Long-term Changes in the Biological Parameters of Chum Salmon of the Okhotsk Sea

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Abstract: Chum salmon (*Oncorhynchus keta*) of the Okhotsk Sea return to their rivers to spawn in early and late runs. Runs differ in spawning time, areas and periods of spawning, and age, size and fertility of the fish. Length, weight and fertility of chum salmon increase when spawning run abundance is low. During periods of high abundance of stocks, weight and fertility decrease. Age at maturity and run abundance are inversely related. The biological characteristics of the Okhotsk Sea chum salmon stock is presumably affected by the abundance of the local stocks as well as by the total salmon population in the North-West Pacific. Changes in the climatic and oceanological conditions may affect ocean carrying capacity, and in turn affect the biological characteristics of the chum salmon stock in the Okhotsk Sea.

INTRODUCTION

The continental coast of the Okhotsk Sea is one of the main areas of Pacific salmon reproduction and fishery in the western Pacific Ocean. The coastline extends about 3,500 km from the Uda River in the southwest to the Penzhina River in the northeast. Sockeye salmon (*Oncorhynchus nerka*), chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), coho salmon (*O. kisutch*) and chinook salmon (*O. tshawytscha*) reproduce in the coastal lakes and rivers. Chum and pink salmon are more numerous than the other species. Chum salmon make up 40–45% of the total quantity of salmon stocks.

Chum salmon are heterogeneous as a species and may be divided into two ecological forms, early and late run forms, which differ in spawning migration time, reproduction areas and biological characteristics, such as length and weight, fertility, gonado-somatic index (GSI) and genome structure (Volobuev 1984; Volobuev et al. 1990; Volobuev and Rogatnykh 1997; Mednikov et al. 1998) (Fig. 1).

This report describes some of the intraspecific diversity of chum salmon of the Okhotsk Sea, and examines the relation between stock abundance and changes in some biological parameters, such as length and weight, fertility, and age at maturity over a period of 37 years.

MATERIAL AND METHODS

The material in this paper was collected chiefly by the author and fish biologists of the salmon research laboratory during their field trips to the main salmon rivers entering the Okhotsk Sea, the Gizhiga, Yama, Taui and Kukhtui rivers, from 1960 to 1996. Data for the Uda River were collected from 1967 until 1988.* The quantity of chum salmon sampled at each river annually varied from 400 to 1000, averaging 500–600 specimens. Newly caught fish were measured for fork length, whole fish weight, and weight of gonads, and scale samples were taken for the age identification. Fertility was determined first by counting the number of eggs in 20 gram samples, and then in one gram samples. The results were multi-plied by the total gonad weight. CPUE was calculated as the average quantity of fish per specified piece of fishing gear. GSI was the ratio between the gonad weight and fish weight, and represented as a percentage.

*Salmon rivers of the continental coast of the Okhotsk Sea are divided into relatively large, up to 300–400 km in length, medium and small rivers running for only a few tens of km. The Gizhiga, Yama, Taui, Kukhtui, and Uda rivers are of the first category. The hydrological, hydrogeological and climatic conditions in this type of river are much more diversified than those of smaller rivers. This fact results in intraspecific heterogeneity of chum salmon. Major rivers are inhabited by both early and late runs of chum salmon. Early runs prevail in small rivers.

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Food composition was determined by counting and weighing stomach contents accompanied by calculation of stomach fullness indices (%$_{00}$), the ratio between stomach content weight and fish weight multiplied by 10,000. Content of oxygen in the water, as well as concentration of hydrogen ions were measured by L-7, portable field analyzer ("Horiba", Japan). The speed of river current was measured using a GR-51 current meter.

Chum salmon abundance in rivers was visually determined from an airplane at a distance of 100–150 m. A correction factor was used to compensate for possible errors.

RESULTS

Spawning Migration

Spawning runs of chum salmon to coastal rivers consist of both early and late runs. However, some rivers have only one run. Early run chum salmon enter spawning rivers from the second part of June until the end of July. The end of the early run overlaps the beginning of the late run. The late run lasts until mid September. Where two runs occur, the first peaks in July, the other in August (Fig. 1a).

Reproductive Environments

The Okhotsk Sea chum spawn from July through November, in some rivers continuing until January (Volobuev 1984). Early run chum spawn from July through August in small and large rivers, and tributaries of the first and second categories at a depth from 0.3 to 1.5 m. Spawning occurs at water temperatures of 9.8–14.0°C; current speed 0.2–0.8 m/sec; pH 6.7–7.3, oxygen content 9.0–11.5 mg/L.

No phreatic discharge (from the ground water saturated zone) was found in the early run spawning areas. Eggs are incubated within the intragravel flow. Topography of the early run spawning areas is similar to that of pink salmon (Volobuev et al. 1992).

Reproduction of late-run chum occurs in the middle and upper reaches of large and medium-length rivers. Spawning occurs mainly in September–October in tributaries, streams, creeks, springs and limnocren. Late run chum reproduce in spring-type spawning areas and gravitate to phreatic discharge zones. Current speed at spawning areas varies from 0.03 to 0.8 m/sec; depth from 0.2 to 2.0 m; pH from 6.3 to 6.8, oxygen content from 9.5 to 13.5 mg/L. Water temperature in different streams may vary from 4 to 9°C, reaching 1.1–2.4°C by the end of the winter (Volobuev and Rogatnykh 1997).

Incubation Period and Development

Observations of the late run chum embryo development in the natural environment showed incubation lasted 117–122 days, and 353–405 degree-days. Fry leave the gravel and in April begin to feed mainly on larvae and pupae of chironomids in warmer spawning areas. Index of stomach fullness ranged from 223 up to 356%$_{00}$. Stomach fullness index for fry migrating to the sea was much lower, 83–120%$_{00}$ (Table 1).

Fig.1. Timing of various parameters of early and late run chum salmon of the Taui River, a) CPUE, b) gonado-somatic index (GSI), c) length, d) weight, e) frequency of males (%), and f) fertility.

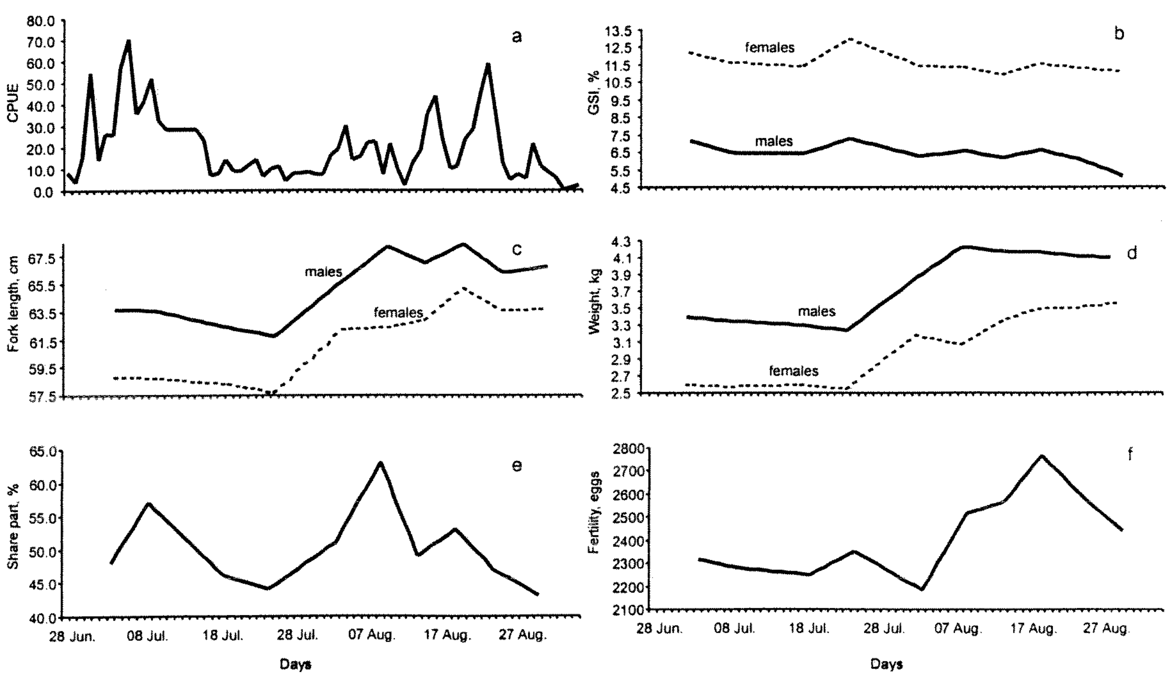


Table 1. Biological characteristics of late run chum fry (Taui River basin) migrating to the sea (mean ± SD).

	Years			
	1980–1985	1986–1990	1991–1996	1980–1996
Fork length, mm	36.2±0.73	35.5±0.29	36.1±0.12	36.0-±0.27
Weight, mg	359.5±9.51	344.1±14.9	353.1±17.7	352.8±7.9
Yolk sac weight, % of total body weight	4.06±0.58	6.10±1.77	5.83±2.76	5.36±1.14
Stomach fullness index, ‱	159.0±15.9	67.0±17.7	126.3±30.8	120.4±15.5
Percentage of feeding fish, %	49.0±2.40	38.3±2.01	33.2±7.9	40.4±3.40
Coefficient of fatness	1.04±0.06	1.08±0.02	1.06±0.05	1.06±0.03
Number sampled	1353	1440	1295	4088

Migration

Downstream migration of fry starts simultaneously with a rise in water level, and lasts from mid May until late June with a peak in late May to early June. The majority of fry migrate at night, from 0:00 to 3:00 a.m. Dates of downstream migration and diurnal activity for early and late run chum fry are the same. The main biological characteristics of late chum fry migrating downstream when averaged over 5 year periods appear to have remained the same from 1980 to 1996 (Table 1).

Biological Characteristics of Spawning Stocks

Length and weight

Chum salmon of the Okhotsk Sea coastal area are characterized by sexual dimorphism for length and weight: males are usually larger than females. The minimum recorded length of Okhotsk Sea chum salmon was 47.0 cm (female); maximum recorded length 83.0 cm (male), weight 1.18 kg and 10.35 kg, respectively. Chum salmon of the Yama River tend to be the largest in length and weight; chum salmon of the Gizhiga River tend to be the smallest (Table 2).

Average long-term length and weights for odd and even year chum salmon showed that even year generations of chum salmon are basically 0.5–1.1 cm and 0.07–0.20 kg larger than those of the odd years. Odd year generations are apparently suppressed by high abundance of pink salmon, which have similar feeding requirements (Kostarev 1964).

Analysis of the long-term changes in average length and weight showed an increase in these values during the depression in abundance of the 1970s, presumably due to total reduction in abundance of Asian salmon and their food in the salt water environment (Fig. 2a and 2b). Average decline in weight, of 0.4–0.5 kg, and length, of 3–4 cm was recorded in the late 1980s and early 1990s. Changes in length and weight are inversely proportional to chum salmon abundance. Correlation coefficients between body length and population abundance ranged from -0.55 to -.84 ($p \leq 0.05$). Correlation coefficients between weight and abundance varied from -0.36 to -0.68 ($p \leq 0.05$).

Absolute fertility

It is known that absolute fertility (number of eggs) is correlated with fish length. The absolute fertility of the Okhotsk Sea chum salmon ranges from 1008 to 4830 eggs. The average long-term annual fertility for the main populations varies from 2633 to 3008 eggs (Table 2). Some increase in fertility occurred in the 1970s, and a decline in the 1980s–1990s (Fig. 2 c). Fertility and abundance of chum salmon are also inversely proportional to length (r = -0.86 to -0.95, $p \leq 0.05$).

Age composition

Chum salmon reproducing in coastal rivers return to spawn mainly at the age of 3–5 (0.2+ to 0.5+) years. Spawning at the age of 0.1+ to 0.6+ is rare. Age groups maturing at age 0.3+ make up 58.9% of spawning Okhotsk Sea chum salmon. The long-term average age at spawning is 3.19–3.51 years (Table 2).

A decrease in average age at maturity in the 1970s and 1980s and increase in the 1990s occurred (Fig. 2d). In the mid 1990s age 0.4+ to 0.5+ made up 82–92% of chum salmon spawning in 1995 and 1996, respectively. In comparison with length, weight and fertility, age at maturity and abundance of chum salmon during spawning season were directly proportional (r = 0.57 to 0.79, $p \leq 0.05$). Average age at maturity, which was 3.21 to 3.31 years in the 1970s, increased to 3.41–3.64 years in the 1990s. Similar values were recorded for chum salmon of Japanese origin (Kaeriyama 1998).

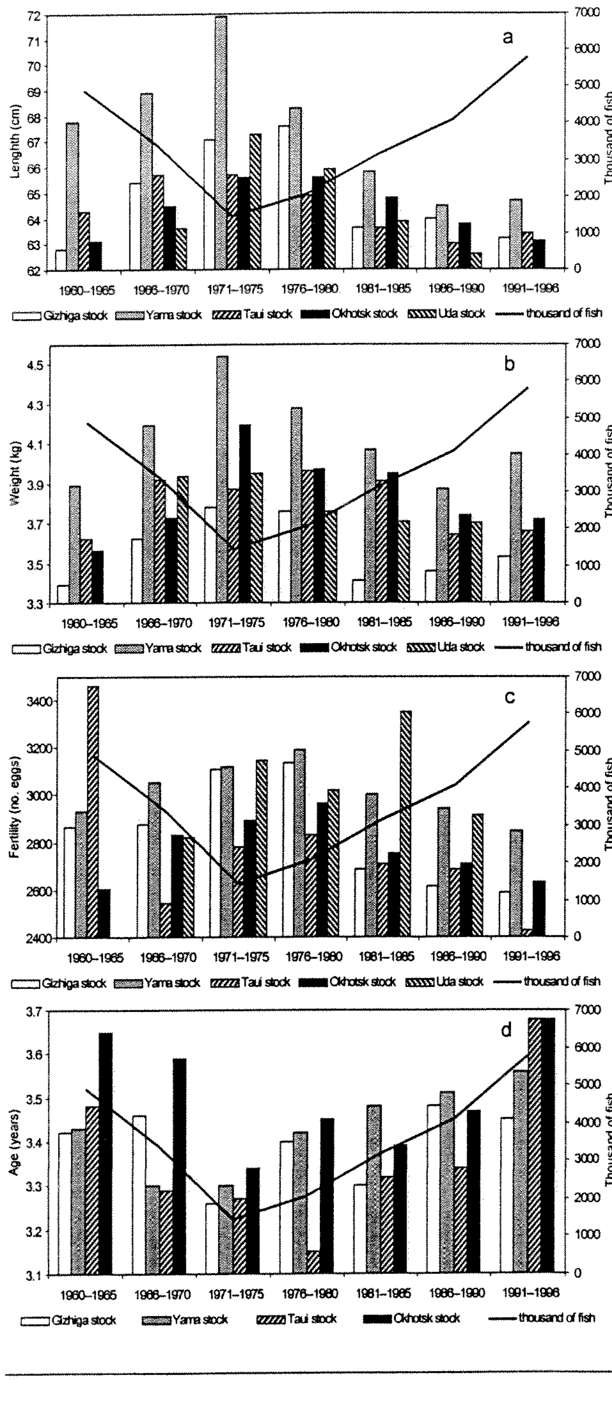
DISCUSSION AND CONCLUSION

Both early and late runs of Okhotsk chum salmon differ in spawning time and areas, reproduction ecology and main biological characteristics. Similar differences are known in Alaska, Kamchatka, Amur River, and Yukon River (Salo 1991). Along the coast of the Okhotsk Sea these temporal forms or ecotypes can be sympatric, inhabiting the same river basin, or allopatric, inhabiting different drainage-basin systems. Chum, as well as the majority of *Oncorhynchus* salmon, are

Table 2. Okhotsk Sea chum salmon length, weight, fertility and age at maturity (1960–1996).

River	Length, cm		Weight, kg		Fertility, eggs		Age 0.3+ spawning %	Age 0.3+ among generations %	Average age of spawners (years)
	Mean ± SD	Range in annual means	Mean ± SD	Range in annual means	Mean ± SD	Range in annual means			
Gizhiga	64.7±0.39	61.1–69.7	3.56±0.05	3.01–4.23	2830±22.3	2366–3459	57.1	58.0	3.39
Yama	67.4±0.49	63.4–75.2	4.13±0.05	3.57–4.66	3008±22.8	2443–3375	54.8	54.5	3.43
Taui	64.3±0.31	61.1–70.3	3.79±0.05	3.22–4.85	2633±24.1	2195–3124	56.3	58.9	3.36
Kukhtui	64.3±0.27	61.3–67.0	3.83±0.05	3.02–4.38	2741±19.4	2234–2981	48.3	52.0	3.51
Uda	65.0±0.41	61.3–68.9	3.82±0.05	3.33–4.18	2940±18.1	2599–3940	62.8	-	3.19

Fig.2. Long-term changes in (a) length, (b) weight, (c) fertility and (d) mean age-at-maturity of coastal chum salmon stocks of the Okhotsk Sea. Trend line indicates numbers of spawning chum salmon.



relegated to monotypic polymorphous species. The existence of ecological forms of chum salmon can be considered an adaptation to environment, or a species life strategy to enhance survivability and stability of the population in time and space.

Changes in biological parameters of Okhotsk Sea chum salmon are associated with long-term fluctuations in abundance of chum salmon stocks, and are caused by density-dependent factors and availability of food. During the period of low abundance in the 1970s, the numbers of Pacific salmon (including chum salmon) declined by three compared with stock levels of the 1930s. This resulted in increases in length, weight and fertility, and a reduction in age at maturity. (Fig. 2a–2d).

The period from 1936 until 1939 saw the first peak in salmon yield in the North Pacific in the twentieth century. Chum salmon biomass during spawning reached 500,000–600,000 tonnes and amounted to 47% of the total biomass of all six salmon species (Neave 1961; Salo 1991). The next increase in abundance of salmon stocks in Pacific Rim countries began in the early 1980s. This increase was caused by the favorable hydrological conditions in ocean feeding areas, and intensification of artificial reproduction of salmon by Pacific countries. As a result, by the mid 1990s hatchery output totalled 5.5 billion juveniles per year (Heard 1998). Most impressive is the output by Japanese chum salmon hatcheries: coastal chum salmon yield increased from 12,000 tonnes in the 1960s to 250,000 tonnes in the 1990s (Hiroi 1998).

As a result, the total catch of salmon in Russia, Japan, Canada and the USA by 1995 reached 1 million tonnes, with chum salmon comprising about 36% (NPAFC 1995; Klyashtorin and Rukhlov 1998; Noakes et al. 1998). Salmon stocks increased more than three times compared with levels in the 1970s. This increase affected the biological structure of the stock: the average age at maturity increased, and the length, weight and fertility of chum salmon decreased.

Size and weight of chum salmon decreased significantly between 1987 and 1990 in the Anadyr River compared with long-term values; in spawning runs from 1992 until 1994 the average weight of fish decreased by 0.8–0.9 kg, and the length by 4–5 cm

(Putivkin 1999). A decrease in length and weight, and increase in age at maturity were also observed for salmon of Japanese and North American origins (Ishida et al. 1993; Ricker 1995; Bigler et al. 1996; Helle and Hoffman 1995, 1998).

Analysis of biological parameters of Okhotsk Sea chum salmon over time has shown a deterioration during the past decade. This is probably associated with the increase in abundance of Asian (Russian and Japanese) salmon stocks, and intensification of competition for food among the different species. The level of biomass production, maturation rate and size of spawning runs are affected by the total number of Asian and North American salmon feeding simultaneously in the North Pacific. Inadequate food resources in the ocean and intensification of competition may have caused reduction in the Okhotsk Sea chum salmon weight, length and fertility, and an increase in age at maturity.

The North Pacific ecosystem has a limited carrying capacity for salmon production. Further increases in hatchery production of Pacific salmon will likely result in further deterioration of fish size and commercial value of yield. Moreover, increases in hatchery production have a negative impact on the wild salmon populations, reducing their genetic diversity and ability to adapt (Hindar et al. 1991; Nielsen et al. 1994; Altukhov et al. 1996; Berejikian et al. 1997). The number of artificially reared salmon fry of Asian origin in the 1990s amounted to 2.6 billion, including more than 2.2 billion chum (NPAFC 1998).

Currently at least two factors are influencing the development of the North Pacific ecosystem. These factors are the release of large numbers of hatchery-reared fry, and climatic shifts that affect the hydrological regime and food reserves. These factors ultimately are probably causing the changes in the biological parameters of the Asian and North American salmon populations.

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