Inter-Annual Dynamics of Pink Salmon Abundance in the Sea of Okhotsk Populations in the 1990s

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In the 1990s, large-scale changes (now called "regime shifts") took place in the pelagic ecosystems of the far-eastern seas. At this time, some relations between global physical factors and salmon stocks have been analyzed and considered. This led to general conclusions that salmon production must also change in the near future. Since salmon abundance was relatively high in the late 1980s, a forthcoming decrease has been predicted (Beamish and Bouillon 1993; Chigirinsky 1993). However, in the 1990s, pink salmon catches were as high in the Russian Far East as in Alaska. This fact attracts special attention to the issue of inter-annual dynamics of Asian pink salmon abundance.

To better understand my paper, I define some of the terms used below. Young pink entering the sea are called "outmigrants." Pink salmon in their first fall and winter are called "juveniles." I also define "immature" pink salmon as those fish that occur in the Pacific before the start of their anadromous (adult) migrations. "Maturing" fish are those in their last summer of ocean migrations, "mature" salmon are those approaching the coast and coastal fisheries, and "spawners" are adult fish on the spawning grounds.

In the 1990s, data were collected from the Sea of Okhotsk populations on all basic stages of pink salmon life history. In 22 research vessel cruises, data to estimate juvenile and maturing pink salmon abundance were collected. Surveys were conducted by pelagic trawl (108/528 m). The horizontal diameter of the trawl mouth was about 50-55 m, and the vertical opening was 45-50 m. The highest tow speed (4.5-5.0 knots) was maintained. Wire length, which reflects distance from the trawl to vessel, was 350-400 m. The upper trawl panel was kept on the sea surface.

Salmon biomass and numbers were calculated by the square method (Shuntov et al. 1988). The formula for this method is as follows: $B(orN) = \frac{Sq}{sk}$; where B - fish biomass, N – numbers, S - investigated area, q - average catch on survey area, s - the area swept during a 1-hour haul, k - factor of trawl catchability. The factor k takes into account the body size, form, and motility of fish, and their propensity to schooling. On the basis of long-term experience, the factor k value for salmon is 0.3. The data on spawners and outmigrants numbers were provided by Drs. A. Kaev (Sakhalin NIRO) and S. Sinyakov (Kamchatka NIRO). Harvest data are based on fisheries statistics.

In 1992-1993, some disturbances were observed in the stock dynamics of all regional groupings of pink salmon. On the eastern Sakhalin coast, there was an unexpectedly low pink salmon catch in 1993. In the Kuriles region, the catch level became almost stable in 1994-1997, after the catch decrease in 1993. However, there was a slight predominance of the even-year race. Among secondary pink salmon stocks, the northern Okhotsk Sea coast population estimates of mature pink salmon and harvest in 1992 and 1993 increased sharply. There was a noticeable increase in the western Kamchatka pink salmon stocks in 1994 and 1996. Estimates of mature fish increased to 130-140 million fish. The enhanced Hokkaido pink salmon population acquired a two-year cyclisity in that time, despite the almost equal numbers of smolts that were released annually (Table 1). The total estimate of mature Okhotsk Sea pink salmon in even years increased sharply in 1994 (215 million fish), and the even-year runs were higher than odd-year runs.

The predominance of the even-year race of pink salmon since 1994 was evident from the early 1990s, as can be seen in the higher estimates for outmigrants of these generations (Table 1). After 1992, this predominance was set at a level of 1 to 2.4 billion fish.

Another unexpected circumstance was the sharp increase in the estimated numbers of pink juveniles in the offshore waters of the Okhotsk Sea and North Pacific Ocean since 1993, which were approximately three times higher than 1991-1992 estimates. Before 1993, natural mortality of pink outmigrants before late fall appeared rather high (92.8-94.1%). After 1993, survival rates were stable for two even years (30.5-30.7%) and for two

Table 1. Total estimate of pink salmon abundance (millions of fish) of the Okhotsk Sea populations at various life history stages in 1990s.

Year	Spawners	Outmigrants, Russian coast:	Release by Japan	Total Outmigrants	Pelagic estimates: Juveniles fall	Pelagic estimates: Maturing summer	Mature to Russian coast	Mature to Japan coast	Total Mature	Russian Catch, (tons $^{\times}10^3$)
1990	42.1	3364	130	3494	450	n/a	78.1	5.5	83.6	50.4
1991	51.2	4119	136	4255	250	277.0	154.6	12.4	167.0	129.3
1992	25.7	3764	132	3896	279	103.7	70.9	15.6	86.5	67.8
1993	57.0	4938	138	5076	882	107.0	91.4	17.1	108.5	48.8
1994	109.8	2488	140	2628	807	271.0	195.4	19.6	215.0	103.6
1995	34.7	4855	140	4995	834	230.0	96.4	9.6	106.0	89.5
1996	81.6	3157	118	3275	1000	210.0	148.0	19.1	167.1	88.0
1997	38.9	4115	138	4253	n/a	n/a	165.8	6.1	171.9	102.3

odd years (16.7-17.4%). According, pink survival in ocean gradually declined during the 1990s. Estimates of maturing pink salmon varied from those of juveniles by 61.6% in 1991 to 25.2% in 1996. Catch and escapement varied from the previous fall pelagic estimates by 38.9% in 1993 to 13.7-14.1% (with the lowest value in 1995).

Two pairs of time-series estimates of pink numbers display high correlation with one another ($R > 0.7$), the results of fall and summer surveys and also the results of summer surveys and estimates of total mature pink salmon. The high correlation between fall and summer surveys demonstrates the gradual increase in natural mortality rate during the ocean phase. These results suggest that this increase is determined by some large-scale factor or process developing from year to year, which may be related to changes in the North Pacific pelagic ecosystems. It can be noted that numbers of spawners are not correlated with any other time series. Furthermore, the correlation coefficients gradually decrease from outmigrant numbers to estimates of mature pink salmon.

Growth rate of pink salmon was described by a logarithmic relationship between pink salmon body weight and dates of year for eight months after sea entrance (Fig. 1A). In summer, growth rate is noticeably higher than in fall and winter. Therefore, in Fig. 1B a shorter period for inter-annual comparisons of juvenile pink salmon growth is used. In this case, growth in weight can be approximated by linear regression: $y = 2.3177x + 164.09$. The mean pink salmon body weight for January 1 was calculated as follows: $y = 2.3177*15 + 164.09 = 198.9$ g (15 is number of 5-day periods in the time interval).

The calculations indicate that the weight of pink juveniles in even years changed from 164.7 to 186.2 g by January 1 (after 1992). This emphasizes the close relation between mean body weight and outmigrant numbers. The smallest juveniles occurred after the most abundant downstream migration in 1993 (4.94 billion fish). The biggest juveniles – 226.9 g, or at 28 g above average, were caught after the lowest number of outmigrants in 1994. Maturing pink salmon were also largest in 1995; mean weight in coastal catches was 1.45 kg for the Okhotsk Sea coast stocks. On the whole, pink salmon generations spawned in 1994-1997 demonstrated a good correlation between initial body weight of juveniles and final body weight of mature fish. In contrast, in 1991-1992 the body weight of spawners was more likely related to numbers of maturing and mature pink

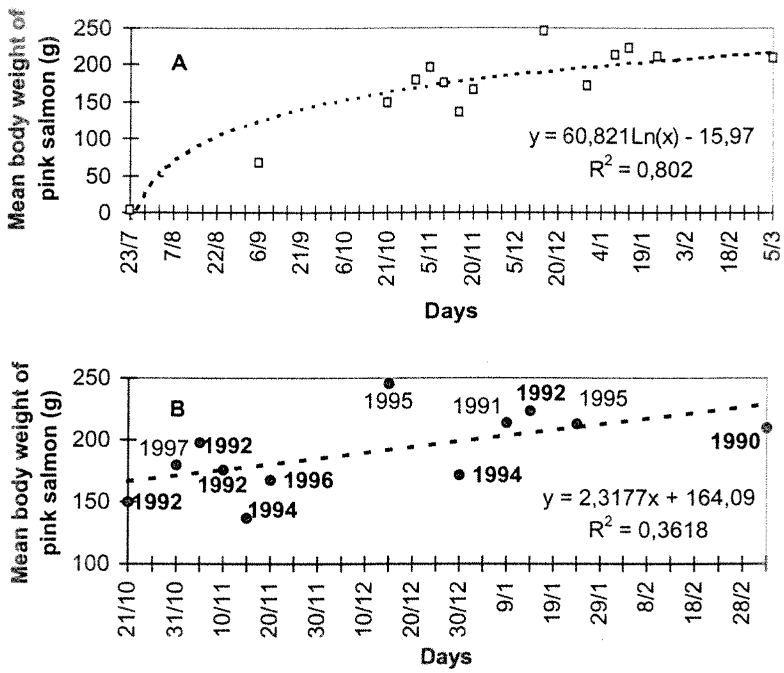

Fig. 1. Mean body weight (g) of pink salmon juveniles during oceanward migration through the southern Okhotsk Sea in the 1990s. (A) Approximated from late June; (B) Approximated from late October to early March.

salmon. According to coastal fishery statistics, mean body weight was 1.25 kg in 1991, which was a high-yield year and 1.50 kg in 1992, a low-yield year, despite the almost equal body weight of juveniles in both years.

Significant fluctuations in pink salmon numbers and body weight in the 1990s suggest that processes of large-scale changes are not finished in Okhotsk Sea pink salmon populations. There is some evidence that the environmental conditions for pink salmon feeding routes in the ocean may be less favorable in the 1990s than in 1980s (Beamish and Bouillon 1993). Secondly, salmon juveniles have become the ordinary prey for common predatory species of fish and mammals because of their high abundance.

Change in the mean weight of pink salmon is mainly related to their population density during the ocean phase. Asian pink salmon are usually larger in years of low numbers of mature fish than in adjacent years (Shuntov 1994). However, in the 1990s no relation was found between body weight of juveniles and their survival in ocean. From the time of sea entrance to late fall, survival was higher for smaller and more abundant outmigrants in 1993 and 1995.

For analysis of environmental change and its influence on salmon stocks, it is important to determine what large-scale changes in climate and hydrological regimes of the Okhotsk Sea and North Pacific Ocean took place in 1991-1993. At that time, the most significant changes were observed in salmon abundance dynamics, survival, and body weight.

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