North Pacific Anadromous Fish Commission
Bulletin No. 4: 45–51, 2007

Trends in Abundance and Feeding of Chum Salmon in the Western Bering Sea

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Starovoytov, A.N. 2007. Trends of abundance and feeding of chum salmon in the Bering Sea. N. Pac. Anadr. Fish Comm. Bull. 4: 45–51.

Abstract: Results from surveys of the western Bering Sea and adjacent Pacific epipelagic waters, performed by TINRO-Centre are reported. Surveys of the nekton community were conducted from 1986 through 2005, annually. Information on the distribution of all chum salmon by age group, the abundance and biomass of chum salmon, and other fish in the western Bering Sea and adjacent Pacific Ocean water are reported. Chum salmon diet differed according to location in the western Bering Sea.

Keywords: chum salmon, catches, biomass, abundance, zooplankton, consumption

INTRODUCTION

Pacific salmon (*Oncorhynchus* spp.) have been studied for more than 100 years and yet considerable interest in this genus of fish remains. Despite significant progress in our knowledge of Pacific salmon biology, there are still many issues relating to the reliability of short-term and long-term forecasts of fish abundance and population dynamics. With the development of marine studies of the Pacific salmon in the 1950s, new information about the sea life of these fish appeared, expanding our knowledge about ocean distribution of salmon, salmon feeding behavior, mortality, and factors influencing abundance (Takagi et al 1981; Heard 1991; Salo 1991; Myers et al. 1996; Shuntov et al. 1996).

Beginning in the mid-1980s, studies of Pacific salmon ocean life history have been conducted and large amounts of data collected and tabulated in databases. These data include information pertaining to hydrology, nekton, and zooplankton. Twenty years of research into the Far East seas substantially increased the existing knowledge about salmon ecology during foraging and spawning migrations and facilitated the collection of new data on feeding behavior and trophic relationships in marine ecosystems. This paper presents data collected during TINRO-Centre investigations in the Far Eastern seas from the mid-1980s through 2005. The role of chum salmon (*O. keta*) in the Bering Sea ecosystem, the current state of chum salmon stocks and trends in their abundance are also analyzed.

MATERIALS AND METHODS

Chum salmon and other pelagic nekton were collected in a standard midwater rope trawl type 80/396 m for surveys conducted during 1986 to 1995, and in a standard midwater rope trawl type 108/528 m for surveys conducted during 2002 to 2005. The length of the headrope was 80 m for the 80/396 and 108 m for the 108/528, and the perimeter of the trawl opening was 396 m or 528 m, respectively. Rigging specifics are described by Volvenko (2000). Trawl operations lasted 24 hours. The trawl hydrodynamic plate was maintained at 0 m (the position of the plate was verified by acoustic readings and by sight) and the length of the warp was 245–280 m. Each trawl was towed for one hour.

The abundance (in millions of individuals) and the biomass (in thousands of tons) of chum salmon, other fishes and cephalopods were calculated by multiplying the average density (individuals/km^2) and mass (kg/km^2) for the particular species times the area of the biostatistical region. Oceanographic conditions were sampled at the same approximate location of the trawl tows. A "Neil Brown" MARK-II CTD was used to measure temperature and salinity to a maximum depth of 1,000 m.

To sample plankton, a Juday net (mouth opening – 0.1 m^2, kapron mesh #49, mesh size - 0.168 mm) was used during both day and night. Plankton was sampled at every station at the approximate location of the trawl tows. The plankton net was towed in 200-0 m strata in deepwater areas or between bottom and 0 m in shallow areas. Each plankton sample was divided into 3 fractions: small (< 1.5 mm), medium (1.5 to 3.5 mm), and large (3.5 mm or more). The biomass was determined using a volumeter. When calculating plankton biomass, the correction factors were as follows: for the small fraction -1.5; for the medium fraction - 2.0; for the large fraction: euphausiids and chaetognaths shorter than 10 mm - 2.0; for specimens 10 to 20 mm long - 5.0; for specimens over 20 mm in length - 10.0. The correction factor for hyperiids

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shorter than 5 mm - 1.5; 5 – 10 mm long - 5.0; for copepods under 5 mm - 2.0; over 5 mm - 3.0.

Chum salmon feeding patterns were examined in groups according to body size: 10–20 cm, 21–30 cm, 31–40 cm, 41–50 cm, 51–60 cm, and > 61 cm. The samples including from 10 to 25 stomachs of the same body size group were selected from catches and processed without prior fixation. Upon weighting the sample the species composition of food, the percentage of most numerous species and other typical parameters were analyzed. The stage of food digestion was evaluated using 5-step scale. The index of stomach fullness was calculated as the relation of food mass in the stomach divided by fish body weight times 10,000. The daily food intake was calculated with due regard to feeding peaks. Thus, the daily food intake was counted as the overall sum of all prey consumed for every period of time studied.

RESULTS AND DISCUSSION

In the last 50 years, the Bering Sea has been warmer than normal. In general, the 1990s appeared relatively warm, and winters were without extensive ice cover. However, a shift towards cooling occurred in the atmosphere and hydrosphere in the North Pacific in 1998, which led to an increase in the extent of ice in the Bering Sea during winter (Ustinova et al. 2004).

The cold regime persisted in 2001–2002, and though positive temperature anomalies occasionally dominated in certain areas, subarctic currents were rather strong. During four years from 2002 to 2005, areas with the highest sea surface temperatures were distributed in the southwestern Bering Sea (Khen and Basyuk 2004). The year 2003 was anomalously warm. In late June 2005, the sea surface temperature was close to the long-term average over almost in the entire western Bering Sea, and positive anomalies of sea surface temperature were observed in northern areas. Increasing trends of the hydrothermal regime in the Bering Sea appeared as a result of shifts in atmospheric processes. In particular, in 2003 and 2004, trajectories of summer and winter centers of atmospheric activities (Far Eastern and Aleutian depressions) were displaced somewhat farther south than in cold seasons (Glebova in press).

Beginning in the late 1990s, water exchange rate between the Pacific Ocean and the Bering Sea showed an increasing trend (Table 1). The amount of water flowing through Kamchatka Strait may serve as an indicator of trends in annual variability of water exchange rate between the ocean and the sea. Most of the water flowing out of the sea is discharged through this strait, while the inflow of oceanic waters occurs mainly through other Aleutian passes. Intensification of oceanic water inflow has been registered in the summers of 2003 and 2005, and was the highest over the last 7 years in 2005. In the 2000s, patterns of geostrophic circulation were close to the known patterns of currents. Speeds of major geostrophic currents were also the highest at that time (Khen and Basyuk 2004).

Table 1. Average water flow in the 0-1500 m layer of Kamchatka Strait in summer and autumn by year.

Year	Water flow (10^8 m^3/s)
1999	3.37
2000	1.65
2001	5.18
2002	5.35
2003	6.05
2004	4.81
2005	6.60

The above-mentioned observations suggest that in the last 10 years, the warm period of the mid-1990s was succeeded by a short-term cold period at the beginning of the 20th and 21st centuries in the Bering Sea, and the last years (early 2000s) again appeared rather warm. We may expect that these shifts from warm to cold regimes and back will persist in future.

The structure of nektonic communities also experienced notable rearrangements in the last 20 years in the Bering Sea. Walleye pollock (*Theragra chalcogramma*) was a predominant species in epipelagic nekton in many Bering Sea areas in the 1980s (Fig. 1). The stock collapsed in the 1990s, which was associated with natural decrease in the species' reproductive rate. Walleye pollock almost disappeared from offshore areas, but retained its position as a dominant species in the northern shelf and upper slope areas. At the same time, Pacific salmon, Pacific herring, mesopelagic fish and occasionally atka mackerel have increased their abundances in deepwater offshore areas.

Beginning in the late 1980s (1986–1990) and early 1990s (1991–1995) and up to the 2000s (1998–2004), the number of chum salmon per square kilometer has increased considerably in the western Bering Sea. Estimates of relative abundance of chum salmon averaged 29, 50 and 543 individuals per square kilometer during these periods, respectively. The total relative abundance of chum salmon was assessed at 4785, 4677 and 60,785 individuals per square kilometer in these years, respectively.

Summer surveys in 2003 and 2005 revealed that in the western Bering Sea, the combined biomass of all Pacific salmon has increased three times compared to values in the late 1980s and early 1990s. Salmon biomass accounted for 78 and 85% of total fish biomass, or 842.2 and 464.2 thousand tons in the upper epipelagic zone in 2003 and 2005, respectively. Chum salmon accounted for 63 and 54% of total fish biomass in 2003 and 2005, respectively.

Data obtained during large-scale autumn surveys across the entire western Bering Sea appeared consistent with these data as Pacific salmon dominated epipelagic nektonic communities in the Bering Sea (Fig. 2). The proportion of

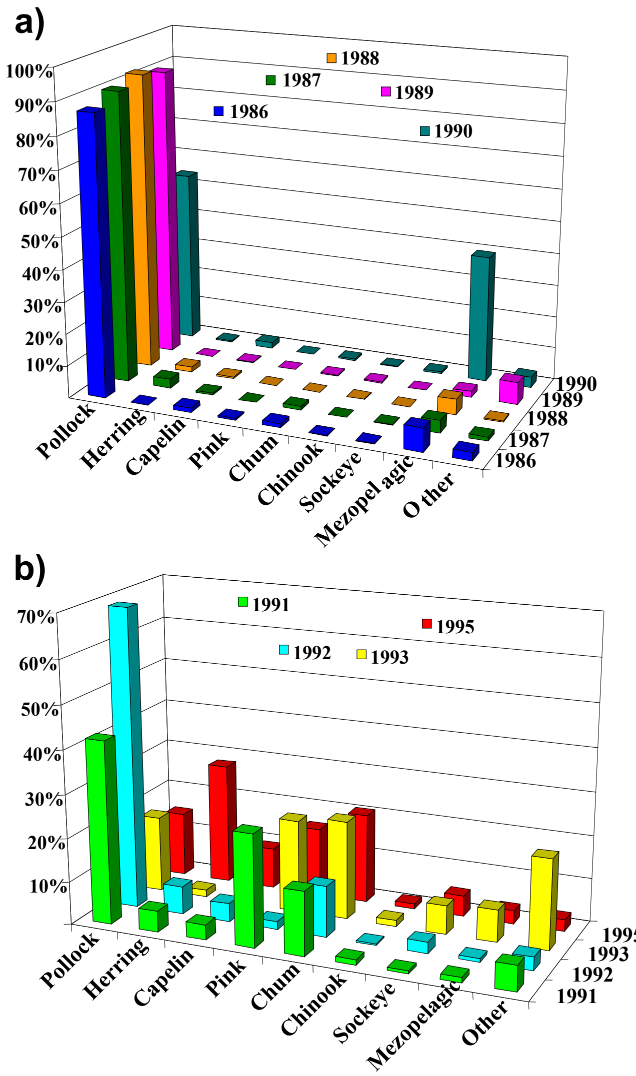

Fig. 1. Fish biomass (%) in the southwestern deepwater Bering Sea in the late 1980s (a) and early 1990s (b).

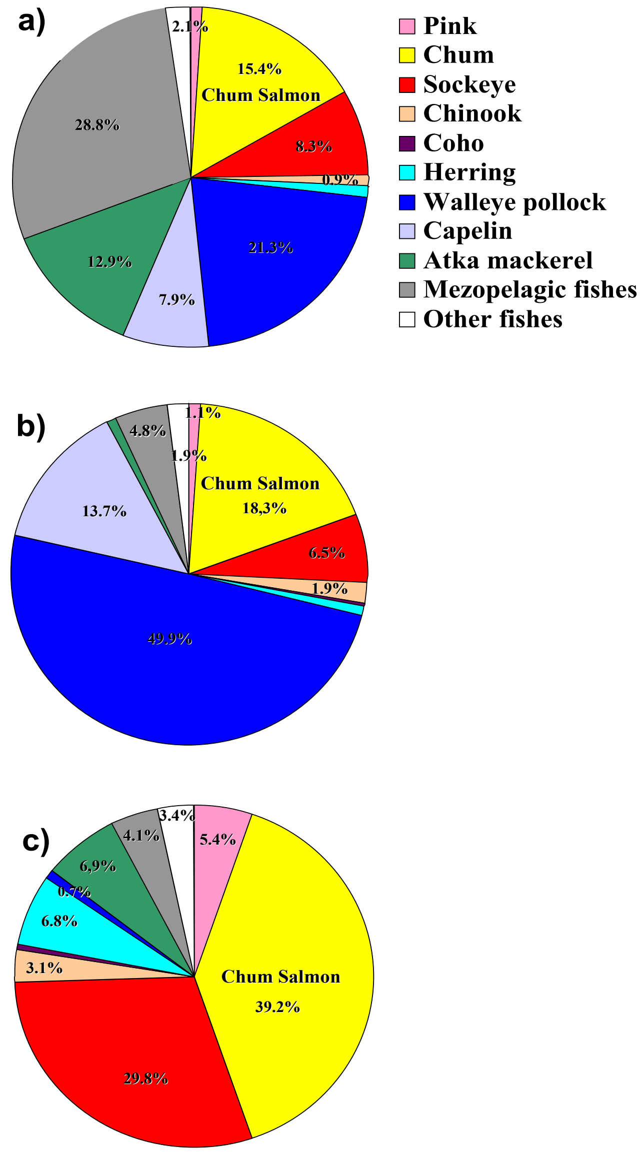

Fig. 2. Biomass (%) of Pacific salmon and other fish in the upper epipelagic layer in the western Bering Sea during autumn 2002 (a), 2003 (b) and 2004 (c).

salmon in the total fish biomass appeared to be low only in several cases. First, the proportion was low when lantern fishes increased in abundance in the upper layers (these fish migrate from deep to surface layers only at night) in 2002. Second, salmon were relatively less abundant in areas where juvenile walleye pollock occurred in large quantities, e.g., in the Navarin-Anadyr region in 2003 while juvenile pollock accounted for 98% of the total species biomass, which was assessed at 710 thousand tons in that area. Chum salmon appeared the most abundant Pacific salmon species, and accounted for 15.4–39.2% of total fish biomass which amounts from 2,180.9 (2002) to 1,424.1 (2003) to 371.8 (2004) thousand tons.

It is worth noting that immature chum salmon accounted for the bulk of the total chum salmon biomass in the western Bering Sea upper epipelagic zone during summer and autumn in the 2000s. Maturing chum salmon aggregate in coastal areas in summer, and those maturing fish that are going to spawn outside the western Bering Sea area, start their ocean-ward migrations, and by autumn, most of them are found in the Pacific Ocean. At the same time, in autumn, chum salmon juveniles migrate offshore from coastal areas.

During BASIS research, the highest biomass of immaturing chum salmon, almost 594.45 thousand tons, was found in the western Bering Sea in summer 2003. Extremely high abundance of chum salmon in the western Bering Sea in summer 2003 was presumably associated with an intensive flow of water from the east to the western part of the sea, and with favorable forage conditions in the latter area. In summer 2005, the biomass of foraging chum salmon was estimated

Table 2. Biomass (in thousands of tons) of chum salmon in the upper epipelagic layer in the western Bering Sea from 2002 to 2005.

Group	Autumn 2002	Summer 2003	Autumn 2003	Autumn 2004	Summer 2005
Juvenile	2.21	0.01	3.07	1.63	-
Immature	316.83	594.45	246.28	132.76	144.9
Maturing	15.94	90.01	10.82	11.32	149.05
Total	334.98	684.47	260.17	145.71	293.95

at 144.9 thousand tons, which was four times lower than in 2003. No summer data were available from the western Bering Sea in 2002 and 2004. The abundance and biomass of chum salmon showed a positive long-term trend (from the 1980s to the 2000s); however, these parameters fluctuated from year to year. Autumn biomass of immature chum salmon varied from 132.76 thousand tons in 2004 to 316.83 thousand tons in 2002 in the western Bering Sea (Table 2).

The autumn abundance of all age groups of immature chum salmon decreased in the 2000s. For example, mean catch per unit effort (CPUE) for age 0.1 chum salmon decreased from 28.9 individuals per hour trawling (IPHT) in 2002 to 17.8 IPHT in 2003 and 8.2 IPHT in 2004. CPUE for 0.2 age chum salmon decreased, from 5.96 to 4.39 and 1.85 IPHT, while that for older fish decreased from 2.55 to 1.04 and 0.57 IPHT for the same years.

Distribution patterns of immature chum salmon were similar in years of high and low species abundance in the western Bering Sea. In 2002–2004, the highest density of immature chum salmon was observed in the deep area of the Commander Basin, while to the north and south of these areas, catches were much lower. Individuals in the second year of marine life dominated the catches of immature salmon in the Bering Sea in autumn. Figure 3 shows that maximum catches of this age group were also distributed mainly over the deep Commander Basin. Older chum salmon leave the Bering Sea earlier and would not be expected to be numerous in the catches at this time. These older chum salmon in their third year of marine life are distributed mainly near the Commander Islands and east of the Commander Basin. Mean body lengths of chum salmon were distributed as follows: most chum salmon from 35 to 44 cm in length occupied deep basins of the western Bering Sea during autumn, and larger fish (age 0.2 and older) were more numerous in northern areas and in waters adjacent to the Commander Islands, particularly, in the ocean (Fig. 3).

Based on the distribution patterns of immature chum salmon, the deepwater Commander Basin could be considered as an optimal foraging area for fish in the second and third years of marine life. Large catches of chum salmon are distributed over wider areas when abundance is increasing.

A significant positive correlation between normalized catches for immature two- and three-year-old chum salmon is shown in Fig. 4a. Correlations between relative densities of age 0.1 and 0.2 chum salmon and sea surface temperature were not significant (Fig. 4b). Chum salmon tend to live mainly within a temperature range of 6 to 11^{o}C. The strong relationship between catches for two- and three-year old chum salmon may suggest that similar mechanisms govern their distribution; however, temperature does not appear to affect distribution. For example, in autumn 2002, immature chum salmon aggregated mainly in the area with negative seas surface temperature anomalies, while in autumn 2003 and 2004, in the area of positive anomalies.

Forage conditions, in particular, prey availability in forage areas, could be considered as one of the most important factors governing immature chum salmon distribution. Small and medium-sized animals dominate the zooplankton community in most areas of the eastern Bering Sea, while large-sized zooplankton are more abundant in the western Bering Sea and adjacent waters of the Pacific Ocean. Large zooplankton also form a forage base for nektonic animals. Copepods and chaetognaths comprise the bulk of the large zooplankton biomass in most Bering Sea areas. In the western part of Bering Sea euphausiids, amphipods and pteropods (major prey for chum salmon) were more abundant (Volkov et al. 2004).

A negative trend in the biomass of forage zooplankton has been observed during the last three years; however, fluctuations in zooplankton abundance occur at regular intervals of about 5–7 years in the Far Eastern seas of Russia. In 2003, the biomass of large zooplankton was the smallest in the eastern part of the sea, particularly, on the shelf of Bristol Bay, where representatives of this size group comprised about 9% of the total zooplankton biomass. In the deepwater marine areas, the biomass of large zooplankton was much greater, and accounted for 78–85% of the total zooplankton biomass (Volkov et al. 2004). Therefore, western areas of the sea, particularly, the deep basin, are favorable forage areas for Pacific salmon, particularly, for chum salmon.

Chum salmon diet may vary in different regions and from year to year. From the late 1980s to the early 1990s, chum salmon (> 30 cm body length) preyed predominantly on large zooplankton (87–93% of the diet), and less intensively on nektonic fish and squid (7–13% of the diet) in the Commander Basin (Fig. 5). In the 1980s, euphausiids and hyperiids comprised a larger portion of the chum salmon diet. In the 1990s, the chum salmon diet consisted mainly of pteropods, and to a lesser extent euphausiids and hyperiids. Significant annual variability has been observed in the chum salmon diet. For example, pteropods may serve as the main prey item in some years, and be of minor importance in years of low abundance. The same is true for other groups of planktonic animals, such as euphausiids, copepods and hyperiids. The observed shifts in the feeding activity of chum salmon are not always associated with annual changes in the stock abundance of major large zooplankton groups. Availability and abundance of small nektonic animals, which occasionally dominate in the diet of chum salmon of older age classes, may account for the observed variability in the fish diet.

In 2002 and 2003, chum salmon preferred to prey upon

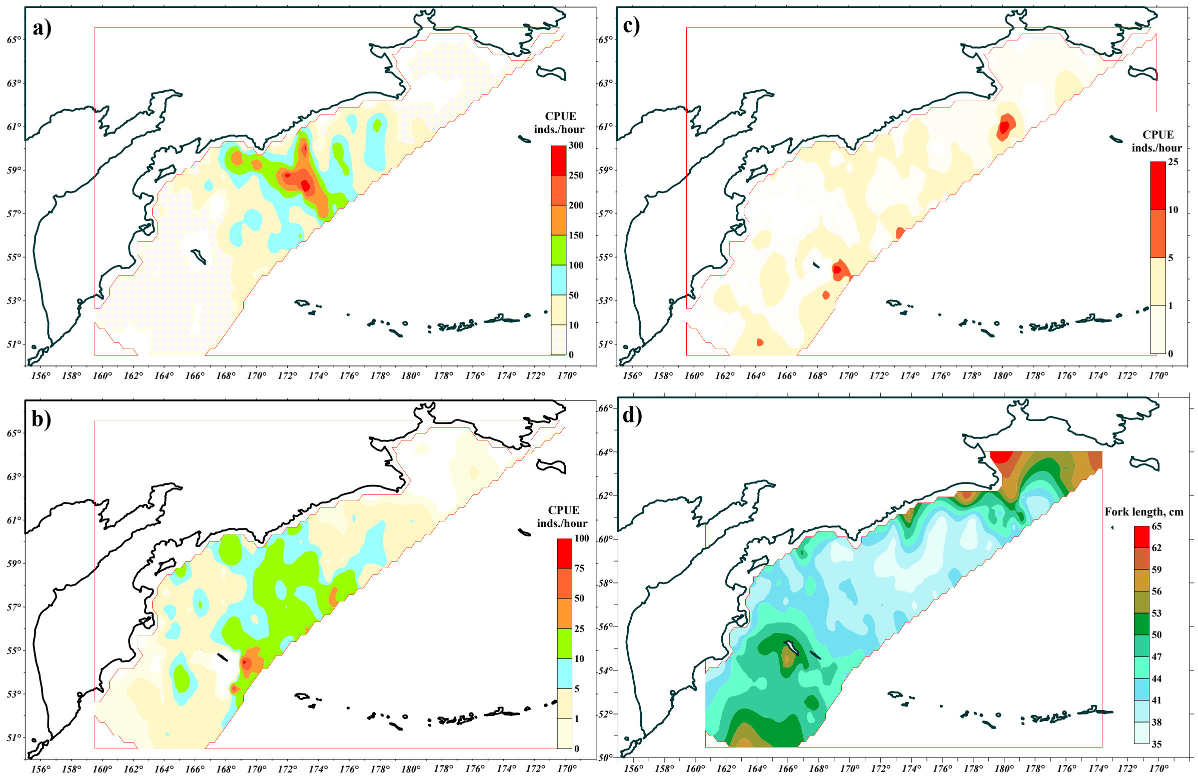

Fig. 3. Average CPUE (individuals per 1-h trawling) distribution of age 0.1 (a), 0.2 (b), 0.3 and older (c) immature chum salmon and their average fork length (d) in the autumn of 2002-2004.

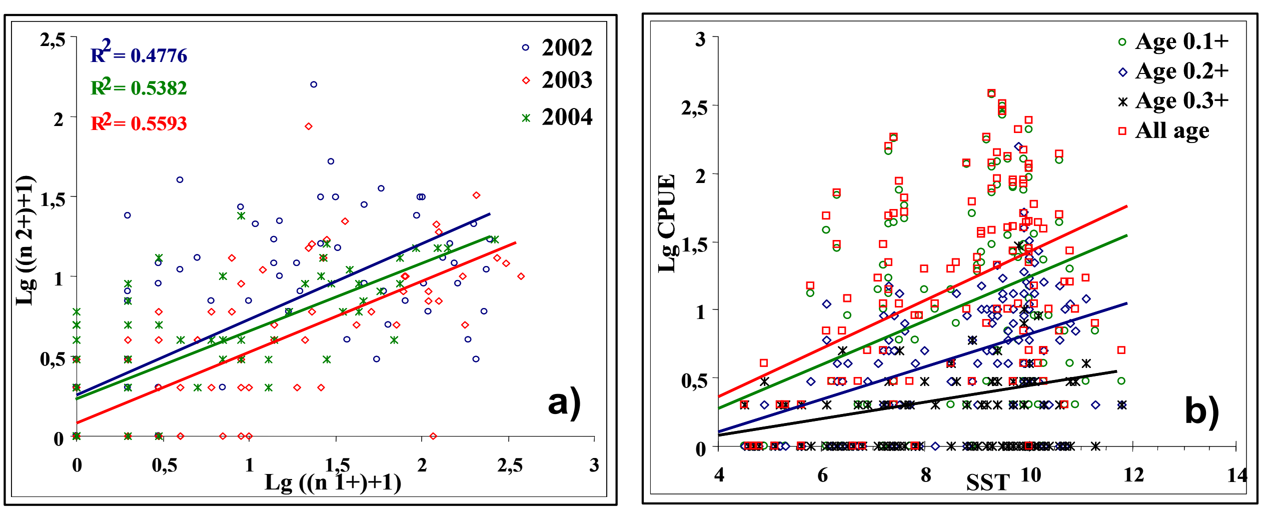

Fig. 4. Correlation between normalized CPUE values for age 0.1 and 0.2 immature chum salmon (a) and between normalized CPUE values for immature chum salmon and sea surface temperature (SST)(b), 2002-2004. Values of correlation coefficients are significant at 95% (r = 0.69-0.75, p < 0.01).

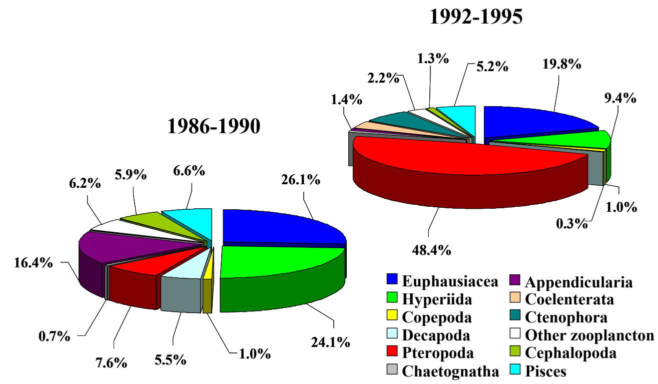

Fig. 5. Average diet composition of chum salmon (excluding juveniles) in the Commander Basin during autumn in 1986-1990 and 1992-1995.

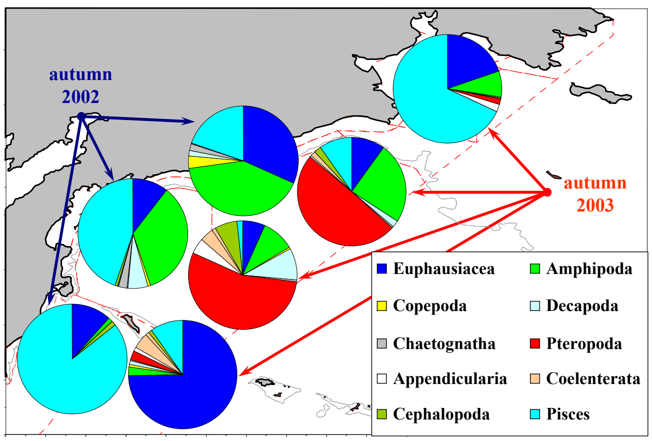

Fig. 6. Average diet composition of chum salmon (excluding juveniles) in the western Bering Sea during autumn 2002 and 2003.

planktonic organisms such as pteropods, euphausiids and hyperiids in the deepwater Bering Sea regions (Fig. 6). In the shallow coastal areas, nektonic animals, primarily fish dominated in the chum salmon diet. For example, juvenile walleye pollock, capelin (*Mallotus villosus*) and sand lance (*Ammodytes hexapterus*) were favorite prey in Anadyr Bay and shelf areas. Though food habits of chum salmon varied from region to region, they tended to prefer pteropods and hyperiids, even when their abundance in the plankton was low. Chum salmon also frequently feed upon gelatinous planktonic animals, such as medusas, ctenophores, salps and appendicularians. These gelatinous animals are most frequently present in the diet of large (mainly maturing) chum salmon in coastal areas, while in deepwater areas, these animals account for less than 5.3–7.4% of the fish diet.

Nektonic and planktonic communities of the Bering Sea have experienced considerable changes recently, and as a result, the impact of abundant fish species on plankton resources has also changed. For example, in the 1980s the total amount of zooplankton consumed by fish, including

Table 3. Trophic relationships of chum salmon in the western Bering Sea during summer 1995 and 2003.

Prey organisms	Consumption of prey (thousand tons)	
	Summer 1995	Summer 2003
Euphausiids	79.2	336.8
Amphipods (Hyperiids)	15.5	353.7
Copepods	4.4	0.2
Decapods	1.0	82.8
Pteropods	195.7	230.7
Gelatinous zooplankton	76.3	214.6
Fish + squids	15.7	385.4
Other	27.0	93.1
Total	415.3	1831.7
Biomass of chum (thousands of tons)	186.6	749.0

salmon, reached 10.5 million tons only during autumn, and dropped down to 2.4 million tons in the 1990s, resulting in an increase in food supply.

The ratio between standing crop of macroplankton and fish biomass increased tens of times, compared to the 1980s: from 7.0 and 9.5 (in 1986 and 1987) to 45.3 and 80.9 (in 2000 and 2002). This parameter was even greater in autumn 2002, when the combined amount of forage zooplankton consumed by fish was assessed at 10.2 million tons. It is worth noting here that, in these years Pacific salmon accounted for 2–9% of the total amount of plankton consumed by all fish. Salmon consumed 218 thousand tons of forage zooplankton in the mid-1980s, and 234 thousand tons in the early 1990s. In autumn 2002, the biomass of forage zooplankton consumed by salmon increased more than three times and amounted 806 thousand tons, of which 479 thousand tons or 4.7% were accounted for by chum salmon. In contrast, walleye pollock consumed 87, 61 and 44% of all forage resources consumed by all fish in 1986, 1990 and 2002, respectively, in the western Bering Sea.

Chum salmon occurred in increased numbers in summer 1995 and in summer 2003. Total amount of zooplankton and nekton consumed by chum salmon in 2003 was more than four times greater than in 1995 (Table 3). In these years, chum salmon preyed predominantly upon pteropods, euphausiids and hyperiids. Gelatinous organisms (medusas and ctenophores) also were important, and in summer 1995, they were the third most important prey in the chum salmon diet after pteropods and euphausiids. In summer 1995, maturing individuals accounted for 70% of the total chum salmon biomass, while in summer 2003, immature fish accounted for 90% of the species biomass. We have already mentioned that maturing fish were more selective in cropping gelatinous organisms. These observations were supported by data collected in summer 1995.

Even in years of highest stock abundance chum salmon consumed much less food than walleye pollock, whose annual consumption rate was assessed at 4.5–9.2 million tons in the 1980s and 1990s. As a result, the influence of chum salmon on the flow of energy (or forage resources) in the Bering Sea ecosystem is not substantial because chum salmon biomass and consumption of plankton are much smaller than those of pollock. In addition, chum salmon are known for their wide trophic flexibility, and consume both planktonic and nektonic animals. These results indicate that the recent speculations that salmon exceeded carrying capacity in the North Pacific Ocean may not be correct. Furthermore, chum salmon daily rations were high even in 2003, when the species abundance was the highest, supporting the idea that there was plenty of food for chum salmon and prey availability was far below the critical level.

CONCLUSIONS

We believe that high abundance of Pacific salmon, particularly chum salmon in the 2000s, compared to the 1980s and 1990s, in the western Bering Sea was associated with favorable forage conditions, particularly, with the high standing crop of planktonic resources in the Russian waters. However, Pacific salmon abundances and trends in their abundance are related to changes in global climate-oceanographic processes. Salmon stocks have persisted at a high level for about 20 years, and we expect a decline in their abundance in the near future. In years of high abundance, chum salmon occur both in offshore and coastal areas. In years of large abundances and increased aggregations of forage zooplankton chum salmon are forced out of the deepwater Commander Basin into areas with lower carrying capacity. At lower stock abundances, chum salmon aggregate in areas with optimal forage conditions. Thus the spatial structure of a species is related to species abundances in a manner that reduced density-dependent competition for food.

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