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ABSTRACT

Inter-annual changes in body size, age composition, and intra-annual changes in growth of Anadyr chum salmon collected in 1962-2010 were studied. From the 1960s to the 2000s, body size of Anadyr chum salmon significantly decreased and the average age of spawners slightly increased. Annual growth dynamics showed different patterns. Estimated from measuring intersclerite distances on scales, first-year growth of Anadyr chum salmon samples collected in 1962 to 2007 was enhanced. After the first year, growth was reduced. The greatest reduction occurred in the third (ages 0.3 and 0.4) and forth (age 0.4) years. Intra-annual scale increments showed that growth reduction after the first year occurred both in over-wintering and foraging areas. This contrasts with the wide-spread suggestion that chum salmon size decreased due to a poor foraging conditions during the winter period. Based on published results and our data, it seems the growth of at least two salmon species (chum and pink salmon) changed similarly in recent decades. Hence there are some large-scale factors that influenced these species and had an effect in the vast areas of the North Pacific and marginal seas. Our results don't corroborate the decisive importance of density-dependent interactions for Pacific salmon productivity in the last 50 years. Negative correlations between some climatic indices (ocean surface temperature, ground air temperature, and heat content of North Pacific Ocean) and scale increments of Anadyr chum salmon in the second, third and fourth year zones suggest that warming of North Pacific may have adverse impact on chum salmon growth after the first year of life. Chum salmon growth reduction after the early marine period may be a mixture of increasing abundance of Pacific salmon combined with warming ocean.

INTRODUCTION

Evidence is accumulating that body size-at-return of Pacific salmon has varied significantly over the past hundred years. Changes in chum salmon body size attract special attention. It was shown in many publications that increases of Pacific salmon abundance in the North Pacific accompanied decreases of age-specific body length, weight, and growth after the first year for 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 shortage of food resources and overpopulation of the North Pacific by Pacific salmon (Ishida et al., 1993; Welch, Morris, 1994; Bigler et al., 1996; Klovach, 2003). Over the past decade, total abundance of Pacific salmon has been continuing to rise (Irvine, Fukuwaka, 2011). This means that density-dependent interactions may be more intensive.
We studied changes in body size, age, and growth of Anadyr chum salmon in the last 50 years and discussed possible factors affecting chum salmon growth.

MATERIAL AND METHODS

This study was based on body-size and scale-measurement data obtained from chum salmon returning to the Anadyr River. Adult chum salmon were sampled annually from 1962–2010, except for 1963, 1967, 1969, 1970 and 2005. Fish samples were collected in the Anadyrskiy estuary using a trap net and from the spawning grounds of the Anadyr River (Fig. 1). We analyzed scales of ages-0.3

and -0.4 chum salmon, which are the dominant age-groups of spawners in the Anadyr River (Putivkin 1999).

A total of 2,506 chum salmon was sampled. A similar number of males and females was sampled in each year. Fork length and body weight were measured, and scales were collected. Scales were taken from the chum salmon in the preferred body area, located a few rows above the lateral line and below the posterior insertion of the dorsal fin.

Scale measurements included the length along the long axis, the number and length of annual zones, and intersclerite (intercirculus) distances (Fig. 2). Annual growth was estimated by intersclerite distances of chum salmon scales.

The inter-annual trends in chum salmon body size and growth (mean ± 95% confidence interval) were evaluated by simple linear regression analysis: $y = ax + b$, where the independent variable (x) is return year and the dependent variable (y) is either mean body length, weight, or intersclerite distance in that year.

Climate impact on chum salmon growth was estimated using following climate predictors: HC PO and HC NP – heat content of Pacific ocean (PO) and North Pacific (NP) (Levitus et al., 2005; Global ocean…, 2011), GLB.Ts + dSST – GLOBAL Temperature Anomalies (Peterson, Vose, 1997, Smith et al., 2008; Global land…, 2011) N.HEMI – Northern Hemisphere Temperature Anomalies (Peterson, Vose, 1997, Smith et al., 2008; H.HEMI…, 2011), NP – North Pacific Index (Trenberth, Hurrel, 1994; NCAR…, 2011), ALPI – Aleutian Low Pressure Index (Beamish et al., 1997; Aleutian..., 2010), AFI – Atmospheric Forcing Index (McFarlane et al., 2000; Atmospheric …, 2010), PDO – Pacific Decadal Oscillation (Mantua et al., 1997; Zhang et al., 1997; PDO Index, 2011).

RESULTS

Body size of Anadyr chum salmon significantly decreased from the 1960s to 2000s (Fig. 3). In 1962–1980, mean fork length was 67 cm for age 0.3 chum salmon and 71 cm for age 0.4 chum salmon. In 1990–2007, chum salmon body size decreased from 67 to 61 cm for age 0.3 chum salmon and from 71 to 64 cm for age 0.4 chum salmon.

From 1962–1980, mean fork lengths of chum salmon did not show any trends, and were relatively stable. A significant decrease in body size began in the early 1980s and continued to the mid 1990s. After 1994–1995, the length and weight of chum salmon increased. However, this trend lasted only for several years, and did not reach the levels seen in the 1960s–1970s.

From 1960s to 1990s, the mean age of Anadyr chum salmon tend to increase. In 1968-1990, mean age was 3.2, in 1990s it rose to 3.4. Last decade, mean age of chum salmon has decreased. In 2000s it was 3.3.

The inter-annual trends in chum salmon growth were evaluated by simple linear regression analysis: $y = ax + b$. Fig. 4 shows slope ratios, or parameter a, that describe changes in chum salmon growth from 1960s to 2000s.

According to Birman (1968), the fourth annulus forms on the chum scale mainly in May – early July. The third annulus forms at the end of March – April. The second annulus forms in February – March. And the first annulus forms probably in January – February. Based on these data, we estimated intra-annual growth of Anadyr chum salmon and linked the foraging areas that relate to each period of chum salmon life.

First year growth of Anadyr chum salmon was enhanced (Fig. 4, 5). And the best growth enhancement occurred during second half of first year, during late fall and in winter. After the first year, the trend of chum salmon growth changed. From March through August, growth was relatively stable in 1960-2000s. After the first half of the second year, growth began to reduce. The greatest reduction occurred in the third and fourth years. Slope coefficients of linear regressions for these year zones were the most negative.

DISCUSSION

Changes in body size of Pacific salmon

Body size trends of other Asian and American stocks of chum salmon show similar patterns. There are significant positive correlations in body weights of chum salmon from several large Russian rivers in 1960-2009 (Temnykh et al., in press). The same trends occurred for some stocks of 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).

Chum salmon growth was also similar for some Russian, Japanese and Korean stocks. First year growth enhanced, while the third and fourth year growth reduced over the last several decades (Ishida et al., 1993; Kaev, 2003; Kaeriyama et al., 2007; Seo et al., 2009). Therefore, published and our data show that growth trends of many chum salmon stocks from various regions have the same pattern.

Inter-annual changes in body size of others salmon species usually differed from trends for chum salmon. But growth of some populations of pink, sockeye, and Chinook salmon had the common features (Temnykh, 1999; Ruggerone et al., 2007, 2009; Martinson et al., 2008). Like Anadyr chum salmon, increasing first marine year growth and decreasing third marine year growth occurred. This suggests that there are common large-scale factors that affected these salmon species in the same way.

Potential factors affecting salmon growth

Fish growth is a complex process that results from mixture of many factors. Growth reflects internal and external impacts on metabolism, physiological functions, food consumption and excretion.

As it was shown before, factor (factors) caused Anadyr chum salmon growth reduction was large-scale and it affected various salmon populations. Therefore, internal factors could not be the main origin of the growth changes. Unlikely that internal factors could synchronously reveal themselves for several salmon species and could take place on the vast area.

The main external influences for Pacific salmon productivity are considered to be climatic (first of all, oceanological conditions) and density-dependent factors (as a ratio of available and needed food = food supply).

Our results on Anadyr chum salmon growth reduction both in foraging and over-wintering areas do not corroborate the decisive importance of density-dependent factors for chum salmon productivity over the last decades. In view of the published data on forage resources, it seems unlikely that long-term decreasing in the salmon food supply (that could cause long-term decreasing of fish size) occurred synchronously in the vast areas of the Bering Sea and North Pacific. And it seems incredible that chum salmon have been experiencing insufficient feeding conditions both in the Bering Sea and North Pacific.

At least, in the western Bering Sea that is very important foraging area for Pacific salmon, macrozooplankton biomass has increased from 1980s to 2000s (Shuntov et al., 2010). Based on the high plankton resources and low percentage of Pacific salmon consumption in comparison with total available forage base (Naydenko, 2007), there is no reason to suggest strong competitive interactions between and among species of salmon in the western Bering Sea.

In addition, negative correlation between total salmon abundance and chum salmon body size was obvious only in 1980-1990s. After the mid-1990s, this relationship did not occur. After 1997, growth of Anadyr chum salmon tended to increase and average age tended to decrease. So, despite of increasing abundance of Pacific salmon, production characteristics of Anadyr chum salmon improved. It is possible, that density-dependent interactions are not the only determinant factor of chum salmon productivity.

In last 50 years, there was three universally recognized regime shifts in the North Pacific (1977, 1989 и 1998) (Hare, Mantua, 2000; Overland et al., 2008). We compared scale increments in each climatic period to estimate if regime shifts have influenced Anadyr chum salmon growth. We found out that growth of adult chum salmon significantly differed between most climatic periods (Table 1). Therefore, changes of ocean environment arising from regime shifts may affect Anadyr chum salmon growth.

Table 2 shows correlation between Anadyr chum salmon growth and some climatic indices that reflect climatic changes in the North Pacific. The first year growth of Anadyr chum salmon correlated positively with temperature indices such as Heat Content of Pacific Ocean (HC PO), Heat Content of North Pacific (HC NP), GLOBAL Temperature Anomalies (GLB.Ts + dSST), and Northern Hemisphere Temperature Anomalies (N.HEMI). This supports the hypothesis of favorable conditions for juvenile chum salmon over last decades. On the contrary, the growth at second and third years correlated negatively with these indices.

There was not significant relationship between Anadyr chum salmon growth and North Pacific Index (NP), Aleutian Low Pressure Index (ALPI), Atmospheric Forcing Index (AFI), and Pacific Decadal Oscillation (PDO) (Table 2).

Negative correlations between temperature indices and both second and third year growth of Anadyr chum salmon suggest that warming of North Pacific may have adverse impact on chum salmon growth after the first year of life. Thus, chum salmon growth reduction after the early marine period may be a mixture of increasing abundance of Pacific salmon combined with warming ocean.

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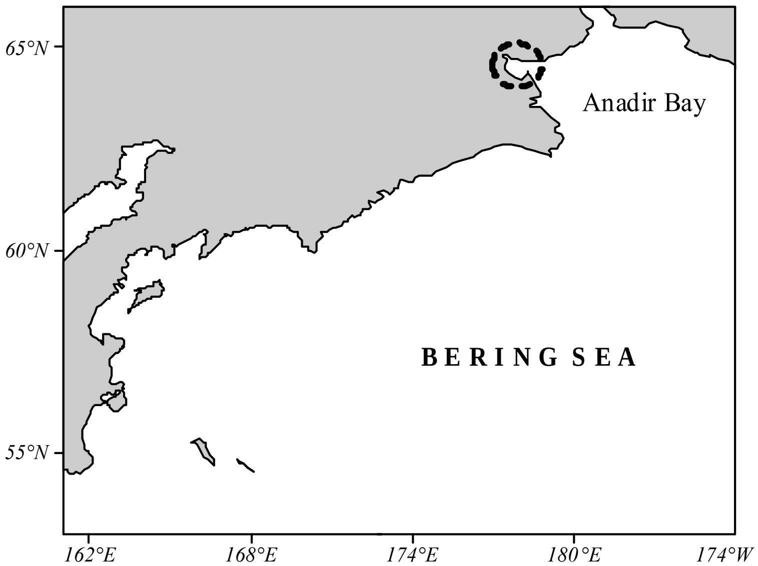

Fig. 1. Map showing the location of our sampling area (Anadyr estuary, Chukotka autonomous Okrug, Siberia, The Russian Federation).

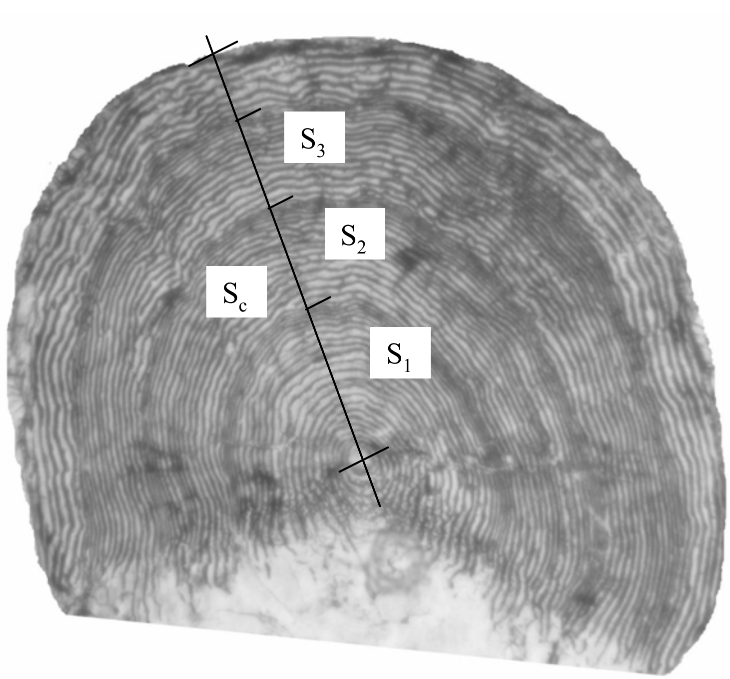

Fig. 2. The scale of an age-0.3 chum salmon collected in August 2003 in the Anadyrskiy estuary, showing the measurement axis (black line) and variables. S_1-S_3= scale radius of individual annuli, S_c= radius of the whole scale.

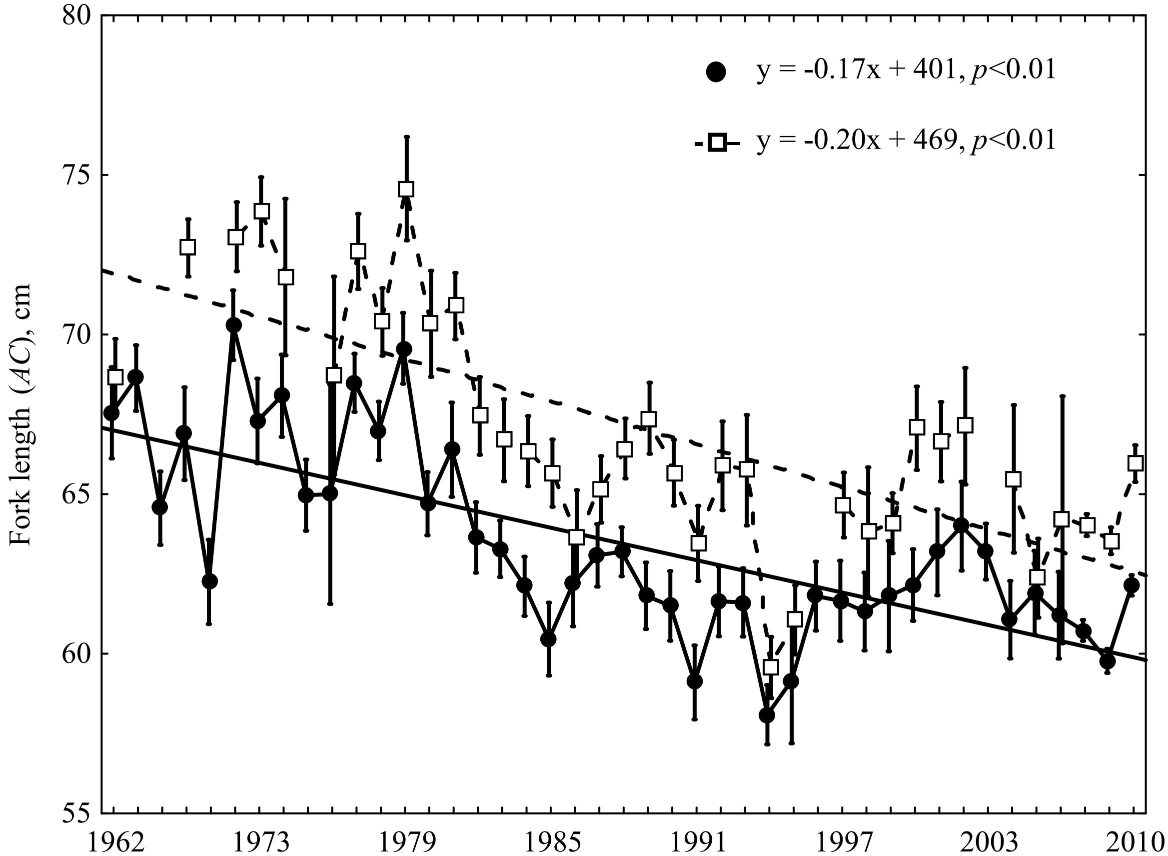

Fig. 3. Changes in mean fork length (cm) of Anadyr chum salmon (● - age 0.3, □ – age 0.4) from 1962–2010. Bars = 95% confidence interval.

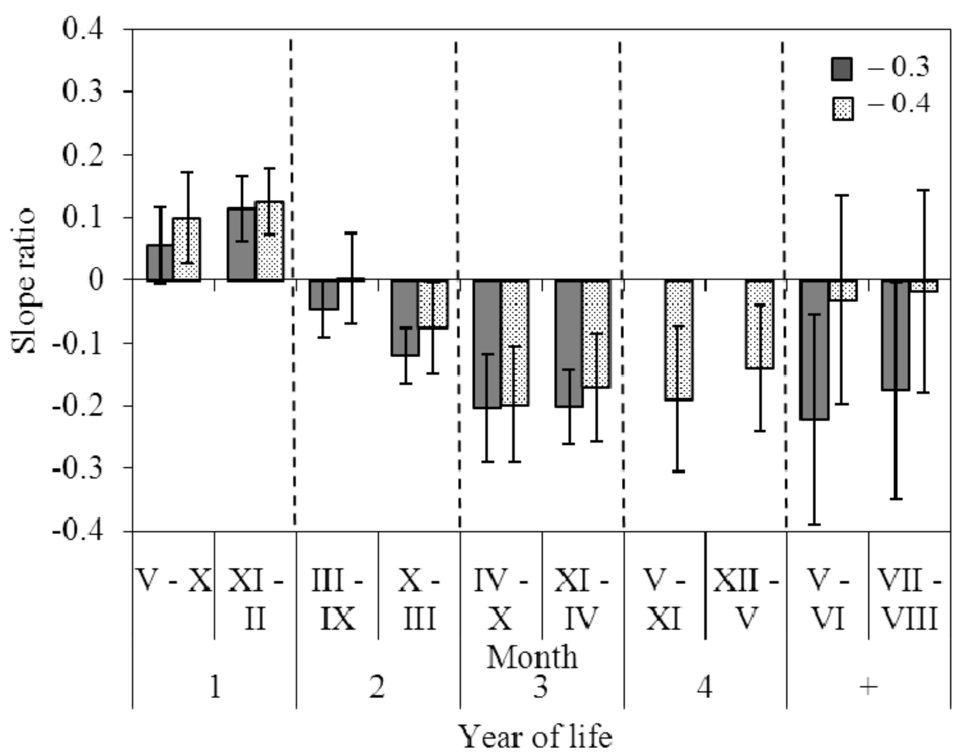

Fig. 4. Slope ratios (a) of linear regression y = a·x + b where the independent variable (x) is return year (1962-2007) and the dependent variable (y) is intersclerite distance in that year.

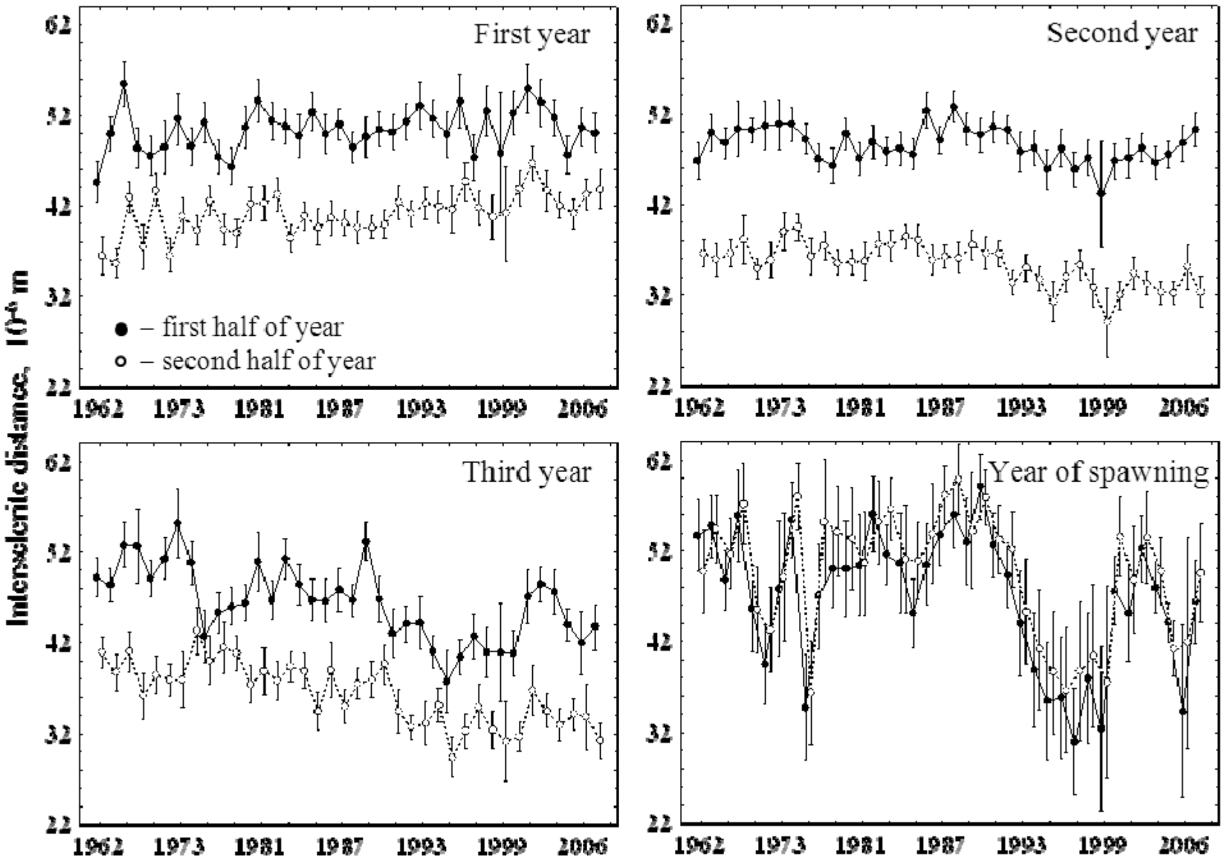

Fig. 5.Changes in mean intercirculus distances of 0.3-age Anadyr chum salmon from 1962–2007. Bars = 95% confidence interval.

Table 1. Mean intercirculus distances (10^{-6} m) on scale of Anadyr chum salmon in different climate periods. M – mean, CI = confidence interval, N = number of samples. * - significant change, $p<$ 0.05.

Climate period	M	95%CI	N	M	95%CI	N
	Age 0.3			Age 0.4		
First year						
1947-1976	44.4	0.6	321	43.1*	0.9	166
1977-1988	45.1*	0.5	505	45.3*	0.5	420
1989-1998	46.1*	0.5	382	45.4	0.6	302
1999-2007	47.3*	0.6	248	47.8*	0.7	162
Second year						
1947-1976	43.1	0.5	321	41.8	0.8	166
1977-1988	42.7*	0.4	548	42.5*	0.4	463
1989-1998	41.2*	0.4	357	41.5*	0.6	276
1999-2007	40.2*	0.5	230	40.1*	0.6	145
Third year						
1947-1976	44.4*	0.6	363	42.8*	0.8	222
1977-1988	42.9*	0.5	554	41.2*	0.5	455
1989-1998	37.5*	0.6	341	36.6*	0.7	258
1999-2007	39.6*	0.8	198	37.0	0.9	115
Fourth year						
1947-1976	-	-	-	44.3	0.9	250
1977-1988	-	-	-	44.2*	0.6	469
1989-1998	-	-	-	38.5*	0.8	258
1999-2007	-	-	-	41.2*	1.7	73
Year of spawning						
1947-1976	51.3*	1.1	408	48.9*	1.4	268
1977-1988	55.2*	0.9	554	54.2*	1.0	478
1989-1998	47.5*	1.1	328	48.2*	1.2	257
1999-2007	48.5	1.5	165	45.1	3.3	44

Table 2. Pearson correlation coefficients relating mean intercirculus distances of Anadyr chum salmon (age 0.3) to some climatic indices. * – $p < 0.05$

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
	$p = 0.67$	$p = 0.87$	$p = 0.49$	$p = 0.42$