Feeding Strategies and Trends of Pink and Chum Salmon Growth in the Marine Waters of Kamchatka

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Keywords: pink salmon, chum salmon, feeding, ration, body weight, temperature, growth, productivity, West and East Kamchatka

This study is based on long-term data of feeding of Pacific salmon in the marine waters of Kamchatka and biological parameters of spawners returning to the Kamchatka coast. Trophological data were collected by researchers of the Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO) on marine expeditions in three main regions: northwestern Pacific Ocean, Okhotsk Sea, and Bering Sea. At various times since 1952, several methods were used to catch salmon including drift-nets, purse and beach seines, and pelagic trawl.

In total, 24,112 pink and chum salmon stomachs (13,322 juveniles and 10,790 adult fish) were analyzed for this study. Laboratory analysis of salmon feeding habits since 1952 has employed one standardized method at KamchatNIRO, which is the same method that has been standardized across Russian laboratories (Anonymous 1974). Thus, we hope that we have managed to avoid the problem of data comparability for different periods of observation. For analysis of changes in growth of salmon populations, we used annual commercial catch statistics and the average weight of salmon in West and East Kamchatka from 1971 to 2010.

It is well known that most of the growth of the individual and the formation of total production of the population occurs during the marine period of life. Figure 1 shows the generalized growth of Kamchatka pink and chum salmon for the first year at sea. This figure illustrates differences in growth rate between these species over the seasonal feeding periods. In the early period of marine life, pink and chum salmon growth rates are similar. Differences become apparent in winter months, and by the end of the over-wintering period pink salmon average weight is twice as large as that of chum salmon. This difference in weight is maintained until the following year.

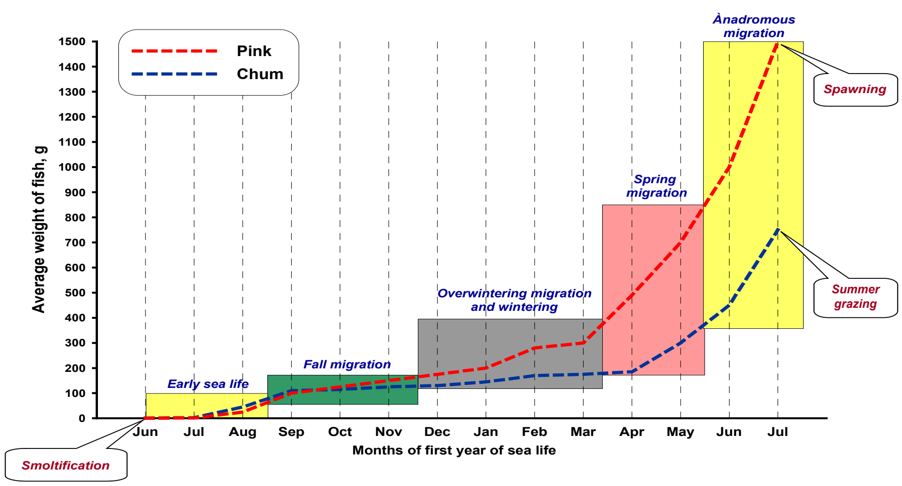

Fig. 1. Generalized growth trajectory of Kamchatka pink and chum salmon throughout the first year at sea.

Most fish biologists agree that growth rate of salmonids is driven by three basic factors: ration, body size, and temperature (e.g., Stauffer 1973; Elliot 1975; Hoar et al. 1979; Shulman and Love 1999). Ration is the locomotive power of the organism; temperature controls the metabolic process; and body weight is the scaling factor modifying the metabolic process according to body size of the growing fish.

Analysis of the food composition of different salmon species shows that while in rivers, estuaries, and in littoral zones, juvenile pink and chum salmon consume similar food. Well-marked differences in diet begin to appear in Kamchatka coastal waters. During fall migrations, differences in diet decrease somewhat and wintering pink and chum salmon consume similar

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food items. However, during the spring-summer period differences in pink and chum salmon food composition increase (Koval 2007). Therefore, feeding habits of pink and chum salmon during the seasonal marine feeding periods account for some of the differences in growth rates of these species.

It is known that salmon can be divided into two main groups–plankton-eaters and predators. The first group (pink, chum, and sockeye salmon) generally consume zooplankton. The second group (coho and Chinook salmon) generally consume nekton. Among the plankton-eaters, pink salmon has the highest feeding rate and sockeye salmon has the lowest. In this group, chum salmon feeding rates are intermediate.

Feeding strategies of different salmon species are associated with morphological and physiological characteristics (Koval 2007). For example, chum digestive system morphology and internal organs differ considerably from other Pacific salmon species (Azuma 1992; Klovach 2003). Total calorie content of adult chum salmon food is appreciably lower than the food of pink salmon (Fig. 2).

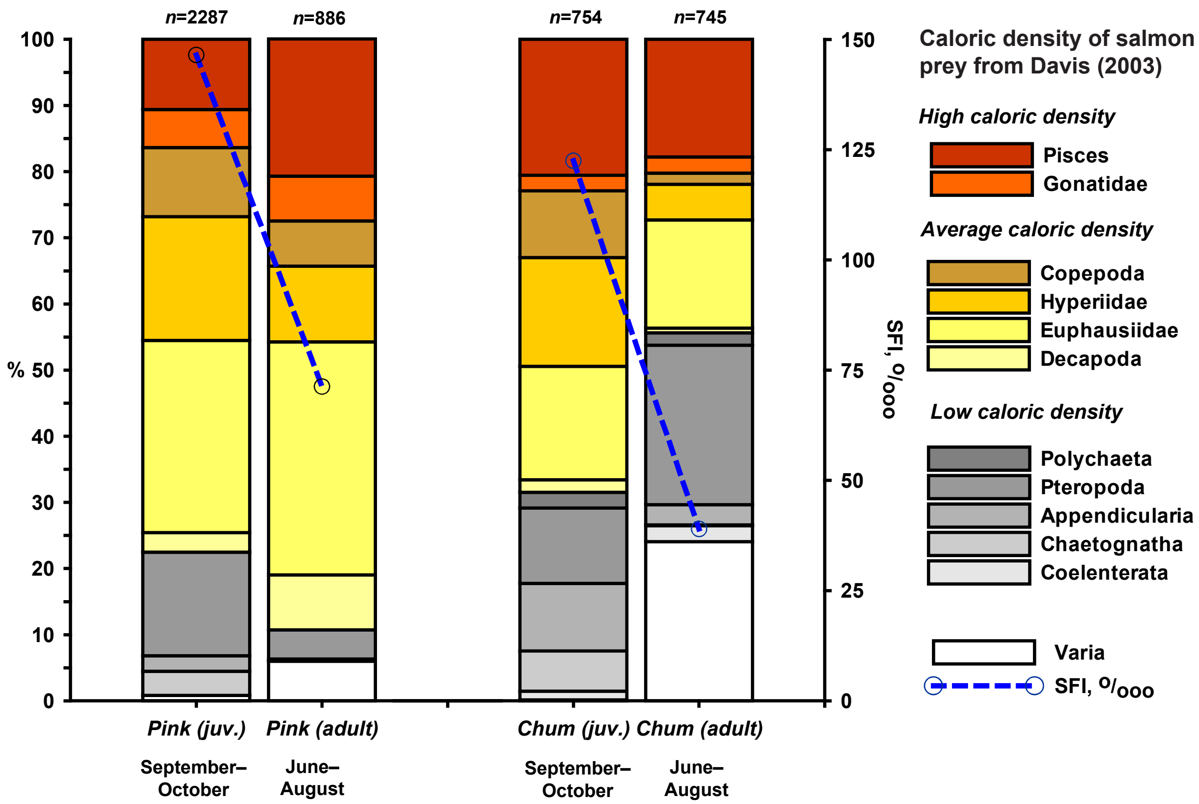

Fig. 2. Composition of basic prey items (% of food weight) and intensity of feeding (stomach fullness index (SFI)) of juvenile and adult pink and chum salmon in Kamchatkan waters of the Bering Sea, 1965–2005. (Values for caloric density from Davis 2003.)

Pink salmon prey consumption rates are less than that of chum salmon, but the nutritional value of pink salmon food is higher than the food of chum salmon. These factors determine the growth rate of pink salmon, which is able to prepare the fish for spawning in one year. Chum salmon also feed actively at sea, but low-caloric animals prevail in the ration. Nevertheless, the large size of the stomach and rapid digestion rate provide chum salmon with energy essential for vital functions, growth, and maturation. Perhaps, these are an adaptive mechanism allowing chum salmon to avoid food competition with other salmon species in common feeding areas. However, chum salmon are obliged to "pay" for consumption of low-caloric prey with reduced growth rates, as they are not able to attain spawning size in one year (Fig. 1).

During recent decades, increasing abundance has been observed for West and East Kamchatka pink, chum, and sockeye salmon. With gradual increasing abundance of pink salmon, average weight has also increased. However, in years of maximum abundance, average weight can be significantly lower than the long-term average (Fig. 3). Over the same period, the linear trend of chum and sockeye average weight has declined, particularly for chum salmon.

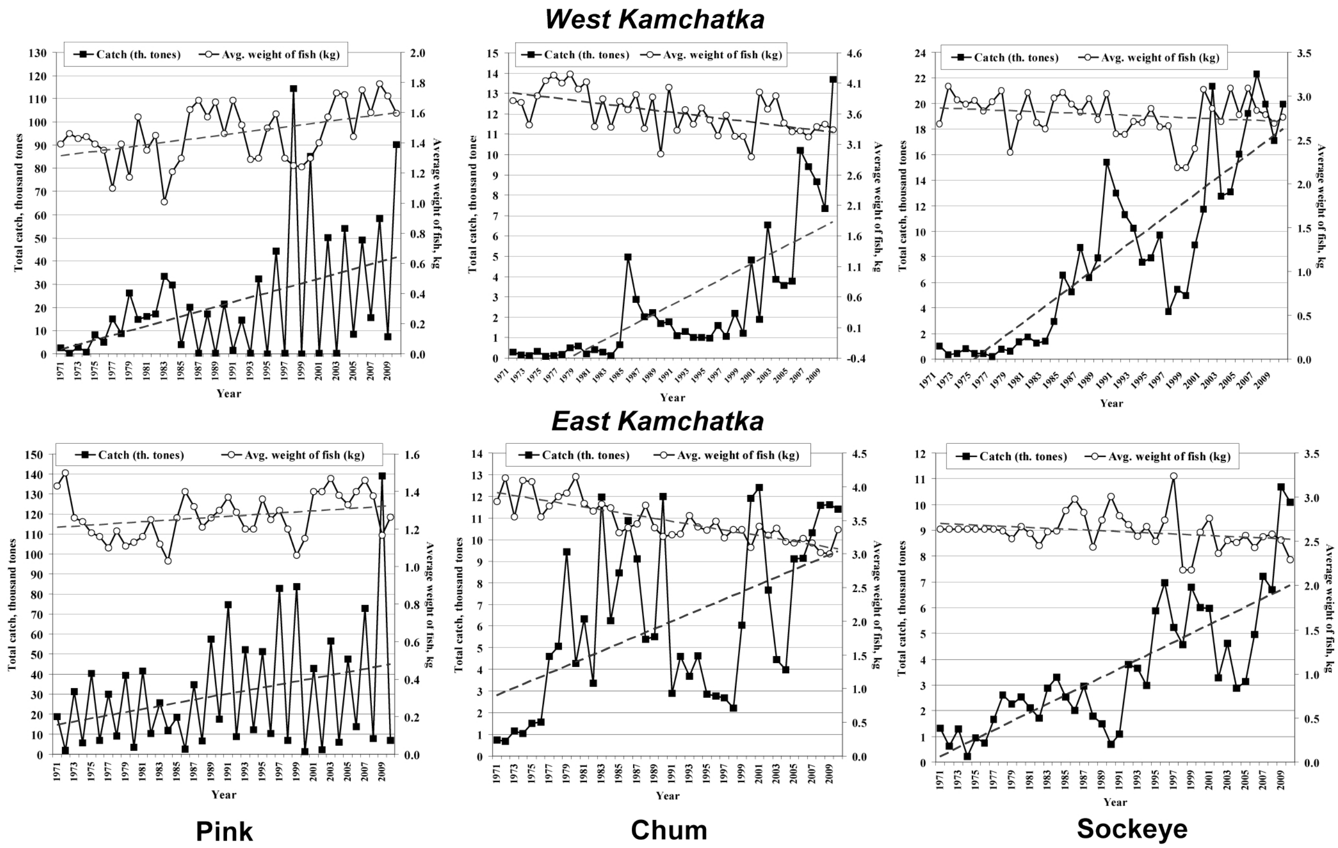

Fig. 3. Total commercial catch (thousand tonnes) and average body weight (kg) of pink, chum, and sockeye salmon in West and East Kamchatka, 1971–2010.

Decreasing chum salmon average weight has been observed not only in Kamchatka, but practically everywhere for Asian populations with the exception of the Primorye region (Table 1). At the same time, decrease in average weight has been less considerable in chum salmon originating from areas where chum salmon populations are less abundant (e.g., East and Southwest Sakhalin, North coast of the Sea of Okhotsk, and the Bering Sea). In the opinion of Bugaev et al. (2007), a large population of pink salmon causes changes of sockeye salmon body size in stocks from both Kamchatkan coasts. This phenomenon is observed under the influence of both West and East Kamchatka pink salmon. The influence of pink salmon abundance on the size characteristics of Alaskan sockeye salmon has been observed by scientists (Ruggerone et al. 2003; Ruggerone and Nielsen 2004; Ruggerone et al. 2005, 2007), and a number of researchers note increasing average age composition of sockeye and chum salmon in fish returning to regions of the western North Pacific.

Table 1. Average body weight (kg) and percent change in average body weight of pink, chum, and sockeye salmon in different regions of the North Pacific from the 1970s to 2000s.

Region	Pink		Chum		Sockeye	
	kg	%	kg	%	kg	%
West Kamchatka	1.44	16.8	3.64	–12.1	2.78	–1.1
East Kamchatka	1.26	13.8	3.53	–19.0	2.62	–5.0
Kuril Islands	1.32	10.2	3.78	–8.4	–	–
East Sakhalin	1.24	8.2	3.58	–25.6	–	–
North coast of the Okhotsk Sea	1.27	5.6	3.78	–7.0	2.59	–2.0
North part of the Bering Sea	1.35	1.4	3.58	–7.2	3.33	1.2
West Sakhalin	1.24	–7.9	3.61	–7.0	–	–
Primorye region	1.48	–11.0	3.57	3.8	–	–

Over several decades, Russian trophologist L.D. Andrievskaya noted repeatedly that during periods of extremely high abundance of pink salmon in Kamchatkan waters the number of prey items consumed by pink and chum salmon increased, but the average weight of fish decreased (Andrievskaya 1966, 1975, 1998). She considered this observation was related to large aggregations of salmon at sea that could lead to salmon accidently consuming low–calorie prey items.

Analysis of our long-term trophological data showed that in recent decades the portion of low-calorie prey items in juvenile pink and chum salmon diets in the Okhotsk Sea has increased considerably. At the same time, there was a considerable expansion in the number of prey items in their diet. In recent years we noted an increase in the total number of prey items of juvenile salmon in the southwestern part of the Bering Sea. However, there was no distinct change in caloric content of food in this area, as there was in samples collected in the Sea of Okhotsk. According to our data, conditions for salmon feeding in Kamchatkan waters of the Bering Sea are always less stable than feeding conditions in the Sea of Okhotsk. This is associated with lower productivity of the forage base and the smaller area for salmon feeding in the Bering Sea. As a result, the food spectrum of Pacific salmon in the Bering Sea is always wider than in the Sea of Okhotsk.

We have a longer series of observations of adult salmon feeding in the northwestern part of the Pacific Ocean. Unfortunately, this series has some missing years, but if we consider it as a whole, there are some time periods when the food spectrum of salmon expands or contracts. When comparing data collected from salmon during the same period in other areas (Okhotsk and Bering Seas from 1965 to 2005) we observed expansion of the food spectrum for adult salmon. Chum salmon showed these changes to a greater degree. Almost without exception, the portion of low-calorie food was more than 50% in adult chum salmon diets in this area. From the 1950s to the 1970s zooplankton dominated in pink salmon diets. In the subsequent period, the portion of young fish and squids in the diet increased, and the calorie content of the diets increased.

We have discussed two of the main factors of salmon growth, ration and body weight, and that leaves the third important factor, temperature. In our opinion, temperature was the main factor contributing to the record increase of pink salmon productivity observed in recent decades in Kamchatka. Pink salmon is one of the most thermophilic species of Pacific salmon, so increased temperatures (within limits) is particularly favorable for pink salmon growth. Perhaps total temperature increases in the North Pacific (including coastal waters of Kamchatka) were favorable for survival of the abundant species of Kamchatka salmon (pink, chum, and sockeye salmon). Continuing increased environmental temperature might contribute to better growth of pink salmon at sea. This hypothesis requires further study.

The abundance of pink salmon is influenced not only by its biological characteristics, but also by the biology of other salmon, like chum and sockeye salmon that have a similar feeding ecology. For example, in the mid 1990s, chum salmon fed on gelatinous animals to a great extent, which lead to muscle structural changes expressed as flabbiness (Klovach 2003). Chum salmon feeding habits could be associated not only with high abundance of pink salmon at sea, but also to the large number of young chum salmon released from hatcheries in Japan, USA, Russia, and Canada (Klovach 2003). The decrease of chum salmon average body weight in recent decades could be linked to limited forage resources in the North Pacific and the diverse prey composition of chum salmon (e.g., Birman 1985; Ishida et al. 2001; Davis et al. 2005; Karpenko et al. 2007). In our opinion, chum salmon is at some disadvantage in competition with other more favorably adapted salmon species.

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