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Climate and Density Effects on Growth of Chum Salmon in British Columbia, Canada (Extended Abstract)

by

Allan J. Debertin[1,2], James R. Irvine[1], Carrie A. Holt[1], Gladys Oka[1,3], Marc Trudel[1,2]

[1]Fisheries and Oceans Canada, Pacific Biological Station
3190 Hammond Bay Road, Nanaimo, B.C., Canada V9T 6N7

[2]Present Address: Fisheries and Oceans Canada, St. Andrews Biological Station,
531 Brandy Cove Road, St. Andrews, New Brunswick, Canada E5B 2L9

[3]Present Address: University of British Columbia, Earth, Ocean and Atmospheric Sciences Department, 2020-2207 Main Mall, Vancouver, B.C., Canada V6T 1Z4

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Abstract

This study provides evidence for climate and competition effects on the body growth of a southern British Columbia population of chum salmon (*Oncorhynchus keta*) using 39 years of scale growth measurements. Growth at all ages was reduced when the biomass of North American chum, sockeye (*O. nerka*) and pink salmon (*O. gorbuscha*) was greatest. When North Pacific Gyre Oscillation (NPGO) was positive, indicating increased primary productivity, growth at all ages was greater. Climate variation affected the strength of density-dependent competition. Density-dependent effects on growth were strongest when NPGO became more positive and Pacific Decadal Oscillation more negative (indicating cooler conditions). Southern British Columbia chum salmon are likely to exhibit continued reduction in growth at age due to increased ocean temperatures driven by climate change and high aggregate salmon biomass.

Introduction

There have been recent downward trends in size-at-age for many Pacific salmon (*Oncorhynchus* spp.) populations (Jeffrey et al. 2016), although variability among populations and regions exist. Climate variation affects salmon growth as the bioenergetics of salmonids can be altered by changes in the amount and composition of salmon prey (Beauchamp 2009) in conjunction with changes in ocean temperature and productivity (Hare and Mantua 2000). In addition, relatively high abundances of salmon, especially during periods of low marine productivity, have been hypothesised to cause reductions in size-at-age and salmon survival (e.g. Irvine and Akenhead 2013, Yasumiishi et al. 2016). The relative importance of competition and climate variation on individual size-at-age and age-at-maturation remains uncertain for many Pacific salmon populations, including those in Canada.

The purpose of this document is to present some of the key results from a published paper by Debertin et al. (2017). We encourage readers to refer to this published paper for more details. In this paper we tested whether growth patterns for a population of southern British Columbia (BC) chum salmon could be explained by competition and climate variation. We focused on chum salmon because of its relatively wide spatial distribution in the ocean, and potential for competitive, density-dependent interactions with chum, pink, and sockeye salmon from other regions.

We tested the following hypotheses: (H1) growth is affected by density-dependent interactions with competing chum, sockeye, and pink salmon, (H2) growth is affected by climatic variation; and (H3) the strength of density-dependent competition on salmon growth is related to climate conditions and fish age, such that under particular environmental conditions, density-dependent competitive effects could be strengthened or reduced.

Methods and Materials

Data

We sampled a population of chum salmon that spawns in the Big Qualicum River that drains into the Strait of Georgia between Vancouver Island and mainland BC. Adult chum salmon returning to the lower Big Qualicum River were sampled for sex, length and scales at a counting fence from 1971 to 2010 (for further details see Oka et al. 2012). We focused on five annual growth zones on the scales, growth until the first marine winter (SW1) to growth to the last marine winter (SW5). The yearly incremental radial growth of each scale was measured along the longest anterior axis starting from the middle of the scale for SW1, then for all other growth zones the outer edge of the previous sea winter to the edge of the annulus of the year of interest, until reaching the outer margin of the scale for the final year (Oka et al. 2012).

To test the relative strength of density-dependent effects of intra- and interspecific competition, scale growth at each age was compared with salmon biomass estimates of mature chum, sockeye and pink salmon within the Gulf of Alaska from Irvine and Ruggerone (2016). Wintertime oceanic indices has been used to explain growth and body size patterns in Pacific Salmon (Agler et al. 2013; Jeffrey et al. 2016), as well as regime shifts in productivity (Helle and Hoffman 1998). Values of winter season variability were calculated by averaging monthly values from November to March for the PDO (available from research.jisao.washington.edu/ pdo/) and NPGO indices (available from www.o3d.org/npgo), as in (Agler et al. 2013).

Analytical Methods

We used a longitudinal mixed-effects model design to test our hypotheses. This method allowed us to account for correlations among repeated measures within an individual by treating each individual as a random effect (Marco-Rius et al. 2013). We found curvilinear relationships between ages and growth; therefore we used a quadratic regression model. Individual variation was accounted for by adding a random intercept term for each individual. Model description can be found in Debertin et al. (2017).

To determine if including chum salmon from Asia had an additional effect to the abundance of North American chum salmon, we compared a model that included both Asian and North American origin chum salmon biomass to a model that only had North American origin chum salmon biomass, using conditional R^2 (Nakagawa and Schielzeth 2013). Differences between these models were insignificant (conditional R^2 was 0.86 in both cases). Consequently, Asian chum salmon biomass was not included in the full candidate model. We also considered models that did not include North American pink salmon and sockeye salmon, respectively. Most variation was explained with all three North American species so we included them all in the full model.

To examine the effects of salmon biomass and climate on total scale size for each age of maturity, we predicted total scale size for male and female chum salmon that returned after 3, 4 and 5 sea winters at sea, by summing fitted-value mean sea winter scale growth and 95% CIs from SW1 to SW3, SW1 to SW4, and SW1 to SW5, respectively, and under various levels of salmon biomass and climate indices. Low, medium and high levels (i.e. 10th, 50th and 90th percentiles, respectively) of the observed covariates were selected to represent of salmon biomass and climate variables.

Results

Temporal patterns in growth (i.e. SW1 to SW4) were largely synchronous for Big Qualicum chum salmon over the time series. Because different aged chum salmon must occupy somewhat separate areas of the North Pacific, this suggested to us that factors influencing growth operate across a large area of the northeastern Pacific Ocean. In general, scale size at each growth zone increased from 1970 to 1975, remained relatively high until 1980, and was low until 1990. Following 1991, scale size at each growth zone increased to a peak in 2000 and subsequently decreased until 2009 and then peaked again during 2010. Biomass of chum, sockeye and pink salmon increased from 1950s to 2010s. In particular, the increase in aggregate biomass during the late 1970s and 1980s coincided with a decreased scale size at each growth zone however when aggregate biomass was high during the 2000s, scale size at each growth zone increased.

During the late 1980s and 1990s, PDO was mostly positive, indicating warm ocean temperatures, and NPGO was mostly negative, indicating weak currents; this coincided with reduced scale size at each growth zone. From 1998 to 2003, scale size at each growth zone increased while NPGO was positive (i.e. stronger currents) and PDO was relatively negative (i.e. cooler ocean temperatures).

Table 1 shows that predicted scale size was reduced across all levels of climate indices when salmon biomasses were high. We also found that as NPGO strengthened, scale size was larger, but this effect depended on PDO. In particular, when PDO was in a cool phase (i.e., is negative) and NPGO was strong (i.e., is positive), density-dependent effects tended to be strong, illustrated by the relatively large range in predicted total scale size between low and high salmon biomass when NPGO was high and PDO was low.

Overall, variability in marine scale growth of individual Big Qualicum chum salmon was explained by density-dependent effects of competition from the summed biomass of North American chum, sockeye, and pink salmon, as well as changes in the ocean climate indices, PDO and NPGO. Including Asian chum salmon did not explain additional variability in growth, but given the positive correlation between Asian and the aggregate North American biomass of Chum Salmon (R^2=0.67, p<0.001), we cannot rule out the possibility of density-dependent effects from Asian chum salmon

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Table 1. Predicted total scale size (mm ±standard error) of Big Qualicum chum salmon (return age-4, females) under low (10th percentile), medium (50th percentile), and high (90th percentile) values for salmon biomass of North America origin chum salmon, sockeye salmon and pink salmon, PDO, and NPGO.

Salmon Abundances	PDO	NPGO	Scale increment (mm)	±standard error
low	low	high	3.54	(3.45, 3.64)
medium	low	high	3.04	(3.00, 3.08)
high	low	high	2.83	(2.77, 2.89)
low	medium	high	3.36	(3.30, 3.43)
medium	medium	high	3.10	(3.07, 3.13)
high	medium	high	2.99	(2.96, 3.03)
low	high	high	3.26	(3.17, 3.36)
medium	high	high	3.14	(3.10, 3.18)
high	high	high	3.09	(3.04, 3.14)
low	low	low	3.04	(2.96, 3.11)
medium	low	low	2.90	(2.85, 2.95)
high	low	low	2.85	(2.79, 2.91)
low	medium	low	3.16	(3.08, 3.23)
medium	medium	low	2.98	(2.95, 3.01)
high	medium	low	2.91	(2.88, 2.94)
low	high	low	3.23	(3.11, 3.35)
medium	high	low	3.03	(2.99, 3.07)
high	high	low	2.95	(2.90, 2.99)
low	low	medium	3.26	(3.23, 3.30)
medium	low	medium	2.96	(2.93, 3.00)
high	low	medium	2.84	(2.80, 2.88)
low	medium	medium	3.25	(3.21, 3.29)
medium	medium	medium	3.04	(3.01, 3.06)
high	medium	medium	2.95	(2.92, 2.97)
low	high	medium	3.24	(3.18, 3.30)
medium	high	medium	3.08	(3.05, 3.11)
high	high	medium	3.01	(2.97, 3.05)