Forage Base and Feeding of Pacific Salmon in the Sea

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Key Words: Pacific salmon, food composition, fullness, food supply, production, consumer, competition, oceanology conditions

This paper is devoted to the analysis of feeding of three Pacific salmon species—pink, chum, and sockeye salmon—during their marine life, i.e., from first entering the sea until finishing their anadromous (adult) migration. Data collected by the staff of the Marine Salmon Investigations Laboratory for more than 40 years were used. The general area of the research comprised the southwestern part of the Bering Sea and adjacent waters of the North Pacific Ocean to the south from the Commander Islands. For additional information, some data concerning the area offshore of western Kamchatka in the Sea of Okhotsk and the waters adjacent to the Northern Kuril Islands were also presented. The majority of the data have already been published in Russia and, partially, abroad.

Only a small part of all of the collected data is presented in this report because our general goal was to analyze the dynamics of food composition of salmon during the course of their marine life. The contents of salmon stomachs are a much more reliable indicator of the abundance of general forage organisms, usually large zooplankton species, than the standard plankton catches. Observation of changes in food composition allowed us to make conclusions about structural changes occurring in plankton and nekton communities that resulted from the effects of climatic and oceanographic factors. Observed annual or decadal changes in the forage base and feeding of salmon are discussed by species and zones of distribution. Stomach fullness (‰) = food weight (g)/fish weight (g) x 10,000. Food composition (%) = individual prey species weight (g)/food weight (g) x 100. Food similarity (%) was calculated by summing the minimum food composition for those prey common to the groups being compared. Food variability or differences (%) = 100% — food similarity.

Pink Salmon

Littoral zone: The main of food of pink salmon for all years consisted of insects, larvae and imago, which varied from 47% to 92% of the total food weight. Only in June throughout the 1970s, the dominant prey was Harpacticoida (53.1%), and in July throughout the 1990s small copepods, *Eurytemora herdmani* (40.2%) and *Paracalanus parvus* (21.8%) were dominant.

Food composition in this zone in June and July from the 1970s until the 1990s differed by 94.7% and 21.8%, respectively. Maximum similarity on food composition (58.6%) was noted in June through the 1980s-1990s.

15-mile zone: The main pink salmon food in 1960s-1970s consisted of small copepods, *Pseudocalanus elongatus* and *Eu. herdmani*, and consisted of larvae and juvenile fish in the 1980s-1990s. In the 1990s, the rate of the fish component in the food of pink salmon amounted to 82%. The stomach fullness of fish usually was over 150‰, and when salmon were feeding on crustaceans it was lower than when salmon were feeding on juvenile fish. The spectrum of pink salmon food in the 1980s and 1990s compared to that in the 1970s was changed by 95.6% and 49%, respectively.

Open waters of Karaginsky Bay: The main pink salmon food in the 1960s was Pteropoda (83.3%), and the in the 1970s-1980s it was larvae (40.5%) and juvenile (78.4%) fish, respectively. The stomach fullness of fish was lowest in this zone, rarely more than 100‰. In the 1980s the composition of food was changed by 95.9%, compared to that in the 1960s.

Bering Sea: In the open waters of Bering Sea pink salmon preferably consumed euphausiids, juvenile fish, and hyperiids. In the 1960s-1970s the dominant prey were euphausiids (60%), in the 1980s the dominant prey

was juvenile fish (35%), and in the 1990s hyperiids were dominant (32.6%). The spectrum of food of pink salmon in the 1970s, compared to that in the 1960s, was changed by 37.5%, in the 1980s by 57.9%, and in the 1990s by 69.4%.

Bering Sea (anadromous migrations): In 1965, pink salmon mostly fed on hyperiids and juvenile sculpins, and moderately on euphausiids. In 1992, the main of food was fishes (29.6%), squids (23.0%), and euphausiids (20.0%), and hyperiids were only 10.6% of the food weight. The food spectrum of pink salmon in 1996 comprised euphausiids (mostly *Thyssanoessa longipes*; 67.4%), myctophids (12.3%), and copepods (*Calanus cristatus*; 9.8%); the stomach fullness was 146.2‰.

Chum Salmon

Littoral zone: Chum salmon in this zone almost solely consumed insects (larvae and imago). Only in June was another food component observed; in the 1970s—gammarids (38.6%), and in 1980s and 1990s—fish (29.0% and 22.1%, respectively). The stomach fullness usually was over 200‰. The food spectrum was wide. In June in the 1980s and 1990s, the food spectrum was different than in June in the 1970s (76.1% and 69%, respectively); the food spectrum in July (54.5% and 53.3%) was comparable to the 1970s.

15-mile zone: In the 1970s chum salmon fed on larval and imago insects (51.9%) and gammarids (16.6%). In the 1980s and 1990s chum salmon mostly consumed juvenile fish (28.5% and 57.3%, respectively), and sometimes *Parathemisto japonica* and Appendicularia. Usually the stomach fullness was more than 150‰. In the 1980s food composition differed from the food composition in the 1970s by 89.5%, and in the 1990s it differed by 78.6%.

Open waters of Karaginsky Bay: In the 1960s, chum salmon consumed *P. japonica* (53.9%) and Polychaeta (30.9%), and in the 1970s—sandlance (49.2%) and Appendicularia (29.9%). The stomach fullness in this zone was the lowest, less than 50‰. The spectrum of food in the 1970s differed from that in the 1960s by 96.9%.

Bering Sea: In the 1960s, the main chum salmon food was euphausiids (61.8%), and in the 1980s food mainly consisted of approximately equal parts of Pteropoda (29.3%), Appendicularia (26.4%), and euphausiids (24.6%). In the 1990s chum salmon fed on hyperiids (31.7%) and euphausiids (26.9%). Average stomach fullness was high, and ranged from 130 to 215‰, the highest fullness being noted in the 1990s.

Bering Sea (anadromous migrations): In 1965, chum salmon fed preferably on Pteropoda and hyperiids, episodically consuming copepods (*Eucalanus bungii*). In 1992, chum salmon fed on pteropods (62.9%), euphausiids (15.7%), and hyperiids (11.6%). Pteropoda was the main of food of chum salmon in 1996 (43.0%), and they also consumed myctophids (35.2%) and euphausiids (the rate decreased to 7.1%). Average stomach fullness in 1996 was 69.5‰.

Sockeye Salmon

Littoral zone: The main food of sockeye salmon consisted of insects and juvenile fish. Juvenile fish dominated in the food composition in June and July in the 1970s (60% and 64%) and in June in the 1980s (64.7%); insects were the dominant prey in July in the 1980s (55.5%) and 1990s (63.3%). The food spectrum included significant rates of gammarids, shrimps and Cumacea. The stomach fullness varied extensively (60 -365‰). The year-to-year spectrum of sockeye salmon food in June differed completely (100%). In July in the 1980s, the food spectrum differed by 75.1% in comparison to that in the 1970s, and by 82.8% in July in the 1990s.

15-mile zone: In the 1970s, sockeye salmon fed solely on imago and larval insects (95.9%), in the 1980s and 1990s sockeye salmon consumed juvenile fish (41.2% and 100%, respectively). The stomach fullness was high over 200‰. The spectrum of food in the 1980s differed from that of the 1970s by 91.2%, and from the spectrum in the 1990s by 100%.

Open waters of Karaginsky Bay: In the 1960s, sockeye salmon fed solely on fish; average stomach fullness of fish amounted to 11‰. In the 1970s, sockeye salmon consumed euphausiids (76.3%), and in the 1980s they

fed on zoea of Decapoda (60.6%) and euphausiids (36.4%). The stomach fullness was less than 100‰. The spectrum of food in the 1970s compared to that in the 1960s changed by 94.1%. The spectrum observed in the 1980s compared to that in the 1960s was completely different (100%).

Bering Sea: In the 1960s, sockeye salmon fed mostly on juvenile fish (40.7%) and hyperiids (40.0%), and in the 1980s on *P. japonica* (69.9%) and Pteropoda (17.7%). Average stomach fullness was low (27.6‰ in the 1960s and 72.4‰ in the 1970s). The food spectrum in the 1980s differed from that in the 1960s by 55.1%.

Bering Sea (anadromous migrations): The main food of sockeye salmon in 1965 consisted of hyperiids and juvenile squids, and the percentages of Pteropoda and copepods (*Eu. bungii*) were low. Hyperiids (42.8%) also formed the basis of sockeye salmon food in 1992. The rates of juvenile shrimps, squids, and Decapoda were 16.8%, 16.6% and 11.1%, respectively. In 1993, the main food of sockeye salmon consisted of euphausiids (*Thyssanoessa longipes*; 40%) and hyperiids (21%), and the percentages of Pteropoda and juvenile squids were relatively low (14.9% and 10.9%, respectively). In 1996, the primary foods were juvenile squids (32.2%) and Pteropoda (21.4%), and sockeye also consumed myctophids (12.4%) and *Thyssanoessa raschii* (9.8%). The average stomach fullness in sockeye salmon in 1996 was only 32.4‰.

The above discussion concerned changes in the food composition and stomach fullness of pink, chum, and sockeye salmon within a large, isolate basin, the Bering Sea. The most stable food composition is found in the estuaries and littoral zone, which is related to the high rate of freshwater and brackish water animals in these habitats. As salmon migrate seaward, the variability in the food spectrum and the role of some pelagic animals increases. The highest variability in food composition and volume of zooplankton was found in the most abundant species, pink salmon. In sockeye and chum salmon variability in these characteristics was lower.

Regional changes in climate and ocean conditions, noted by many scientists, have significant effects on the changes in food composition. Moreover, the influence of the abundance of consumers, in particular of pink salmon, is significant. This influence has been revealed by the comparison of food composition in the years of low (1960s-1970s) and high (1980s-1990s) abundance, though the difference between the 1960s and 1970s or 1980s and 1990s is not as clear. Apparently, the abundance of pink salmon had an influence on the level of food supply of other salmon species, and may determine their biological parameters (size, weight, age maturity, and etc.) and production potential.

Similar analysis of the feeding ecology of salmon within different areas, e.g., the Sea of Okhotsk, offshore of the Kuril Islands, and the Pacific waters adjacent to Kamchatka, is expected to be carried out. Studies of the influence of food composition on biological parameters and salmon production is expected to be continued for other areas of salmon reproduction and marine rearing in the North Pacific.