Changes in Size, Age, and Intra-Annual Growth of Anadyr Chum Salmon (*Oncorhynchus keta*) from 1962 to 2010

Alexander V. Zavolokin[1], **Vladimir V. Kulik**[1], and **Yury N. Khokhlov**[2]

[1]*Pacific Scientific Research Fisheries Center (TINRO-center), 4, Shevchenko Alley, Vladivostok 690091, Russia*
[2]*Chukotka Branch, Pacific Scientific Research Fisheries Center, 56, Otke St., Anadyr 689000, Russia*

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Many researchers have reported that increases in Pacific salmon abundance in the North Pacific accompanied decreases of age-specific body length, weight, and growth after the first year of life of chum salmon (Ishida et al. 1993; Bigler et al. 1996; Kaeriyama 1998; Volobuev 2000; Kaev 2003; Helle et al. 2007). This has led to conclusions about shortages of food resources and overpopulation of the North Pacific by Pacific salmon (Ishida et al. 1993; Welch and Morris 1994; Bigler et al. 1996; Klovach 2003). Over the past decade, total abundance of Pacific salmon has continued to rise (Irvine and Fukuwaka 2011). This means that density-dependent interactions may be more intensive now than in earlier decades. We studied changes in body size, age, and growth of Anadyr chum salmon from samples collected over the last 50 years and discussed possible factors affecting chum salmon growth.

Adult chum salmon were sampled annually from 1962 to 2010. Fish samples were collected in the Anadyrskiy estuary using a trap net and on the spawning grounds. We analyzed scales of age-0.3 and -0.4 chum salmon. A total of 2,506 chum salmon was sampled (for details on methods, see Zavolokin et al. 2011, 2012).

Results showed body size of Anadyr chum salmon significantly decreased from the 1960s to 2000s (Fig. 1). In 1962–1980, mean fork length was 67 cm for age-0.3 and 71 cm for age-0.4 chum salmon. In 1990–2010, chum salmon mean fork length decreased to 61 cm for age-0.3 and decreased to 64 cm for age-0.4 chum salmon. From the 1960s to 1990s, the mean age of Anadyr chum salmon increased. During 1968-1990, the mean age was 3.2 yr, and in the 1990s it rose to 3.4 yr. In the 2000s, the mean age of chum salmon decreased to 3.3 yr.

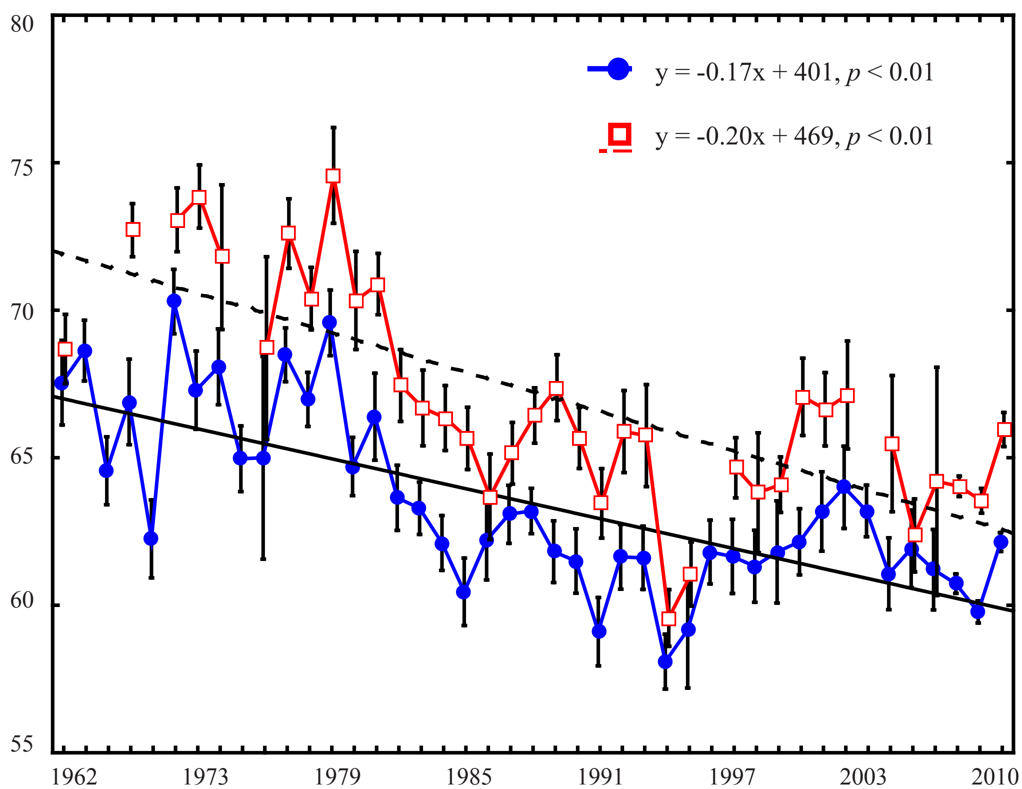

Fig. 1. Changes in mean fork length (cm) of Anadyr chum salmon (● – age-0.3, □ – age-0.4) from 1962 to 2010. Bars – 95% confidence interval.

All correspondence should be addressed to A. Zavolokin.
e-mail: zavolokin@tinro.ru

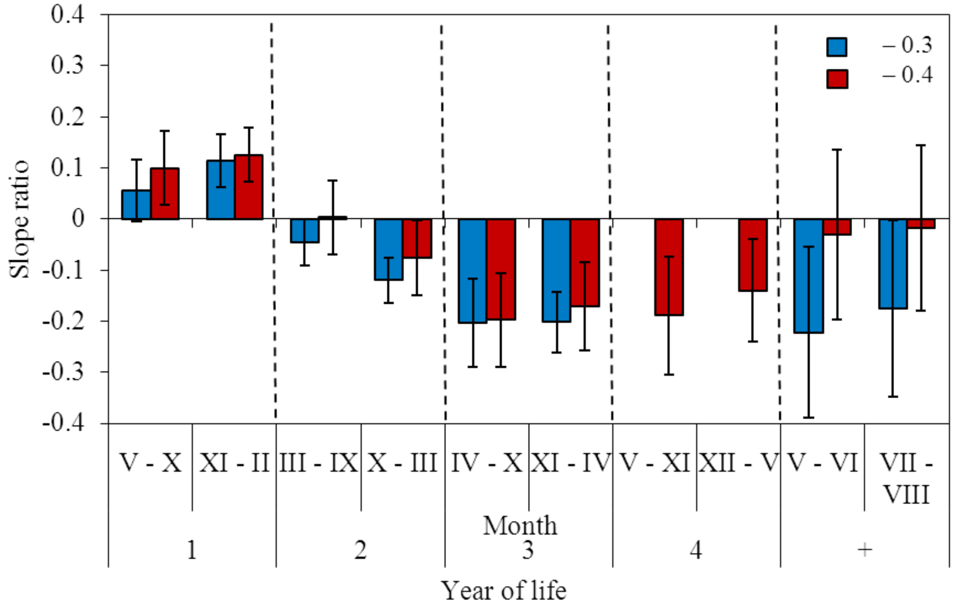

Fig. 2. Slope ratio (a) from the linear regression y = ax + b, where the independent variable (x) is return year (1962-2007) and the dependent variable (y) is the inter-circuli distances in that year. Bars – 95% confidence interval. Data collected from scale analysis of age-0.3 and -0.4 Anadyr River chum salmon.

Inter-annual trends in chum salmon growth were evaluated by simple linear regression analysis: y = ax + b. Figure 2 shows the slope ratio (parameter a) that describes changes in chum salmon growth from the 1960s to 2000s. First year growth of Anadyr chum salmon was enhanced (Figs. 2 and 3). And the best growth enhancement occurred during the second half of the first year during late fall and winter. After the first year at sea, the trend in chum salmon growth changed. From March through August, growth was relatively stable. After the first half of the second year, growth was reduced. The greatest reduction occurred throughout the third and fourth years of life and was the most conspicuous in summer and fall when the fish foraged in the Bering Sea.

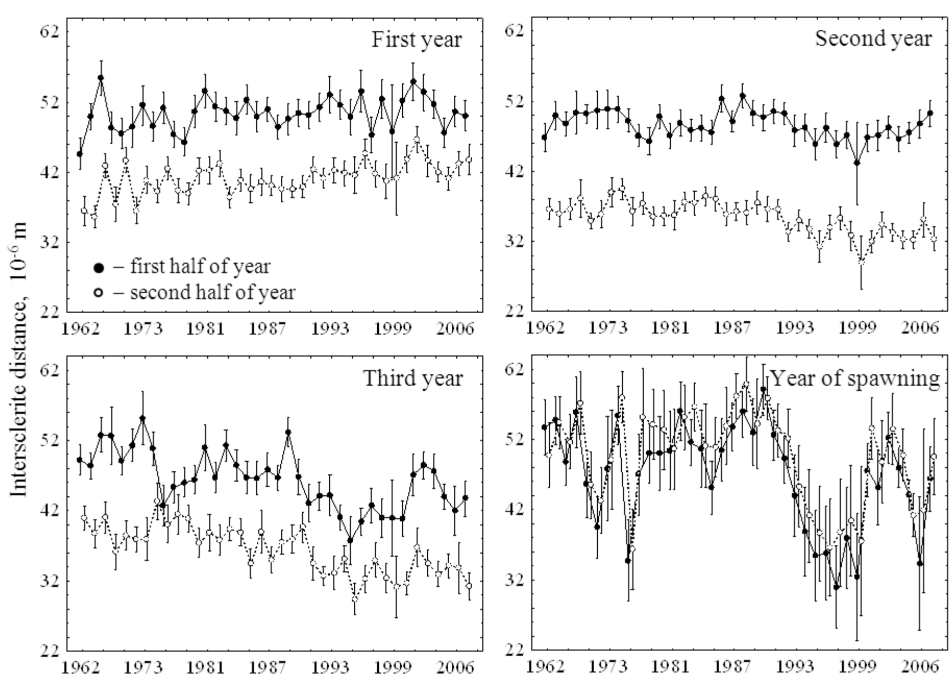

Fig. 3. Changes in mean intercirculus distances of age-0.3 Anadyr chum salmon from 1962 to 2007. Bars – 95% confidence interval.

Changes in Body Size and Growth of Pacific Salmon

Our study and those of other researchers show that growth trends of many chum salmon stocks from several widely separated regions illustrate the same growth pattern. Chum salmon growth patterns that we observed were similar to those of some Russian, Japanese and Korean stocks; the first year growth was enhanced, and the third and fourth year growth was reduced in samples collected over the last several decades (Ishida et al. 1993; Kaev 2003; Kaeriyama et al. 2007; Seo et al. 2009).

Body size trends since the 1960s of chum salmon stocks show similar patterns from areas in Japan, Korea, and North America (Ishida et al. 1993; Bigler et al. 1996; Kaeriyama 1998; Volobuev 2000; Kaev 2003; Seo et al. 2009; Helle et al. 2007). There are significant positive correlations in body weight of chum salmon from several large Russian rivers in samples collected in 1960-2009 (Temnykh et al. 2012). Inter-annual changes in body size of other salmon species usually differed from those of chum salmon, but growth of some populations of pink, sockeye, and Chinook salmon also had common features during this time period (Temnykh 1999; Ruggerone et al. 2007, 2009; Martinson et al. 2008). Like Anadyr chum salmon, these species showed increasing first year marine growth and decreasing third year marine growth that suggests there are common large-scale factors affecting these species in the same way.

Potential Factors Affecting Salmon Growth

Fish growth is a complex process that results from a combination of many factors. Growth reflects internal and external influences on metabolism, physiological functions, food consumption, and excretion. As we have suggested, the factor (factors) leading to Anadyr chum salmon growth reduction was likely operating at the large-scale because it affected several widely separated salmon populations. Therefore, internal factors could not be the main cause of observed growth changes because it is unlikely these could synchronously affect several salmon species and take place over a vast area.

Table 1. Pearson correlation coefficients relating mean intercirculus distances of Anadyr chum salmon (age 0.3) to some climatic indices (see data sources below). * – $p < 0.05$

Index	Year of life			
	1	2	3	+
HC PO	0.55*	-0.57*	-0.52*	-0.49*
	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.05$
HC NP	0.59*	-0.64*	-0.56*	-0.42*
	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.05$
GLB.Ts + dSST	0.45*	-0.64*	-0.48*	-0.23
	$p < 0.05$	$p < 0.01$	$p < 0.05$	$p = 0.27$
N.HEMI	0.43*	-0.64*	-0.49*	-0.30
	$p < 0.05$	$p < 0.01$	$p < 0.05$	$p = 0.14$
NP	-0.07	0.29	0.25	-0.01
	$p = 0.74$	$p = 0.16$	$p = 0.21$	$p = 0.94$
ALPI	0.19	-0.32	-0.13	0.10
	$p = 0.34$	$p = 0.11$	$p = 0.54$	$p = 0.61$
AFI	0.27	-0.17	-0.10	0.14
	$p = 0.19$	$p = 0.40$	$p = 0.64$	$p = 0.50$
PDO	0.09	-0.03	-0.14	0.16
	$p = 0.67$	$p = 0.87$	$p = 0.49$	$p = 0.42$

Aleutian Low Pressure Index (ALPI). 2010.
URL: http://www.pac.dfo-mpo.gc.ca/science/species-especes/climatology-ie/cori-irco/indices/alpi.txt
Atmospheric Forcing Index (AFI). 2010.
URL: http://www.pac.dfo-mpo.gc.ca/science/species-especes/climatology-ie/cori-irco/indices/afi.txt
Global Land-Ocean Temperature Index in 0.01 degrees Celsius. 2011. URL: http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts+dSST.txt
Global Ocean Heat Content. 2011.
URL: ftp://ftp.nodc.noaa.gov/pub/data.nodc/woa/DATA_ANALYSIS/3M_HEAT_CONTENT/DATA/basin/yearly/h22-p0-700m.dat
N.HEMI Temperature Anomalies in 0.01 degrees Celsius. 2011. URL: http://data.giss.nasa.gov/gistemp/tabledata/NH.Ts.txt
NCAR Climate Analysis Section. 2011. URL: http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html#npmon
PDO INDEX. 2011. URL: http://jisao.washington.edu/pdo/PDO.latest

The main external influences on Pacific salmon productivity are likely to be climatic and density-dependent factors. Our analysis of Anadyr chum salmon growth reduction in both the foraging and over-wintering areas does not corroborate the definitive importance of density-dependent factors affecting chum salmon productivity. In view of published data on forage resources, it seems unlikely that a long-term decrease in salmon food supply could cause a long-term decrease in fish size and synchronously occur in large areas of the Bering Sea and North Pacific. Furthermore, it seems incredible that chum salmon have been experiencing insufficient feeding conditions both in the Bering Sea and North Pacific. In the western Bering Sea, which is an important foraging area for Pacific salmon, macrozooplankton biomass has increased from the 1980s to 2000s (Shuntov et al. 2010). Based on the abundant plankton resources available in the forage base in comparison to the low percentage of prey resources consumed by Pacific salmon (Naydenko 2007), there is no reason to suggest there are strong competitive interactions between and among salmon species in the western Bering Sea. Negative correlations between total salmon abundance and chum salmon body size were evident only in our data from the 1980-1990s. After the mid-1990s, there was no such relationship. After 1997, growth of Anadyr chum salmon increased and average age decreased. Even with increasing abundance of Pacific salmon, production characteristics of Anadyr chum salmon have improved. Therefore, it is possible that density-dependent interactions are not the only determining factor of chum salmon productivity.

Over the last 50 years, there have been three universally recognized regime shifts in the North Pacific (1977, 1989, and 1998; Hare and Mantua 2000; Overland et al. 2008). We compared scale increments in each climatic period to estimate if these regime shifts influenced Anadyr chum salmon growth. We found that growth of adult chum salmon differed significantly between most periods. Therefore, changes in the ocean environment arising from regime shifts may affect Anadyr chum salmon growth. Table 1 shows correlations between Anadyr chum salmon growth and some climatic indices that reflect climatic changes in the North Pacific. The first year of growth of Anadyr chum salmon was positively correlated with temperature indices, such as heat content of the Pacific Ocean (HC PO), heat content of the North Pacific (HC NP), global temperature anomalies (GLB.Ts+dSST), and northern hemisphere temperature anomalies (N.HEMI). In contrast, the second and third year of growth was negatively correlated with these indices. Negative correlations between temperature indices and the second and third year of growth of Anadyr chum salmon suggest that warming of the North Pacific may have an adverse impact on their growth after the first year of life. Thus, chum salmon growth reduction after the early marine period may be caused by a combination of increasing abundance of Pacific salmon and a warming ocean.

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