Food Supply of Pacific Salmon During Their Marine Period of Life in the North Pacific in 1980–2011

Svetlana Naydenko

Pacific Research Fisheries Center (TINRO-center),
4, Shevchenko Alley, Vladivostok 690091, Russia

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This study focused on estimates of food supply for salmon and other nektonic species in the epipelagic layer of regions of the subarctic Northwest Pacific (except estuarine and coastal areas). For this purpose, a long-term data series (1980–2011) was analyzed that was developed from integrated Russian research surveys in the pelagic zone of Russian Far East seas and the northwestern Pacific Ocean. Information gained from these surveys includes total quantitative estimates of nekton biomass, stock of forage resources (macroplankton and small nekton), and Pacific salmon and nekton feeding.

Estimates summarizing the dynamics of forage resources were presented by Shuntov (2001), Dulepova (2002), Shuntov and Temnykh (2007), and Volkov et al. (2007). Based on their reports, the total estimated stock of zooplankton in the epipelagic layer of the subarctic Northwest Pacific, including the Okhotsk and Bering Seas, decreased from 722.5 million tons in 1980 to 587.8 million tons in 2000 (decreased approximately 20%). However, the large-sized fraction of zooplankton, which is the basis of feeding for nektonic planktivores, slightly decreased from 1980 to the early 1990s (8%) and there was a slight increase in succeeding years to 520.1 million tons. These dynamics illustrate some specific provincial features. Generally, in spite of a definite decrease in total abundance of macroplankton, the biomass is still rather high (Shuntov 2001; Dulepova 2002; Shuntov and Temnykh 2007).

Abundance of the dominant pelagic nekton species had a clear decrease in the late 1980s to early 1990s, when the walleye pollock stock decreased and Japanese sardines stopped its mass migration to subarctic waters. Later, this reduction was partially compensated for by increasing populations of herring, saury, Japanese anchovy, capelin, several species of squids, and Pacific salmon. Recently, from 1996 to 2011 pelagic nekton resources have remained at a level that is lower than the 1980s, but higher than it was in the early 1990s (Shuntov et al. 1997; Shuntov and Temnykh 2004).

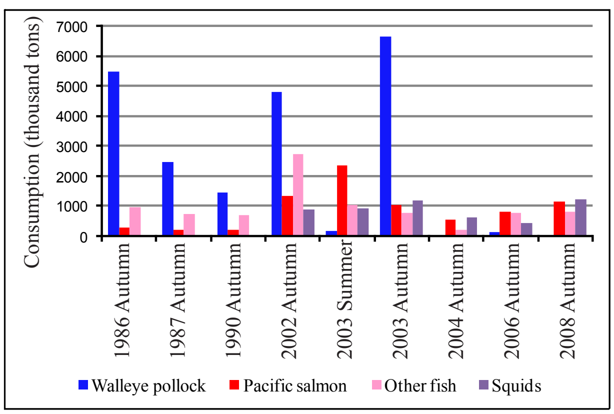

Fig. 1. The total consumption (thousand tons) of forage resources by nekton and Pacific salmon in the upper epipelagic layer in the western Bering Sea during summer 2003 and autumn 1986–2008.

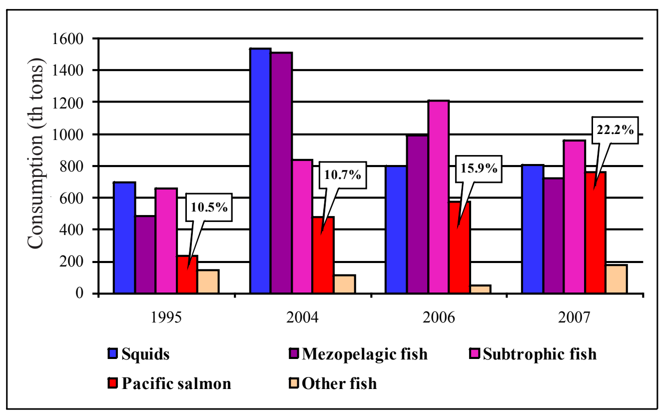

Fig. 2. The total consumption (thousand tons) of forage resources by nekton and Pacific salmon in the upper epipelagic layer of the Pacific waters of Kuril Islands during summer (from Naydenko 2010).

In comparison, Pacific salmon biomass has increased 2- to 4-fold since the 1980s. However, the role of salmon in the trophic structure of the upper pelagic layer is still not as important as that of pollock or sardine in years when these species are highly abundant (Figs. 1 and 2). Salmon consume a lower quantity of the forage resources than species of the low boreal-subtropic complex, or even of mesopelagic fishes and squids, during periods when these species are highly abundant (Naydenko 2002, 2009, 2010; Naydenko et al., 2010a, b).

All correspondence should be addressed to S. Naydenko.
e-mail: naydenko@tinro.ru

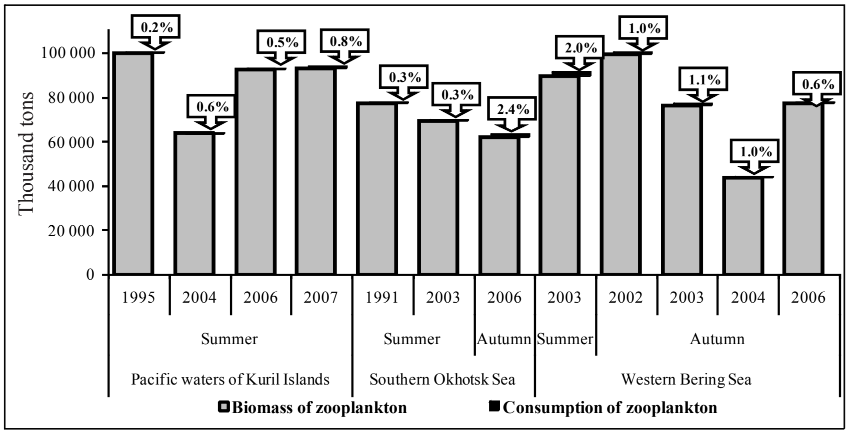

Fig. 3. The biomass of zooplankton (thousand tons, grey columns) and its consumption by Pacific salmon (arrows indicate %) in the upper epipelagic layer of different regions of the northwestern North Pacific, Okhotsk Sea and Bering Sea (data from Naydenko 2009, 2010).

Only during short periods of the pre-anadromous adult salmon migrations (e.g., in the western Bering Sea) beginning before the mass arrival of migrants from the south (e.g., Pacific waters of Kuril Islands), and during the period of post-catadromous juvenile migrations (e.g., October-December in the southern Okhotsk Sea) does salmon become the most important consumer of zooplankton resources, at least when there is a relatively low abundance of mesopelagic fish. In general, salmon (Fig. 3) and all nekton (Fig. 4) consume only a small portion of the total amount of zooplankton that is available.

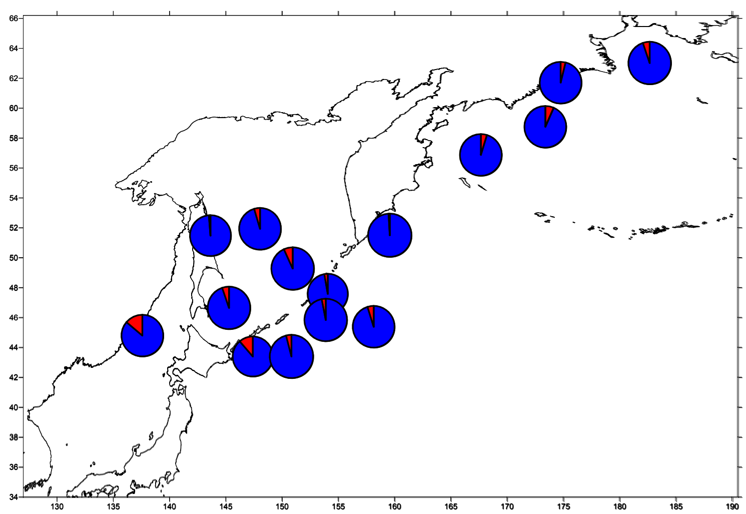

Fig. 4. The zooplankton stock (blue portion of the circle, %) and its consumption by nekton (red portion of the circle, %) in the upper epipelagic layer of different regions in summer.

Separation in space and time of salmon feeding from other consumers are important factors for preventing competition for food with other zooplankton consumers. In certain areas, some competition for food is possible where the feeding grounds overlap, but this is mitigated by plasticity and electivity of prey selection by salmon, as well as abundant forage reserves. A satisfactory food supply for salmon is provided by the stable and high value of their daily ration, which exists against a background of considerable fluctuations in plankton and nekton abundance. Salmon diet composition consistently show their preference to consume hyperiids, pteropods, and euphausiids. Examples of the diet composition (%) of pink and chum salmon in the Northwest Pacific in 1990s and 2000s are shown in Figs. 5 and 6.

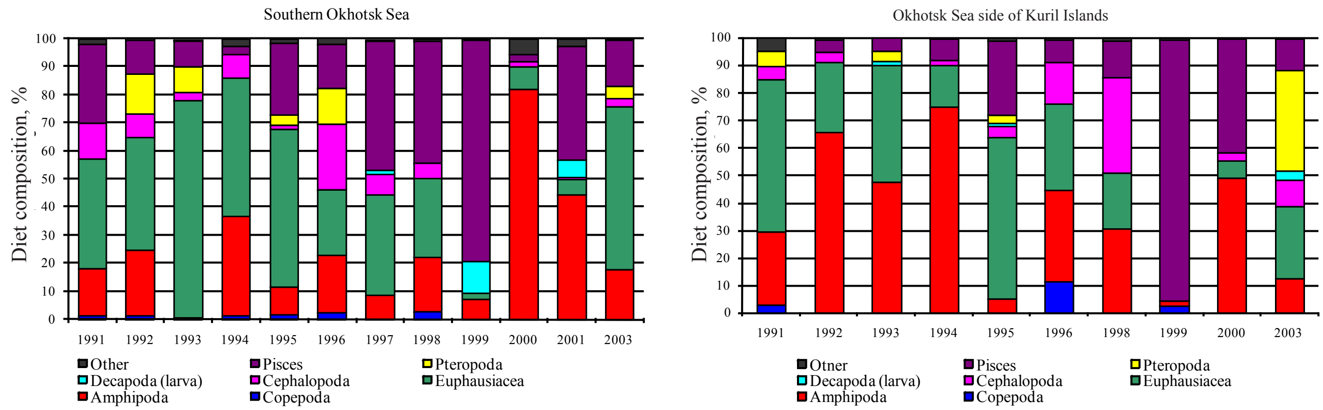

Fig. 5. The diet composition (%) of pink salmon in the Okhotsk Sea in summer, 1991-2003. The 2000s is a period of high pink and chum salmon abundance.

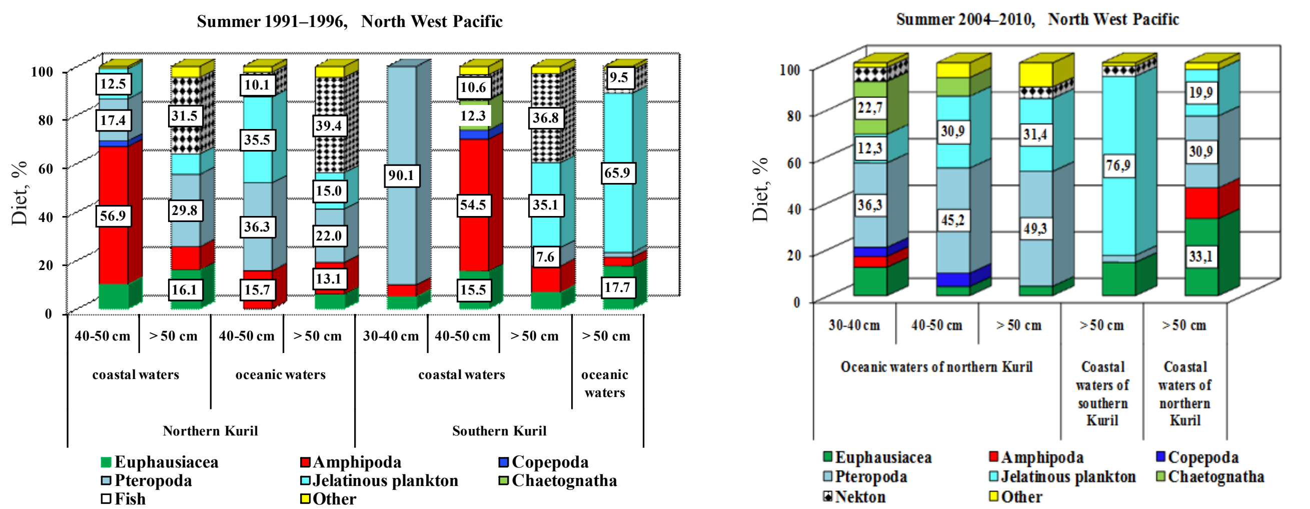

Fig. 6. The diet composition (%) of chum salmon in the Northwest Pacific in summer, 1991–1996 and 2004–2010. The 2000s is a period of high pink and chum salmon abundance.

Research surveys in the central and western North Pacific Ocean that were conducted by TINRO-Center during winter-spring 2009-2011 have provided valuable information on the food supply of salmon during that seasonal period. Plankton studies from the winter-spring cruises do not confirm the conclusions of previous research (Nagasawa 1999, 2000) about a considerable decrease in zooplankton biomass in winter. The biomass reported earlier indicated that mean monthly zooplankton biomasses in winter did not exceed 21.5-46.1 mg/m^3 (northern Pacific), 29.0-34.6 mg/m^3 (western Pacific) and 19.7-52.3 mg/m^3 (central Pacific) and concluded that poor food conditions exist in winter for salmon (Nagasawa 1999, 2000). Results from the TINRO cruises indicated that zooplankton biomass in the pelagic layer during the winter-spring period varied widely, and was higher than levels reported earlier (Fig. 7). The mean zooplankton biomass in the pelagic layer

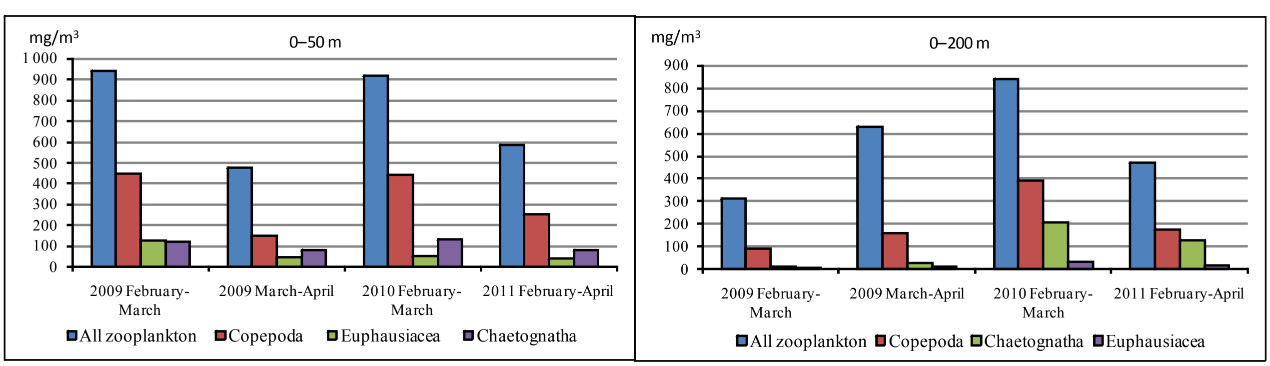

Fig. 7. The plankton composition and biomass (mg/m^3) in the pelagic layer (0–50 and 0–200 m) in the subarctic frontal zone in the North Pacific in February-April 2009-2011 (data from Naydenko et al. 2010 a, b; Kuznetsova and Efimkin 2010; Glebov et al. 2011).

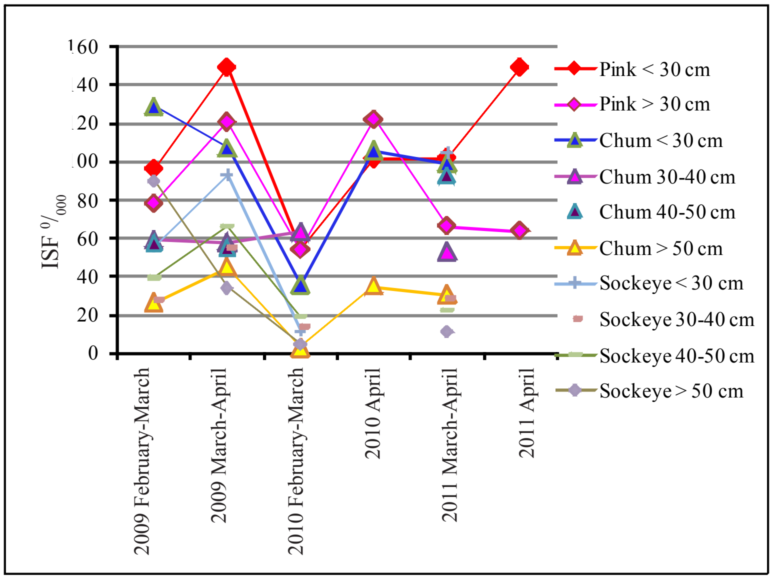

Fig. 8. The feeding intensity (ISF, °/$_{000}$) of Pacific salmon in the subarctic frontal zone in the North Pacific in February-April 2009–2011 (data from Naydenko et al. 2010b; Kuznetsova 2010).

(0-200 m) was estimated at 313 and 631 mg/m^3 (2009), 839 mg/m^3 (2010), and 470 mg/m^3 (2011), and that the biomass in the 0–50 m layer was higher than in the 0-200 m water column (Naydenko et al. 2010a, b; Kuznetsova and Efimkin 2010; Glebov et al. 2011). In winter-spring 2009–2011 the feeding intensity of salmon varied largely depending on fish size and time and location where fish were caught. The index of stomach fullness (ISF) of immature small-sized fish was higher than for large-sized fish (Fig. 8). Although the mean index of stomach fullness in winter-spring samples was lower than in summer-fall samples, the majority of fishes were observed to have a high feeding activity, suggesting the winter-spring is not period of fasting when food resources are scarce. Hyperiids, copepods, euphausiids and pteropods predominated in salmon diets during all research periods (Fig. 9). These results indicate there was sufficient and stable forage reserves for salmon during all seasons of the year.

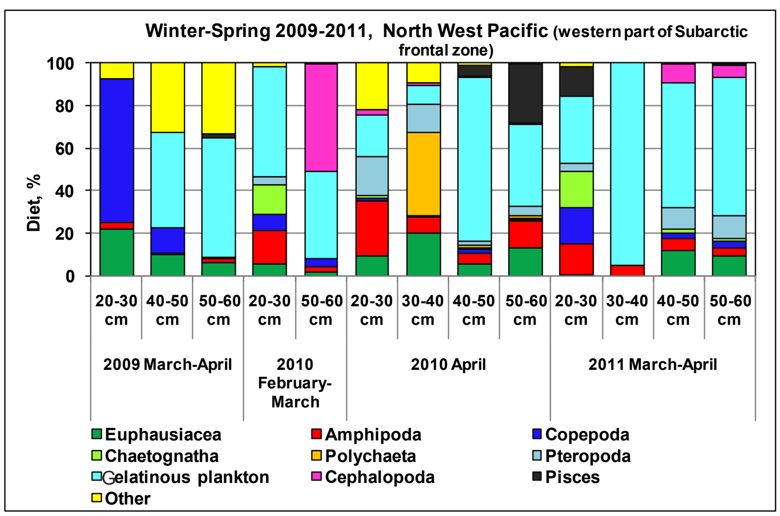

Fig. 9. The diet composition (%) of chum salmon in the subarctic frontal zone in the North Pacific in February-April 2009–2011 (data from Naydenko et al. 2010b; Kuznetsova 2010).

Conclusions based on these long-term data indicate that stable dependence of Pacific salmon abundance and marine survival on zooplankton abundance has not been observed. The feeding intensity of Pacific salmon is high despite substantial year-to-year variability of salmon abundance and zooplankton biomass. Selective and stable feeding on some prey items (hyperiids, pteropods, and some species of euphausiids and copepods) by the most abundant planktivorous salmon species (pink, chum, and sockeye) was observed in different seasons and years, and in different areas of the Russian Far Eastern seas and the northwestern Pacific Ocean. These conditions indicate sufficient food resources for salmon. At the same time, it is necessary to mention that there are certain regions where some competition for food is possible in the local foraging environment. Competition for food is also possible in estuarine and coastal or shelf environments, but these areas were not considered in this research.

On the whole, the portion of forage resources consumed by salmon is insignificant, and the recent rise in salmon abundance scarcely causes serious restructuring of the trophic structure of the upper pelagic layer of the Russian Far East seas and Northwest Pacific. Indeed, population fluctuations of the dominant consumers lead to changes in the trophic structure. However, even if there are multiple shifts in the biomass of those species characterized by large fluctuations, such as pollock, herring, capelin, sardine, scomber, anchovy, and Japanese flying squid, the result in merely the fitting and adjustment of trophic relations and energy transfer that does not cause crises in the pelagic community.

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