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Temporal Growth Patterns of Big Qualicum River Chum Salmon (*Oncorhynchus keta)* in the North Pacific Ocean

By

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Abstract

Increases in salmon abundance in the Pacific Ocean over the past three to four decades have been attributed to favourable environmental conditions and enhanced hatchery production. However, the effects of inter- and intra- species competition for food resources in the ocean remains inconclusive. Chum salmon (*Oncorhynchus keta)* are of particular interest because of the large numbers of hatchery releases and some evidence of density dependence. Scales from Big Qualicum River chum salmon gathered during 1971-2010 were examined to evaluate marine growth during this period. A consistent temporal trend was observed for all growth years for the dominant age classes of chum salmon; growth was most rapid in the early 1980s and 2000s and slowest in years centred around 1990. Future work to continue statistical analysis of these data and examine temporal patterns in growth of other populations and species is recommended.

Introduction

In recent decades, salmon (*Oncorhynchus spp*.) abundance in the north Pacific Ocean has increased as a result of favourable environmental conditions, increased hatchery production, and improving hatchery technologies (Irvine and Fukuwaka 2011). Increases in hatchery production have been exceptionally pronounced for chum salmon (*O. keta*); Ruggerone *et al.* (2010) estimated that the abundance of adult hatchery-origin chum salmon exceeded wild chum salmon in the mid 1980s and thereafter, representing 62% of total chum salmon abundance during 1990-2005. This highlights the issue of competition among wild and hatchery-raised salmon for shared food resources in the North Pacific Ocean. Inter-species competition between pink (*O. gorbuscha*) and chum salmon have been recorded by Azumaya and Ishida (2000). The odd-even year fluctuations in density and distribution of chum salmon suggests that chum salmon distributions were being affected by pink salmon abundance resulting in a shift from the Bering Sea to the eastern North Pacific. However, the growth of chum and pink salmon in the Bering Sea was found to solely depend on their own species abundance suggesting that for salmon intra-species interaction may be more important than inter-species interaction.

The regime shift in 1976/1977 towards more intense Aleutian Lows affected environmental conditions in the entire North Pacific Ocean (Beamish and Bouillon 1993).

Increased marine survival, perhaps due to a large forage base, contributed to increased salmon abundance (Bigler *et al.* 1996). This change can increase the proportion of small, slow growing salmon that may result in a decrease in the average body length. Ishida *et al.* (1993) reported a decrease in mean body size of age four chum salmon in both Russian and Japanese stocks and an increase in mean age at return following 1970. The growth reduction took place in the third year of life when both chum salmon populations overlapped in distribution in the North Pacific Ocean. Thus, Ishida *et al.* concluded that density dependent effects likely took place in the ocean, explaining 35% of the variability in chum salmon body size. Helle and Hoffman (1998) reported similar findings for chum salmon stocks from Southeast Alaska and Washington, observing decreases in the size of age four chum salmon starting in 1980. Competition for food resources as a result of the distributional overlap with Asian chum salmon in the high seas was recognized as a potential causal factor.

This project is part of research to investigate density dependent effects on salmon growth and the implications of a climatically varying carrying capacity for fisheries management and international governance, extending the time series reported earlier (Oka *et al.* 2012). Chum salmon are of particular concern because of significant increases in hatchery production and evidence for both intra- and inter-specific competition for prey resources in the North Pacific Ocean. Big Qualicum (BQ) chum salmon were selected for analysis of marine growth over time because of the long time series of sample availability ranging from 1959-2010 (DFO Sclerochronology Lab Scale Archives, Pacific Biological Station). Big Qualicum Hatchery is located on the eastern side of Vancouver Island, British Columbia, Canada. The Big Qualicum River is a coastal stream which runs 11km from its source at Horne Lake to the Strait of Georgia. The main goals are to determine marine growth patterns over the time period of 1971-2010, evaluate scale of temporal variability in growth (e.g., dominated by annual and/or decadal scale variability), and to develop a standardized protocol for future marine growth assessment of salmon populations.

Materials and Methods

Salmon marine growth was determined by analysing scales from fish captured on the spawning grounds and a counting fence in the lower river. All scales were collected above the lateral line of the fish where it intersects with the row of scales descending from the posterior region of the base of the dorsal fine (Hagen *et al.* 2001). Scales were placed on gummed cards and acetate impressions were made of each card for subsequent scale analyses. Biological data were collected from various DFO sources (e.g. Sclerochronology Lab Scale Archives, the Pacific Age Database System (PADS) online database and from data records located at Big Qualicum Hatchery). The dominant age of maturity for BQ chum salmon are 3_1 and 4_1, with the first number indicating the age at maturity in years and the subscript indicating that chum salmon leave freshwater and enter the ocean in their first year of life. These two age classes were sampled consistently across all years in the time series except in cases where the scale samples available did not permit it. When a high proportion of 5_1 chum salmon were observed, scales from this age group were measured to produce a representative sample.

For each year and major age class, 50 samples were randomly selected: 25 males and 25 females. To avoid fish marking (e.g. fin removal) effects that occur when some hatchery-origin fish are marked, scales were randomly selected from unmarked fish whenever possible. Occasionally not enough scales were available for random selection of samples, in which case every scale available was sampled.

The scales were examined using an Olympus BH2 compound microscope at 250X magnification. TIFF images of the anterior portion of the scale, where the focus, circuli and annuli were clearly defined were captured with a Luminera *Infinity 1* 2.0 megapixel digital camera. Images were saved at high resolution to allow for calibration and measurement. If the selected scales were of poor quality for imaging and measuring (i.e. wet, regenerate, resorbed, or non-preferred), they were excluded from the sampling process. New random samples were selected until scales from 25 male and 25 female were identified for measurement.

Measurements of scale growth were completed using Media Cybernetic's *Image Pro Plus vers. 6.2* image analysis software. The yearly growth pattern of each scale was measured along the longest anterior axis starting from the middle of the focus. Using Image Pro, a marker was placed at the focus, at the outside edge of each annual growth zone (annulus), and at the outer margin of the scale. Once the markers were positioned, the growth increments were measured automatically by the caliper function in Image Pro and the data saved to a Microsoft Excel file. A 'reference' image containing the measurement axis and annual growth increment markers was saved as a jpeg file.

The imaging and measurements for all 40 years (1971-2010) were completed by the senior author except for 6 years, which were completed by the DFO Sclerochronology Lab (1983, 1988, 1996-1999). Calibration and precision were assessed regularly during the study to ensure consistent data capture. Scale measurements were calibrated using a slide micrometer and a calibration file set up within Image Pro. Using a stratified random design, 10 scales were selected for re-measurement by the principal reader and 25 scales were selected for re-measurement by a separate reader from the DFO Sclerochronology Lab. The first measurement assessed the level of consistency for the primary scale reader and the second measurement assessed the level of repeatability for a different scale reader. Intra-reader precision was assessed on seven occasions, and inter-reader precision four times. The original TIFF images were used to reproduce a new axis for measurement using the Image Pro program. R^2 values were then calculated to determine the level of variation between the preliminary and secondary set of growth measurements.

An ANOVA test was completed on data from all years (excluding those years with fewer than 15 scale samples) to test the effects of year, sex, return age (3_1 and 4_1), ocean age (marine growth, MG, years 1-4), and all two-way interactions, on growth increments. .

Results

Growth measurements were consistent for the primary reader and between readers; quality control measurements had high r^2 values ranging from 0.90-1.00 for re-measurement by the same scale reader and 0.78-0.96 by a different scale reader.

Relative to the temporal patterns observed, variability in growth measurements between sexes was minimal (Tables 1-3). Three year old chum salmon grew more quickly than four year old salmon; each of the first three years of marine growth (MG) for three year olds exceeded those for fish returning as four year olds (Figures 1-3). A distinct decadal-scale temporal pattern was found for all years and both age-classes, but was most evident for second, third, and fourth years of ocean life (Figures 1-4). Fish grew most rapidly in the early 1980s and 2000s with slow growth occurring around 1990 and probably in recent years.

We found that year, sex, age at return, and ocean age (i.e. marine growth years 1-4) all had significant effects on growth increments, as did interactions between year and sex, year and return age, sex and ocean age, and return age and ocean age (Table 4). Future analyses will use a time-series version of this model to account for temporal autocorrelation.

Discussion

Our results show decadal-scale variability in growth patterns of chum salmon that are common between fish of ages and ocean-entry year. The observed temporal variability in growth may be related to density-dependent processes, environmental conditions, or a combination of both factors.

Variability in scale growth measurements is meaningful in inferring temporal changes in the somatic growth of chum salmon. Determination of the length of sampled fish and back-calculations from scale measurements were not completed due to limitations in the biodata. Fukuwaka (1998) notes that the relationship between somatic growth and circulus spacing is positive but weak in Pacific salmon. Specifically, somatic growth is measured as the difference between initial fork length and the fork length at the end of the rearing period. This relationship is inferred in the following discussion.

We further found that growth was greatest in the first year of life, and declined in subsequent years in the ocean, consistent with previous literature. Helle (1979) (cited in Groot and Margolis 1991) found that regardless of age at maturity, the first year of growth is similar for all fish of a given stock with the youngest maturing fish growing slightly faster. In their first year, chum salmon fry have been observed to grow exponentially during their nearshore residence with average accumulation of 4% to 6% of their body weight per day (Whitmus and Olsen 1979). Ishida *et al.* (1993) found that Japanese salmon in the North Pacific Ocean experienced density dependent growth from the first to fourth year of their life and especially in their third year. The observed decline in growth rate with age may have been influenced by environmental conditions and/or resource availability. For the Ishikari River chum salmon, Seo et al. (2011) suggested that a high SST in the Okhotsk Sea in the first marine year supported a high population size which indirectly resulted in limited resource availability in the Bering Sea where the chum salmon spend their third year and onwards. Fukuwaka *et al.* (2007) also found that the offshore distribution of chum salmon at ages 1 and 2 differed from those at ages 3 and 4 following changes in SST. Interactions with pink salmon may further contribute to chum growth through density dependent interactions, as pink salmon are effective exploiters of prey resources (Ruggerone and Nielsen 2004).

The temporal trend observed in the scale measurements has also been observed in the fork length of chum salmon. Walker and Myers (1998) and Ishida *et al.* (1998) found that fork length of North Pacific chum declined over 1983-1995 compared to 1950-1980. Fukuwaka *et al.* (2007) observed a decline in ocean growth and fish size at maturity in the 1970s and 1980s with a recovery in the 1990s and 2000s. This trend was largely correlated to ocean conditions. There is a general agreement on the relationship between ocean climate and salmon abundance; however, the mechanism remains unclear. Future statistical analysis may include assessing the variability in growth measurements under different ocean regimes.

In summary, temporal trends in marine growth during 1971-2010 were consistent across marine growth years for all return ages of BQ chum salmon. Growth was most rapid in the early 1980s and 2000s and slowest in years centred around 1990. Three year old chum salmon grew quicker than four year old salmon; each of the first three years of marine growth (MG) for three year olds exceeded those for fish returning as four year olds. The potential influence of density dependent and environmental effects on salmon growth requires further analysis (e.g. statistical adjustments for autocorrelation, inclusion of more populations, and evaluation of density dependence). Quality control of scale measurements indicated that the standardized protocol applied to the Big Qualicum time series can be applied to other salmon populations in the future.

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References Cited

Azumaya, T. and Y. Ishida. 2000. Density interactions between pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) and their possible effects on distribution and growth in the North Pacific Ocean and Bering Sea. *North Pacific Anadromous Fish Commission,* Bulletin No. 2: 165-174.

Beamish, R.J. and D.R. Bouillon. 1993. Pacific salmon production trends in relation to climate. *Canadian Journal of Fisheries and Aquatic Science,* 50: 1002-1016.

Bigler, B.S., D.W. Welch and J.H. Helle. 1996. A review of size trends among North Pacific salmon (*Oncorhynchus* spp.). *Canadian Journal of Fisheries and Aquatic Science,* 53: 455–465.

Fleming, I.A., M.R. Gross. 1994. Breeding competition in a Pacific salmon (Coho salmon: *Oncorhynchus kisutch*): Measures of natural and sexual selection. *Evolution,* 48(3): 637-657.

Fukuwaka, M. 1998. Scale and otolith patterns prove growth history of Pacific salmon. *North Pacific Anadromous Fish Commission,* Bulletin No.1: 190-198.

Fukuwaka, M., T. Azumaya, T. Nagasawa, A.N. Starovoytov, J.H. Helle, T. Saito, and E. Hasegawa. 2007. Trends in abundance and biological characteristics of chum salmon. *North Pacific Anadromous Fish Commission*, Bulletin No. 4: 35–43.

Groot, C. and L. Margolis. 1991. *Pacific Salmon Life Histories*. Vancouver: UBC Press.

Hagen, P.T., D.S. Oxman, and B.A. Agler. 2001. Developing and deploying a high resolution imaging approach for scale analysis. (NPAFC Doc. 567). 11 p. Mark, Tag, and Age Lab, Alaska Department of Fish and Game, P.O. Box 25526, Juneau, Alaska.

Helle, J.H. and M.S. Hoffman. 1998. Changes in size and age at maturity of two North American stocks of chum salmon (*Oncorhynchus keta)* before and after a major regime shift in the North Pacific Ocean. *North Pacific Anadromous Fish Commission,* Bulletin No.1: 81-89.

Irvine, J. and M. Fukuwaka. 2011. Pacific salmon abundance trends and climate change. *ICES Journal of Marine Science*, 68(6): 1122-1130.

Ishida, Y., *S* . Ito, M. Kaeriyama, S. McKinnel I, and K. Nagasawa. 1993. Recent changes in age and size of chum salmon (Oncorhynchus *keta)* in the North Pacific Ocean and possible causes. *Canadian Journal of Fisheries and Aquatic Science,* 50: 298-295.

Ishida, Y., S. Ito, Y. Ueno, and J. Sakai. 1998. Seasonal growth patterns of Pacific Salmon (*Oncorhynchus spp.*) in offshore waters of the North Pacific Ocean. *North Pacific Anadromous Fish Commission,* Bulletin No. 1: 66-80.

Morita, K., Morita, S. H., Morita, K., and Sakano, H. 2001. Growth of chum salmon (*Oncorhynchus keta*) correlated with sea-surface salinity in the North Pacific. – *ICES Journal of Marine Science*, 58: 1335–1339.

Oka, G., C. Holt, J.R. Irvine, and M. Trudel. 2012. Density-dependent growth of salmon in the North Pacific Ocean: Implications of a limited, climatically varying carrying capacity for fisheries management and international governance. *North Pacific Anadromous Fish Commission*, Technical Report 8:112.

Ricker, W.E. 1964. Ocean growth and mortality of pink salmon and chum salmon. *Journal of Fisheries Research Board of Canada*, 21(5): 905-931.

Ruggerone, G.T., R.M. Ruggerone, B. Dorner, K.W. Myers. 2010. Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science,* 2:306–328.

Ruggerone, G.T. and J.L. Nielsen. 2007. Evidence for competitive dominance of Pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. *Reviews in Fish Biology and Fisheries*, 14: 371–390.

Seo, H., H. Kudo, and M. Kaeriyama. 2011. Long-tern climate-related changes in somatic growth and population dynamics of Hokkaido chum salmon. *Environmental Biology of Fishes*, 90: 131-142.

Walker, R.V. and K.W. Myers. 1998. Growth studies from 1956-95 collections of pink and chum salmon scales in the central North Pacific Ocean. *North Pacific Anadromous Fish Commission*, Bulletin No.1: 54-65.

Whitmus, C.J. and S. Olsen. 1979. The migratory behaviour of juvenile chum salmon released in 1977 from the Hood Canal Hatchery at Hoodsport, Washington. *FISHERIES RESEARCH INSTITUTE* College of Fisheries, University of Washington Seattle, Washington 98195.

Table 1. Summary of average growth measurements (mm) for male chum salmon during 1971-2010; 1974, 1981, 1986 and 1995 contained samples of undetermined sex. MG indicates the marine growth year.

Year	Age 3					Age 4						Age 5						
	Sample Size	MG 1	MG 2	MG 3	Total MG	Sample Size	MG 1	MG 2	MG 3	MG 4	Total MG	Sample Size	MG 1	MG 2	MG 3	MG 4	MG 5	Total MG
2010	25	1.24	0.78	0.64	2.67	25	1.22	0.80	0.40	0.51	2.93	13	1.08	0.82	0.40	0.33	0.39	3.02
2009	8	1.23	0.92	0.51	2.65	25	1.17	0.86	0.44	0.40	2.87	11	1.23	0.68	0.32	0.30	0.37	2.90
2008	25	1.19	0.87	0.62	2.69	25	1.22	0.75	0.44	0.48	2.88	7	1.18	0.81	0.37	0.35	0.40	3.11
2007	11	1.20	0.85	0.54	2.60	25	1.10	0.85	0.46	0.45	2.86							
2006	16	1.17	1.10	0.70	2.97	25	1.24	0.71	0.45	0.46	2.86							
2005	25	1.42	0.86	0.74	3.01	25	1.28	0.99	0.50	0.51	3.29							
2004	25	1.33	1.06	0.66	3.05	25	1.30	0.92	0.52	0.53	3.27	25	1.24	0.86	0.44	0.37	0.41	3.31
2003						25	1.25	0.88	0.50	0.53	3.16							
2002						25	1.17	1.00	0.51	0.57	3.26							
2001	25	1.18	1.10	0.71	2.99	25	1.26	0.77	0.53	0.63	3.18							
2000	25	1.27	0.93	0.83	3.03	17	1.09	0.91	0.53	0.64	3.16							
1999	22	1.14	0.99	0.69	2.81	25	1.15	0.92	0.46	0.45	2.98							
1998	18	1.21	1.04	0.62	2.87	25	1.14	0.78	0.51	0.48	2.92							
1997	23	1.16	0.78	0.69	2.63	25	1.19	0.77	0.44	0.50	2.91							
1996						24	1.18	0.78	0.50	0.48	2.94							
1995	9	1.34	1.01	0.64	2.99	25	1.30	0.93	0.53	0.57	3.33	21	1.21	0.84	0.40	0.39	0.48	3.32
1994	14	1.35	0.99	0.69	3.03	25	1.30	0.84	0.48	0.56	3.18	25	1.29	0.75	0.40	0.34	0.46	3.25
1993	6	1.08	0.87	0.59	2.54	25	1.20	0.75	0.46	0.53	2.94	25	1.07	0.78	0.39	0.37	0.42	3.04
1992	3	1.16	0.68	0.49	2.32	25	1.11	0.76	0.43	0.50	2.80	1	1.48	0.75	0.47	0.28	0.56	3.55
1991	25	1.17	0.85	0.63	2.65	25	1.26	0.68	0.40	0.54	2.88	25	1.27	0.63	0.32	0.34	0.43	2.98
1990						25	1.30	0.67	0.43	0.57	2.97	24	1.19	0.81	0.34	0.29	0.43	3.05
1989	25	1.38	0.73	0.64	2.75	25	1.23	0.79	0.41	0.52	2.95	25	1.16	0.67	0.43	0.38	0.45	3.08
1988						25	1.05	0.81	0.55	0.56	2.96							
1987	8	1.18	0.83	0.73	2.74	25	1.20	0.76	0.41	0.58	2.95	22	1.20	0.73	0.37	0.36	0.45	3.11
1986																		
1985	20	1.37	0.95	0.70	3.02	25	1.33	0.79	0.46	0.56	3.15							
1984	25	1.39	0.98	0.81	3.18	23	1.44	0.85	0.47	0.63	3.39							
1983	25	1.27	0.88	0.67	2.82	25	1.09	0.80	0.51	0.53	2.93							
1982	25	1.37	1.05	0.84	3.26	25	1.39	0.82	0.53	0.62	3.36							
1981	2	1.30	1.18	0.80	3.28	20	1.37	0.87	0.50	0.64	3.38							
1980	18	1.31	1.00	0.83	3.15	25	1.36	0.82	0.50	0.71	3.38							
1979	25	1.46	0.92	0.77	3.15	25	1.43	0.90	0.55	0.60	3.48							
1978	17	1.42	0.92	0.76	3.11	25	1.28	0.90	0.57	0.66	3.41							
1977																		
1976						25	1.33	0.86	0.55	0.69	3.42							
1975	25	1.37	1.02	0.70	3.10	25	1.23	0.86	0.58	0.55	3.22							
1974	8	1.28	1.03	0.78	3.09	2	1.04	0.86	0.65	0.76	3.31	4	1.24	0.82	0.45	0.39	0.44	3.34
1973						25	1.24	0.91	0.58	0.69	3.42	25	1.16	0.81	0.49	0.38	0.46	3.30
1972	25	1.29	0.97	0.74	2.99	25	1.19	0.88	0.59	0.62	3.28							
1971	25	1.28	1.00	0.75	3.03	25	1.32	0.82	0.50	0.61	3.24							

Table 2. Summary of average growth measurements (mm) for female chum salmon during 1971-2010; 1974, 1981, 1986 and 1995 contained samples of undetermined sex. MG indicates the marine growth year.

Year	Age 3					Age 4						Age 5						
	Sample Size	MG 1	MG 2	MG 3	Total MG	Sample Size	MG 1	MG 2	MG 3	MG 4	Total MG	Sample Size	MG 1	MG 2	MG 3	MG 4	MG 5	Total MG
2010	23	1.24	0.75	0.66	2.66	25	1.18	0.79	0.35	0.45	2.77	6	1.07	0.80	0.38	0.34	0.35	2.94
2009	13	1.27	0.94	0.58	2.79	25	1.15	0.85	0.42	0.42	2.85	9	1.14	0.75	0.33	0.34	0.40	2.96
2008	25	1.18	0.86	0.60	2.64	25	1.20	0.74	0.40	0.49	2.83	11	1.13	0.81	0.35	0.28	0.37	2.94
2007	6	1.24	0.80	0.63	2.67	25	1.09	0.85	0.46	0.47	2.87							
2006	6	1.19	0.96	0.70	2.85	17	1.24	0.63	0.44	0.50	2.81							
2005	25	1.42	0.81	0.72	2.96	25	1.28	0.94	0.48	0.54	3.24							
2004	25	1.27	1.02	0.67	2.97	25	1.29	0.86	0.48	0.52	3.15	25	1.20	0.84	0.38	0.35	0.41	3.19
2003						25	1.28	0.89	0.51	0.54	3.22							
2002						25	1.15	1.03	0.52	0.59	3.30							
2001	25	1.21	1.05	0.70	2.96	25	1.27	0.77	0.53	0.55	3.13							
2000	25	1.36	0.87	0.83	3.07	25	1.13	0.95	0.46	0.64	3.18							
1999	25	1.18	0.91	0.71	2.80	25	1.13	0.89	0.44	0.45	2.91							
1998						25	1.18	0.75	0.51	0.49	2.94							
1997	25	1.10	0.79	0.70	2.59	25	1.20	0.82	0.44	0.52	2.98							
1996	25	1.21	0.90	0.59	2.70	25	1.15	0.71	0.44	0.47	2.68							
1995	9	1.34	0.94	0.73	3.02	25	1.32	0.86	0.46	0.55	3.19	25	1.20	0.79	0.37	0.37	0.46	3.19
1994	7	1.36	0.91	0.65	2.93	25	1.22	0.87	0.45	0.53	3.08	25	1.29	0.72	0.39	0.32	0.43	3.16
1993	8	1.15	0.84	0.58	2.57	25	1.20	0.70	0.42	0.44	2.75	25	1.07	0.73	0.37	0.33	0.33	2.84
1992	8	1.24	0.76	0.49	2.50	25	1.08	0.76	0.42	0.49	2.75	4	1.02	0.52	0.53	0.43	0.41	2.91
1991	25	1.16	0.80	0.60	2.56	25	1.26	0.66	0.41	0.49	2.82	25	1.27	0.61	0.29	0.31	0.40	2.88
1990						25	1.30	0.64	0.39	0.47	2.80	25	1.24	0.76	0.35	0.28	0.40	3.04
1989	25	1.34	0.63	0.59	2.56	25	1.25	0.74	0.38	0.47	2.84	25	1.11	0.64	0.39	0.34	0.37	2.86
1988						25	1.09	0.76	0.51	0.54	2.89							
1987	7	1.16	0.83	0.69	2.68	25	1.21	0.75	0.37	0.49	2.81	24	1.20	0.70	0.36	0.31	0.43	3.00
1986																		
1985	25	1.42	0.88	0.64	2.94	25	1.35	0.84	0.49	0.52	3.19							
1984	25	1.39	0.95	0.73	3.08	25	1.43	0.84	0.48	0.65	3.40							
1983	25	1.30	0.87	0.59	2.76	25	1.03	0.80	0.45	0.42	2.71							
1982	25	1.37	0.98	0.76	3.11	25	1.32	0.83	0.50	0.61	3.26							
1981	1	1.23	0.98	0.85	3.06	25	1.36	0.83	0.45	0.65	3.28							
1980	25	1.31	0.96	0.84	3.11	25	1.30	0.77	0.44	0.60	3.11							
1979	25	1.39	0.88	0.73	3.00	25	1.42	0.89	0.51	0.57	3.38							
1978	25	1.38	0.97	0.74	3.09	25	1.28	0.88	0.53	0.63	3.32							
1977	25	1.35	0.99	0.81	3.15	50	1.35	0.83	0.57	0.65	3.40							
1976						25	1.33	0.86	0.55	0.60	3.34							
1975	25	1.40	0.91	0.72	3.02	25	1.26	0.87	0.50	0.57	3.20							
1974	7	1.30	1.06	0.80	3.16	10	1.14	0.92	0.60	0.65	3.31	12	1.21	0.84	0.49	0.43	0.42	3.38
1973						25	1.26	0.87	0.55	0.59	3.27	25	1.20	0.84	0.49	0.35	0.44	3.32
1972	25	1.28	0.99	0.79	3.07	25	1.22	0.86	0.50	0.57	3.14							
1971	25	1.27	0.96	0.79	3.02	25	1.35	0.78	0.47	0.54	3.14							

Table 3. Summary of average growth measurements for chum salmon during 1971-2010; 1974, 1981, 1986 and 1995 contained samples of undetermined sex. MG indicates the marine growth year.

Year	Age 3					Age 4						Age 5						
	Sample Size	MG 1	MG 2	MG 3	Total MG	Sample Size	MG 1	MG 2	MG 3	MG 4	Total MG	Sample Size	MG 1	MG 2	MG 3	MG 4	MG 5	Total MG
2010	48	1.24	0.77	0.65	2.66	50	1.20	0.80	0.37	0.48	2.85	19	1.08	0.81	0.39	0.33	0.37	2.99
2009	21	1.26	0.93	0.55	2.74	50	1.15	0.85	0.42	0.42	2.85	20	1.19	0.71	0.32	0.32	0.39	2.92
2008	50	1.19	0.87	0.61	2.67	50	1.21	0.75	0.42	0.48	2.86	18	1.15	0.81	0.36	0.31	0.38	3.01
2007	17	1.22	0.83	0.57	2.62	50	1.10	0.85	0.46	0.46	2.86							
2006	22	1.18	1.06	0.70	2.94	42	1.24	0.68	0.45	0.47	2.84							
2005	50	1.42	0.84	0.73	2.99	50	1.28	0.97	0.49	0.52	3.26							
2004	50	1.30	1.04	0.67	3.01	50	1.29	0.89	0.50	0.53	3.21	50	1.22	0.85	0.41	0.36	0.41	3.25
2003						50	1.27	0.88	0.50	0.53	3.19							
2002						50	1.16	1.02	0.52	0.58	3.28							
2001	50	1.20	1.07	0.70	2.97	50	1.27	0.77	0.53	0.59	3.16							
2000	50	1.32	0.90	0.83	3.05	42	1.11	0.93	0.49	0.64	3.17							
1999	47	1.16	0.95	0.70	2.81	50	1.14	0.91	0.45	0.45	2.94							
1998	18	1.21	1.04	0.62	2.87	50	1.16	0.77	0.51	0.49	2.93							
1997	48	1.13	0.79	0.69	2.61	50	1.20	0.80	0.44	0.51	2.94							
1996	25	1.21	0.90	0.59	2.70	49	1.16	0.75	0.47	0.47	2.81							
1995	19	1.35	0.98	0.69	3.02	50	1.31	0.89	0.50	0.56	3.26	49	1.20	0.82	0.38	0.38	0.47	3.25
1994	21	1.36	0.97	0.68	3.00	50	1.26	0.85	0.46	0.55	3.13	50	1.29	0.74	0.40	0.33	0.45	3.20
1993	14	1.12	0.85	0.58	2.56	50	1.20	0.72	0.44	0.48	2.85	50	1.07	0.75	0.38	0.35	0.38	2.94
1992	11	1.22	0.74	0.49	2.45	50	1.10	0.76	0.42	0.49	2.77	5	1.12	0.56	0.52	0.40	0.44	3.04
1991	50	1.16	0.83	0.61	2.60	50	1.26	0.67	0.41	0.51	2.85	50	1.27	0.62	0.30	0.33	0.42	2.93
1990						50	1.30	0.65	0.41	0.52	2.88	44	1.21	0.79	0.34	0.28	0.42	3.04
1989	50	1.36	0.68	0.61	2.65	50	1.24	0.76	0.39	0.49	2.89	50	1.13	0.66	0.41	0.36	0.41	2.97
1988						50	1.07	0.78	0.53	0.55	2.93							
1987	15	1.16	0.83	0.69	2.68	50	1.21	0.75	0.39	0.53	2.88	46	1.20	0.72	0.37	0.33	0.44	3.05
1986	18	1.30	0.87	0.60	2.77	25	1.19	0.78	0.42	0.47	2.86	14	1.17	0.65	0.40	0.33	0.37	2.92
1985	45	1.40	0.91	0.67	2.97	50	1.34	0.82	0.48	0.54	3.17							
1984	50	1.39	0.97	0.77	3.13	48	1.44	0.84	0.48	0.64	3.40							
1983	50	1.28	0.88	0.63	2.79	50	1.06	0.80	0.48	0.47	2.82							
1982	50	1.37	1.01	0.80	3.18	50	1.35	0.83	0.51	0.62	3.31							
1981	50	1.32	0.98	0.76	3.05	50	1.36	0.84	0.47	0.64	3.29							
1980	43	1.25	0.94	0.81	3.00	50	1.33	0.80	0.47	0.65	3.25							
1979	50	1.42	0.90	0.75	3.07	50	1.42	0.90	0.53	0.58	3.43							
1978	42	1.40	0.95	0.75	3.10	50	1.28	0.89	0.55	0.64	3.36							
1977	25	1.35	0.99	0.81	3.15	50	1.35	0.83	0.57	0.65	3.40							
1976						50	1.33	0.86	0.55	0.65	3.38							
1975	50	1.38	0.97	0.71	3.06	50	1.24	0.86	0.54	0.56	3.21							
1974	50	1.33	1.05	0.78	3.16	50	1.14	0.93	0.60	0.64	3.31	50	1.24	0.84	0.51	0.43	0.46	3.48
1973						50	1.25	0.89	0.56	0.64	3.34	50	1.18	0.83	0.49	0.36	0.45	3.31
1972	50	1.29	0.98	0.77	3.03	50	1.20	0.87	0.54	0.59	3.21							
1971	50	1.27	0.98	0.77	3.02	50	1.34	0.80	0.48	0.57	3.19							

Table 4. Probabilities resulting from a global ANOVA test for annual growth of 3_1 and 4_1 chum salmon for the period 1971-2010 with categorical variables of year, sex, return age (i.e. 3 or 4), ocean age (i.e. marine growth 1, 2, 3, or 4) and all possible interactions. Years with a combined sample size of less than 15 were excluded from the analysis. Results have not been adjusted for auto-correlation.

Year	Sex	Return Age	Ocean Age	Year:Sex	Year: Return Age	Year: Ocean Age	Sex: Return Age	Sex: Ocean Age	Return Age: Ocean Age
<2.00E-16	<2.00E-16	<2.00E-16	<2.00E-16	1.23E-02	<2.00E-16	<2.00E-16	8.32E-01	9.65E-04	<2.00E-16

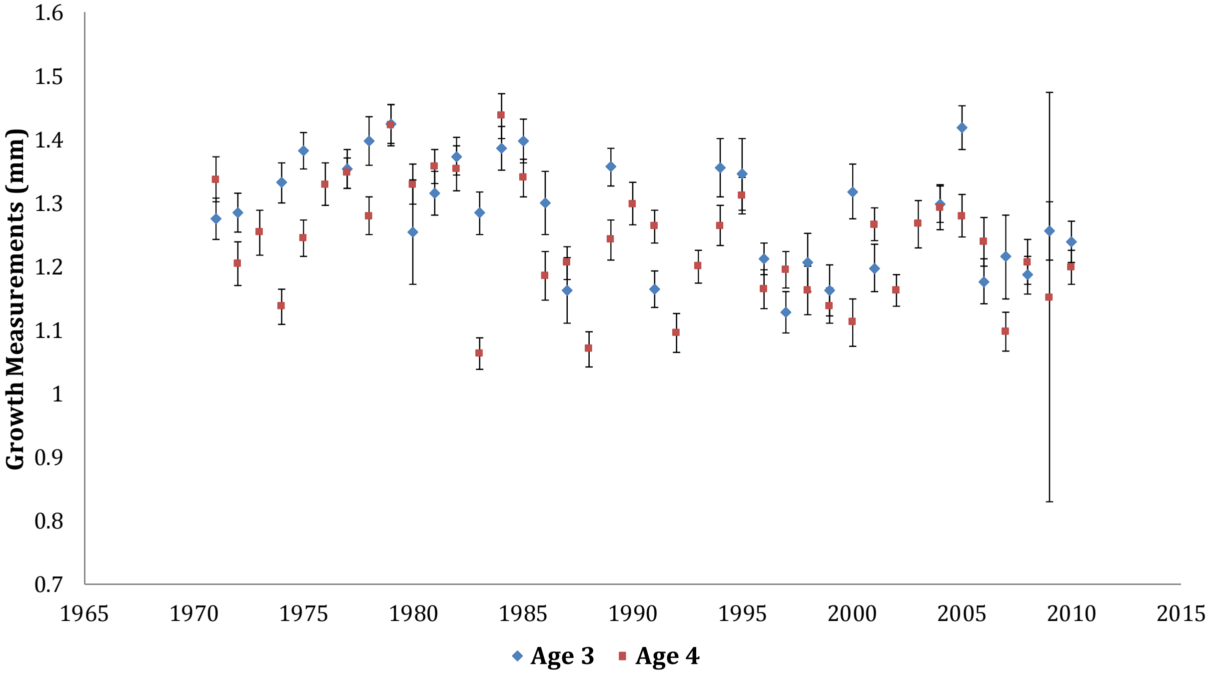

Figure 1. The first year of marine growth (i.e. MG1) for 3_1 and 4_1 chum salmon for the period of 1971-2010; error bars are 95% confidence intervals. Years (1992-1993) are not plotted due to low sample size (<15).

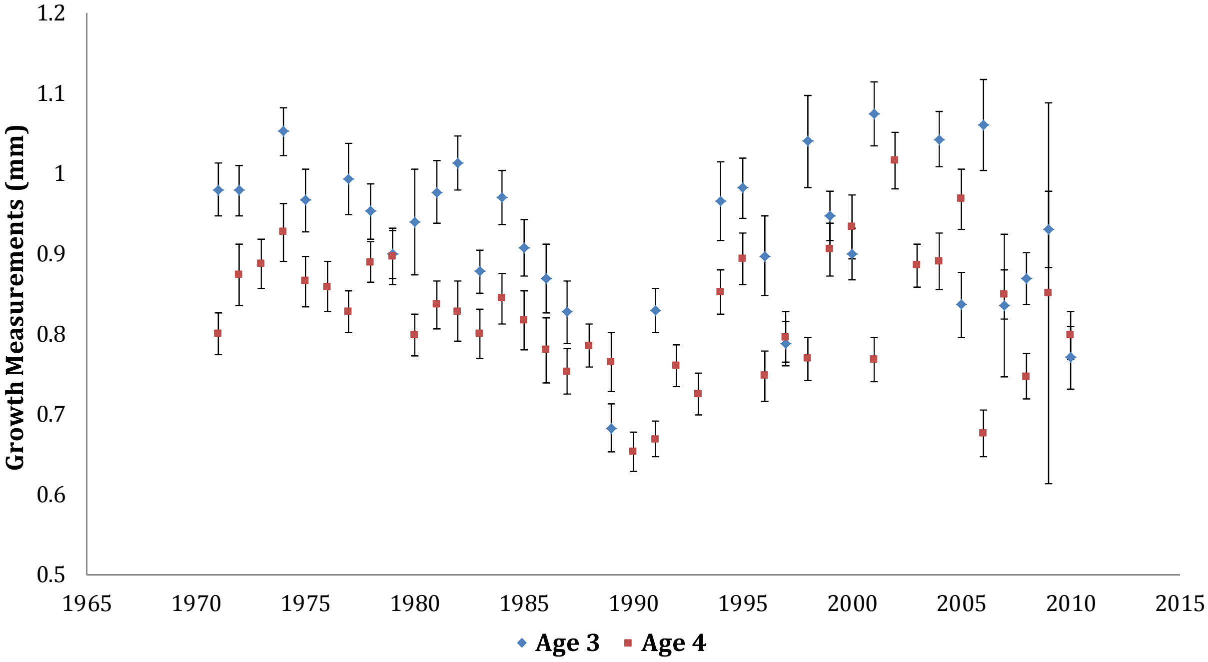

Figure 2. The second year of marine growth (i.e. MG2) for 3_1 and 4_1 chum salmon for the period of 1971-2010; error bars are 95% confidence intervals. Years (1992-1993) are not plotted due to low sample size (<15).

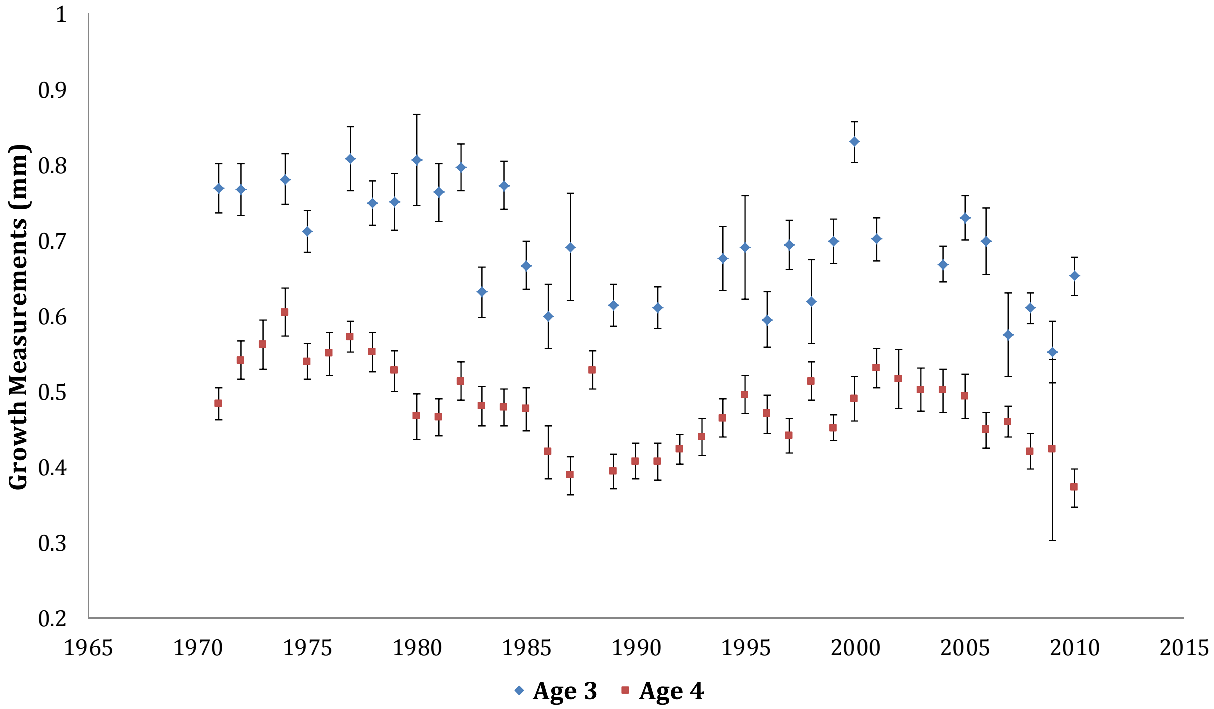

Figure 3. The third year of marine growth (i.e. MG3) for 3_1 and 4_1 chum salmon for the period of 1971-2010; error bars are 95% confidence intervals. Years (1992-1993) are not plotted due to low sample size (<15).

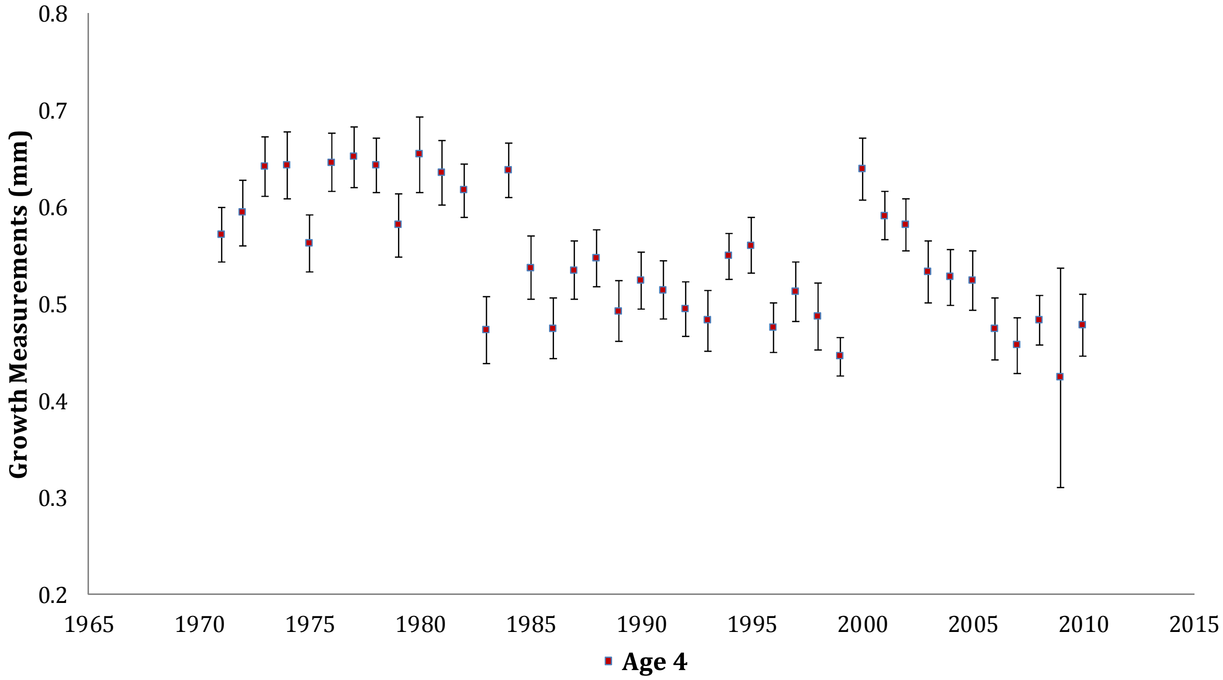

Figure 4. The fourth year of marine growth for 4_1 chum salmon for the period of 1971-2010; error bars are 95% confidence intervals. Years (1992-1993) are not plotted due to low sample size (<15).