Changes in Size and Growth of Anadyr Chum Salmon (*Oncorhynchus keta*) from 1962-2007

Alexander V. Zavolokin[1], Elena A. Zavolokina[1], and Yury N. Khokhlov[2]

[1]Pacific Research Fisheries Center (TINRO-Center), 4 Shevchenko Alley, Vladivostok 690950, Russia
[2]Chukotka Branch, Pacific Research Fisheries Center, 56 Otke St., Anadyr 689000, Russia

Zavolokin, A.V., E.A. Zavolokina, and Y.N. Khokhlov. 2009. Changes in size and growth of Anadyr chum salmon (*Oncorhynchus keta*) from 1962–2007. N. Pac. Anadr. Fish Comm. Bull 5: 157–163.

Abstract: Annual changes in body size and growth of Anadyr chum salmon (ages 0.3 and 0.4) in 1962–2007 were studied. Regression analysis showed that the fork length and weight of Anadyr chum salmon significantly decreased from the 1960s to the 2000s. Mean body length of Anadyr chum salmon was highest in 1972 and 1979, and lowest in 1991 and 1994. The most pronounced decrease in chum salmon body size occurred from the early 1980s to the mid 1990s. In 1962–1980 and 1997–2007, mean fork length and weight remained relatively stable. The first-year growth of Anadyr chum salmon, estimated from intersclerite distances, did not change significantly from 1962 to 2007. Growth reduction began in the second year, and the greatest reduction occured in the third year. There was a significant negative correlation between annual total catches of Pacific salmon and Anadyr chum salmon fork length, body weight, and growth during the second, third and fourth years. Our results may corroborate the conclusions of other researchers that climatic and oceanic conditions can strongly affect the carrying capacity for Pacific salmon and other fish.

Keywords: chum salmon, Russia, fork length, body weight, growth, scale, Anadyr River

INTRODUCTION

Decreases in Pacific salmon production have been observed in many populations (Ishida et al. 1993; Helle and Hoffman 1995; Bigler et al. 1996; Kaeriyama 1998; Volobuev 2000; Kaev 2003; Helle et al. 2007; Kaeriyama et al. 2007; and others). In an analysis of the data on fluctuations in chum salmon (*Oncorhynchus keta*) of Asian and American populations from 1953–1988, Ishida et al. (1993) discovered a reduction in body size, scale radius, and width of the third-year group of 0.4-age fish. Bigler et al. (1996) found that 45 of 47 North Pacific salmon populations, comprising five species from North America and Asia, decreased in mean body size. Based on data from 1960 to 2006, Helle et al. (2007) observed that most American populations of Pacific salmon declined in body weight from the 1970s to the early 1990s and increased in body size after the mid 1990s. It is generally supposed that one of the main causes of these changes is density-dependent growth of Pacific salmon in the ocean.

The present paper discusses the data on inter-annual changes in body length, weight, and growth of Anadyr chum salmon from 1962 to 2007. The availability of long-term data gave us an opportunity to identify the periods characterized by either changeable or relatively stable characteristics.

MATERIALS 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 1962–2007, 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 2,930 chum salmon (age 0.3 – 1640, age 0.4 – 1290) 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). Measurements were performed using the Biosonics Optical Pattern Recognition System (OPRS; BioSonics, Inc., Seattle, Washington, USA). Increments in fork length during each year of marine life were estimated from the measured distances between adja-

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

cent annuli on the fish scale using a direct proportion between body and scale growth (Pravdin 1966): *Lc/Li = Sc/Si*, where L_c and S_c = fork length and scale radius of the captured fish; and L_i and S_i = the same at age *i*. 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.

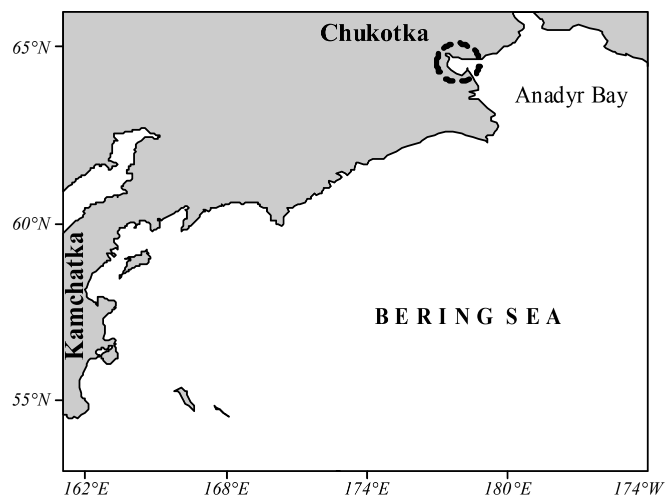

Fig. 1. Map showing the location of our sampling area (Anadyrskiy estuary, Chukotka autonomous Okrug, Far East, Russia).

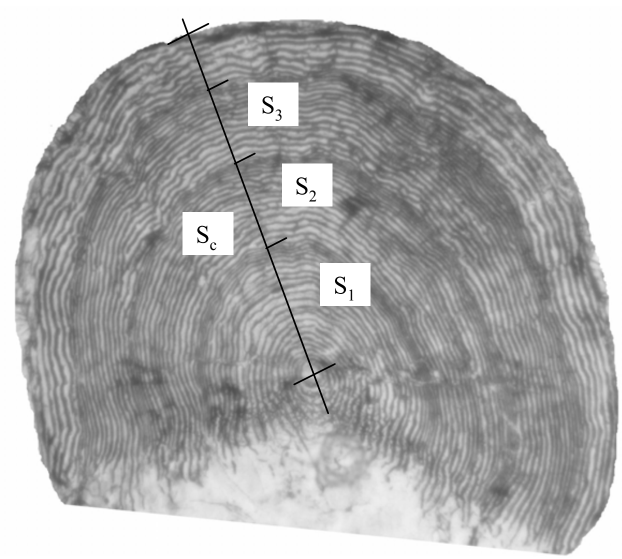

Fig. 2. The scale of an age-0.3 chum salmon collected in August 2003 in the Anadyrskiy estuary, showing the measurement axis (black line) and variables. S_1-S_3 = scale radius of individual annuli, S_c = radius of the whole scale.

RESULTS

Inter-annual Changes in Body Size

Body size of Anadyr chum salmon decreased from the 1960s to 2000s (Tables 1, 2; Fig. 3). In 1962–1980, mean fork length (weight) was 66.8±1.3 cm (3.7±0.2 kg) for age 0.3 chum salmon and 71.2±1.6 cm (4.5±0.3 kg) for age 0.4 chum salmon. In 1990–2007, chum salmon body size decreased to 61.4±0.8 cm (3.1±0.2 kg) for age 0.3 chum salmon and 64.5±1.1 cm (3.6±0.3 kg) for age 0.4 chum salmon.

Regression analysis showed a significant negative trend in mean body sizes of both 0.3-age and 0.4-age chum salmon from 1962 to 2007 (Fig. 3). However, during these years inter-annual trends in mean body size were variable. 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. In 1994–1995, mean fork length of Anadyr chum salmon was the smallest in the study period (approximately 58–59 cm for age 0.3 and 60–61 cm for age 0.4). After 1994–1995, the length and weight of chum salmon increased. However, this trend lasted only for two or three years, and did not reach the levels seen in the 1960s–1970s. In the late 1990s to the mid 2000s, chum salmon body size remained stable. Fork length averaged 62 cm for age 0.3 and 65 cm for age 0.4 fish during this time period.

Inter-annual fluctuations in mean body weights of Anadyr chum salmon were similar to those observed in mean body length. Mean body weight was highest in the 1960s–1970s (~ 3.1–4.3 kg for age 0.3 and ~ 3.8–5.3 for age 0.4 fish) and lowest in the mid 1990s (~ 2.5–2.8 kg for age 0.3 and ~ 2.7–3.0 for age 0.4 fish (Tables 1, 2).

Inter-annual Changes in Growth

First-year growth, estimated from intercirculus distances, did not change significantly from 1962 to 2007 (Fig. 4). There was a positive trend in annual scale growth in the first year, but slope coefficients were low and statistically non-significant (0.3 age fish: 0.04, p = 0.12; 0.4 age fish: 0.05, p = 0.09). During the second, third, and fourth years at sea, annual scale growth declined significantly from the 1960s through the mid 2000s. Slope coefficients of linear regressions for the second, third and fourth years of growth were, respectively, as follows: -0.07, -0.19 and -0.18 (Fig. 4).

Annual scale growth of chum salmon during the second, third, and fourth years was greatest during the 1960s and 1970s (Fig. 4). The mean annual growth in length during this period was 18, 14, and 9 cm in the second, third, and fourth years, respectively. The lowest growth of chum salmon occurred in 1994–1995. Annual growth decreased to 16 cm in the second year, 9 cm in the third year, and 7 cm in the fourth year. Thus, the largest decrease occurred in the third year of the chum salmon life cycle.

Table 1. Average fork length (cm), body weight (g), and intercirculus distances (µm) for age-0.3 chum salmon from 1962–2007. CI = confidence interval, N = number of samples.

Year	Length (cm)	95% CI	Weight (g)	95% CI	Intercirculus distance (µm)						N
					1 year	95% CI	2 year	95% CI	3 year	95% CI	
1962	67.5	1.4	3,946	234	47	2	44	1	47	2	42
1964	68.6	1.0	3,989	188	53	3	51	3	53	3	52
1965	64.6	1.2	3,068	200	52	2	43	2	47	2	41
1968	66.9	1.5	3,563	231	47	2	47	2	47	2	28
1971	62.3	1.3	3,308	221	47	2	45	1	45	2	44
1972	70.3	1.1	3,583	204	47	2	47	1	47	2	41
1973	67.3	1.3	3,479	285	49	2	45	2	47	2	24
1974	68.1	1.3	4,238	264	49	1	48	1	49	2	49
1975	65.0	1.1	3,493	228	50	1	44	1	44	2	59
1976	65.0	3.4	3,290	562	46	4	44	9	44	10	4
1977	68.5	0.9	4,070	194	48	1	43	1	42	1	47
1978	67.0	0.9	3,922	181	46	1	46	2	46	2	50
1979	69.6	1.1	4,279	232	44	2	41	2	42	2	49
1980	64.7	1.0	3,713	204	49	2	45	2	43	2	44
1981	66.4	1.5	3,654	336	49	2	44	2	46	2	33
1982	63.6	1.1	3,576	257	50	2	46	1	44	1	48
1983	63.3	0.9	3,722	188	46	1	44	1	46	2	52
1984	62.1	0.9	3,385	196	48	2	43	1	45	2	44
1985	60.5	1.1	3,242	204	49	2	46	1	43	2	48
1986	62.2	1.3	3,375	322	47	2	45	2	47	3	34
1987	63.1	1.0	3,579	195	47	1	44	1	42	2	60
1988	63.2	0.8	3,693	191	46	1	45	1	42	1	56
1989	61.8	1.0	3,234	211	47	1	45	2	47	2	44
1990	61.5	1.1	3,548	227	46	1	44	1	44	2	48
1991	59.1	1.2	2,840	190	48	1	45	1	40	2	47
1992	61.6	1.1	2,767	188	49	1	44	1	42	1	53
1993	61.6	1.1	2,547	191	49	1	43	1	40	2	41
1994	58.1	0.9	2,524	160	50	1	43	1	40	2	44
1995	59.2	2.0	2,786	318	49	2	41	2	37	3	18
1996	61.8	1.1	3,042	182	51	1	42	1	38	2	36
1997	61.7	1.3	3,216	235	49	1	43	1	42	2	41
1998	61.3	1.2	3,019	219	51	1	42	2	39	2	34
1999	61.8	1.7	3,112	275	53	2	42	2	40	2	21
2000	62.2	1.1	3,388	203	50	1	42	1	39	1	46
2001	63.2	1.3	3,414	250	52	1	45	1	46	2	39
2002	63.8	1.4	3,492	249	50	1	44	1	44	1	32
2003	63.0	0.9	3,050	154	50	1	44	1	44	1	40
2004	61.0	1.2	3,076	211	47	1	42	1	41	1	43
2006	61.8	1.3	3,234	227	49	1	45	1	41	2	35
2007	61.2	1.4	3,217	234	50	2	45	1	42	2	29

Table 2. Average fork length (cm), body weight (g), and intercirculus distances (μm) for age-0.4 chum salmon from 1962–2007. CI = confidence interval, N = number of samples.

Year	Length (cm)	95% CI	Weight (g)	95% CI	Intercirculus distance (μm)								N
					1 year	95% CI	2 year	95% CI	3 year	95% CI	4 year	95% CI	
1962	68.7	1.2	4,165	267	47	2	44	2	42	2	44	2	45
1968	72.7	0.9	4,434	193	48	1	47	1	49	2	46	1	63
1972	73.1	1.1	4,092	218	46	1	44	1	44	2	47	2	47
1973	73.9	1.1	4,409	232	48	2	46	1	47	2	45	2	49
1974	71.8	2.5	4,556	585	49	4	48	2	53	7	49	6	10
1976	68.7	3.1	4,194	849	50	6	42	4	39	5	43	4	7
1977	72.6	1.2	4,812	415	44	3	43	3	42	3	43	5	10
1978	70.4	1.1	4,405	245	46	1	43	1	44	2	48	2	48
1979	74.6	1.6	5,298	413	43	1	42	2	41	2	45	3	28
1980	70.3	1.7	4,871	452	43	1	44	2	42	2	45	3	21
1981	70.9	1.0	4,529	236	49	1	46	1	43	1	47	2	54
1982	67.5	1.2	4,344	279	50	2	44	2	43	2	44	2	40
1983	66.7	1.3	4,348	247	46	1	43	1	41	2	47	2	45
1984	66.3	1.1	4,012	247	47	1	44	1	44	2	45	2	43
1985	65.7	1.1	4,376	277	46	2	44	1	42	2	44	2	41
1986	63.7	1.4	3,712	339	48	2	44	2	39	3	45	4	28
1987	65.2	1.0	3,903	207	48	2	46	2	41	2	43	2	46
1988	66.4	0.9	4,399	258	47	1	43	2	40	1	46	3	44
1989	67.4	1.1	4,319	255	47	2	44	2	43	2	46	2	45
1990	65.7	1.0	4,330	257	46	1	45	1	46	2	44	2	49
1991	63.5	1.2	3,564	255	47	1	46	1	42	2	43	2	44
1992	65.9	1.4	3,515	292	50	2	45	1	38	2	41	2	36
1993	65.8	1.7	3,138	319	47	2	42	2	38	2	39	2	32
1994	59.6	1.0	2,660	158	47	1	42	1	38	2	38	2	49
1995	61.1	1.1	2,971	205	48	1	40	1	35	1	36	2	51
1997	64.7	1.0	3,771	224	48	1	43	1	38	1	41	2	50
1998	63.8	2.0	3,363	328	51	2	43	2	38	2	39	2	27
1999	64.1	0.9	3,564	185	52	2	42	1	38	2	40	1	44
2000	67.1	1.3	4,344	272	51	1	41	1	39	1	39	2	45
2001	66.5	1.2	4,074	242	51	1	43	1	41	2	46	3	45
2002	66.9	1.8	4,209	318	53	1	44	1	43	2	47	2	31
2003	66.1	5.3	3,700	1131	49	10	41	3	42	9	43	8	4
2004	65.3	2.3	3,825	390	47	2	41	2	39	2	40	3	23
2006	62.3	1.2	3,345	227	49	1	45	1	40	2	43	2	38
2007	64.2	3.9	3,680	1084	49	5	42	5	37	3	38	3	5

Biological Characteristics of Anadyr Chum Salmon and Abundance of Pacific Salmon

We used the total catches of Pacific salmon by Russia, USA, Japan, and Canada as the measure of their abundance in the North Pacific Ocean (data source: NPAFC Statistical Yearbooks). Pearson's correlation coefficients between catches of Pacific salmon and some biological characteristics of Anadyr chum salmon are shown in Table 3 and Fig. 5. A statistically significant negative relationship between total catches of Pacific salmon and Anadyr chum salmon body size (length and weight) and scale intercirculus distances for the second, third and fourth years was observed. These relationships were observed for both age groups (0.3 and 0.4). The growth of chum salmon during the first year of life and total Pacific salmon abundance were not significantly correlated.

There was no relationship between the scale growth and body size of Anadyr chum salmon and the abundance of Anadyr chum salmon. Pearson's correlation coefficients among the Anadyr chum salmon catches and fish body size and growth were non-significant.

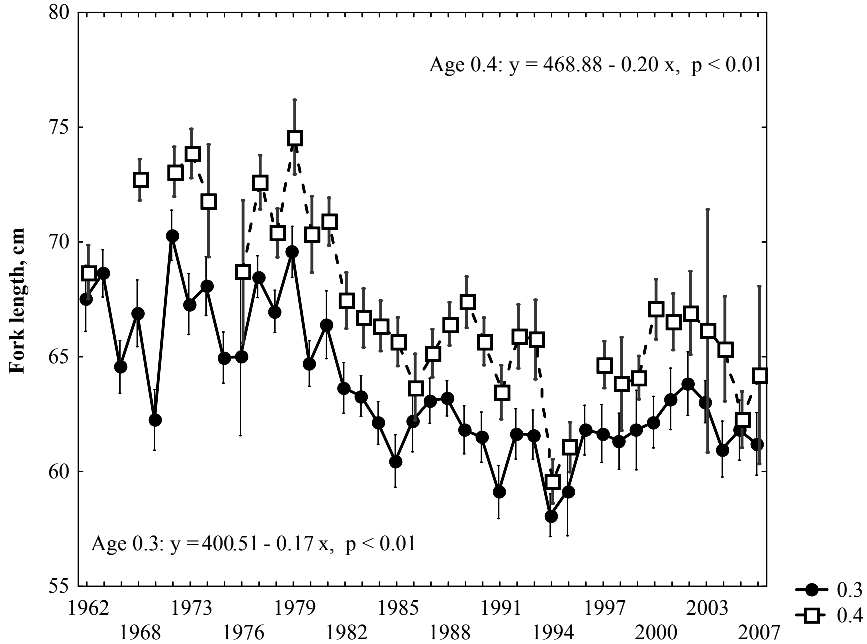

Fig. 3. Changes in mean fork length (cm) of Anadyr chum salmon (ages 0.3 and 0.4) from 1962–2007. Bars = 95% confidence interval.

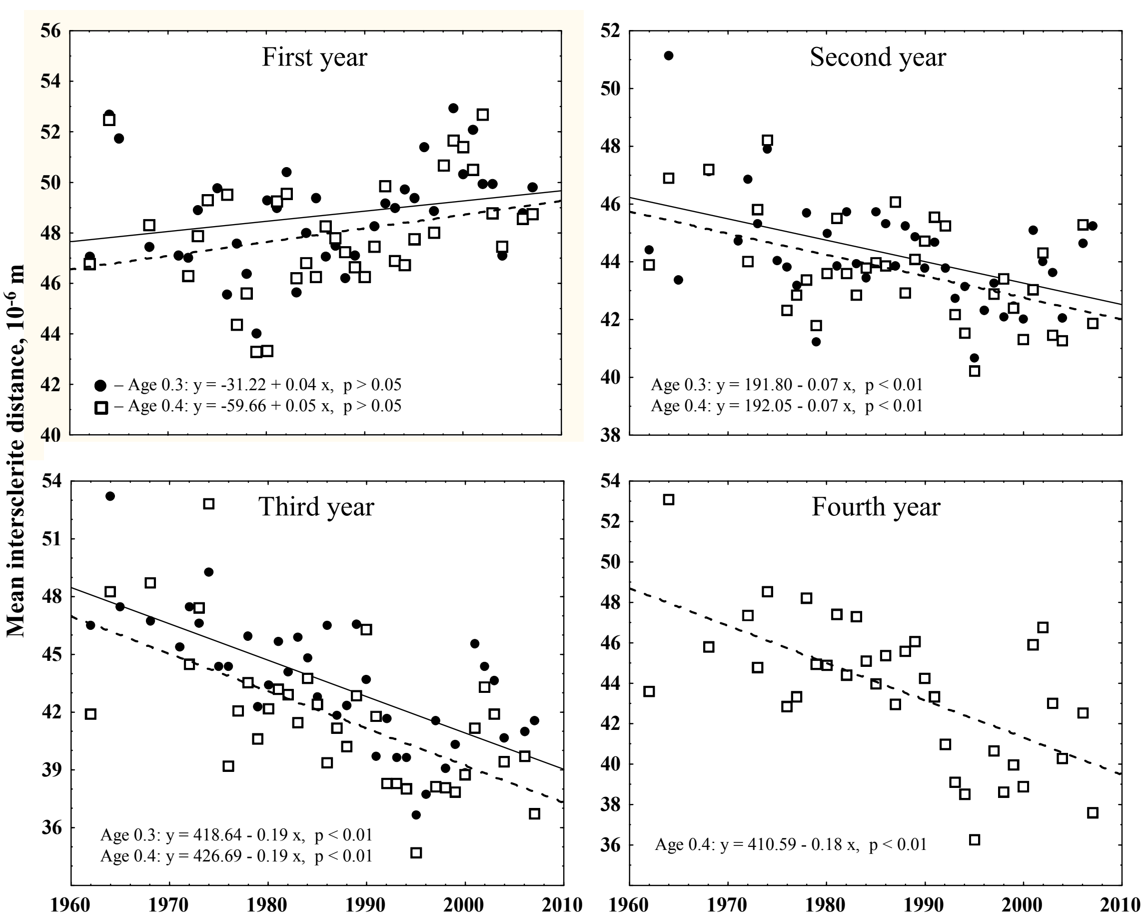

Fig. 4. Changes in mean intercirculus distances of Anadyr chum salmon from 1962–2007. Solid and dashed regression lines indicate for ages 0.3 and 0.4 fish, respectively.

Table 3. Pearson correlation coefficients relating mean body size and intercirculus distances of Anadyr chum salmon to the total catch of Pacific salmon in the North Pacific Ocean.

Age	Fork length	Body weight	Intersclerite distance			
			1st year	2nd year	3rd year	4th year
0.3	-0.78 $P < 0.01$	-0.61 $P < 0.01$	0.18 $P = 0.29$	-0.55 $P < 0.01$	-0.67 $P < 0.01$	-
0.4	-0.72 $P < 0.01$	-0.50 $P < 0.01$	0.12 $P = 0.51$	-0.50 $P < 0.01$	-0.61 $P < 0.01$	-0.59 $P < 0.01$

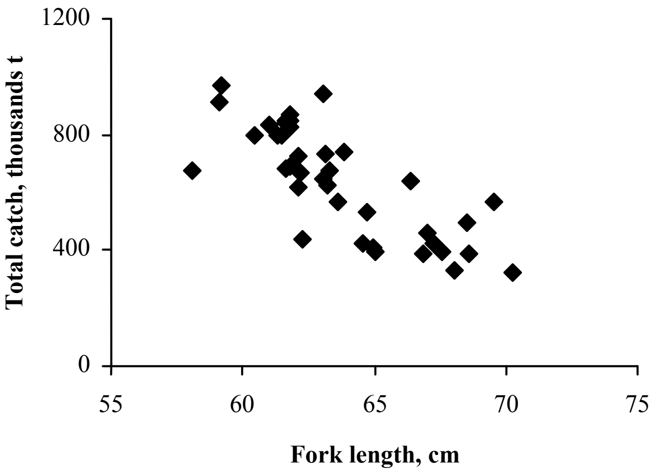

Fig. 5. Mean fork length of Anadyr chum salmon (age 0.3) and the total catch (thousands of metric tons, t) of Pacific salmon in the North Pacific Ocean from 1962–2007 (Catch data source: NPAFC Statistical Yearbooks).

DISCUSSION

The observed declines in body size and annual growth of Anadyr chum salmon that accompanied the large increase in Pacific salmon total abundance may indicate a density-dependent response by Anadyr chum salmon resulting from a decreased food supply. As noted above, growth declines of Anadyr chum salmon started during the second year of life. In the first year (based on scale growth), statistically significant changes in chum salmon growth were not observed. Perhaps feeding conditions in western Bering Sea where Anadyr chum salmon are believed to forage during the first year of life year did not change substantially during the study period. This corresponds with the conclusions of other authors about relatively abundant food resources and a sufficient food supply for Pacific salmon in the western Bering Sea (Shuntov 2001; Shuntov and Temnykh 2004; Naydenko 2007; Zavolokin et al. 2007).

Alternatively, several studies noted that annual scale growth during first year of marine life for many other populations of Pacific salmon did not decrease but even increased during recent decades (Kaeriyama et al. 2007; Martinson et al. 2008). Therefore, not only food conditions but also other factors, for example, size-selective mortality (Farley et al. 2007), can determine salmon growth in the first year of marine life.

Figures 3 and 4 show that there were both less favorable and more favorable periods for Anadyr chum salmon growth and probably survival. In 1962–1980, fork length and body weight of Anadyr chum salmon were the highest. And from the early 1980s to the mid 1990s, fish size sharply decreased. Shifts in Anadyr chum salmon sizes, taking into account a 3–4 year lag, coincided well with the 1976–1977 climatic regime shift (Hare and Francis 1995; Mantua and Hare 2002). These results may corroborate the conclusions of other researchers that climatic and oceanic conditions can strongly affect carrying capacity for Pacific salmon and other fish (Myers et al. 2001; Kaeriyama et al. 2007; Martinson et al. 2008).

REFERENCES

Bigler B.S., D.W. Welch, and J.H. Helle. 1996. A review of size trends among North Pacific salmon *Oncorhynchus* spp. Can. J. Fish. Aquat. Sci. 53: 455–465.

Farley E., J. Murphy, M. Adkison, L. Eisner, J. Helle, J. Moss, and J. Nielsen. 2007. Early marine growth in relation to marine-stage survival rates for Alaska sockeye salmon (*Oncorhynchus nerka*). Fish. Bull. 105: 121–130.

Hare, S.R., and R.C. Francis. 1995. Climate change and salmon production in the Northeast Pacific Ocean. *In* Climate change and northern fish populations. *Edited by* R.J. Beamish. Can. Sp. Pub. Fish. Aquat. Sci. 121: 357–372.

Helle, J.H., and M.S. Hoffman. 1995. Size decline and older age at maturity of two chum salmon (*Oncorhynchus keta*) stocks in western North America, 1972–92. *In* Climate change and northern fish populations. *Edited by* R.J. Beamish. Can. Sp. Pub. Fish. Aquat. Sci. 121: 245–260.

Helle, J.H., E.C. Martinson, D.M. Eggers, and O. Gritsenko. 2007. Influence of salmon abundance and ocean conditions on body size of Pacific salmon. N. Pac. Anadr. Fish Comm. Bull. 4: 289–298. (Available at www.npafc.org).

Ishida Y., S. Ito, M. Kaeriyama, S. McKinnell, and K. Nagasawa. 1993. Recent changes in age and size of chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean and possible causes. Can. J. Fish. Aquat. Sci. 50: 290–295.

Kaeriyama, M. 1998. Dynamics of chum salmon, *Oncorhynchus keta*, populations released from Hokkaido, Japan. N. Pac. Anadr. Fish Comm. Bull. 1: 90–102. (Available at www.npafc.org).

Kaeriyama, M., A. Yatsu, M. Noto, and S. Saitoh. 2007. Spatial and temporal changes in the growth patterns and survival of Hokkaido chum salmon populations in 1970–2001. N. Pac. Anadr. Fish Comm. Bull. 4: 251–256. (Available at www.npafc.org).

Kaev A.M. 2003. Chum salmon reproduction in relation to their size-age structure. SakhNIRO, Yuzhno-Sakhalinsk. 288 pp. (In Russian).

Mantua, N.J., and S.R. Hare. 2002. The Pacific Decadal Oscillation. J. Oceanogr. 58: 35–44.

Martinson E.C., J.H. Helle, D.L. Scarnecchia, and H.H. Stokes. 2008. Density-dependent growth of Alaska sockeye salmon in relation to climate-oceanic regimes, population abundance, and body size, 1925 to 1998. Mar. Ecol. Prog. Ser. 370: 1–18.

Myers, R., B. MacKenzie, K. Bowen, and N. Barrowman. 2001. What is carrying capacity for fish in the ocean? A meta-analysis of population dynamics of North Atlantic cod. Can. J. Fish. Aquat. Sci. 58: 1464–1476.

Naydenko S.V. 2007. Role of Pacific salmon at the trophic structure of the epipelagical in the western Bering Sea in summer–fall 2002–2006. Izv. TINRO 151: 214–239. (In Russian with English abstract).

Pravdin, I.F. 1966. Guide of fish study. Food Industry, Moscow. 376 pp. (In Russian).

Putivkin, S.V. 1999. Biology and abundance dynamic of Anadyr River chum salmon. TINRO-Centre, Vladivistok. 24 pp. (In Russian).

Shuntov V.P. 2001. Biology of far-eastern seas of Russia. TINRO-Centre, Vladivistok. Part 1. 580 pp. (In Russian).

Shuntov, V.P., and O.S. Temnykh. 2004. The North Pacific ocean carrying capacity – Is it really too low for highly abundant salmon stocks? Myths and reality. N. Pac. Anadr. Fish Comm. Tech. Rep. No 6: 3–7. (Available at www.npafc.org).

Volobuev, V.V. 2000. Long-term changes in the biological parameters of chum salmon of the Okhotsk Sea. N. Pac. Anadr. Fish Comm. Bull. 2: 175–180. (Available at www.npafc.org).

Zavolokin, A.V., A.Ya. Efimkin, A.M. Slabinskiy, and N.S Kosenok. 2007. Food supply and trophic relationships of Pacific salmon (*Oncorhynchus* spp.) and Atka mackerel (*Pleurogrammus monopterygius*) in the western Bering Sea in fall 2002–2004. N. Pac. Anadr. Fish Comm. Bull. 4: 127–131. (Available at www.npafc.org).