515
2005	260	698	959	215855
2006	395	424	819	205776
2007	526	362	888	246112
2008	421	751	1171	203321
2009	512	1208	1720	163319
2010	842	1415	2257	132135
2011	973	1208	2181	132682
2012	606	585	1191	154044
2013	233	265	498	141859