Production Trends of Pink Salmon in the Sakhalin-Kuril Region from the Viewpoint of Run Timing

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There are two abundant species of Pacific salmon in the Sakhalin-Kuril region: pink and chum salmon. This paper presents information only on pink production trends because changes in chum salmon abundance are determined mainly by the activity of hatcheries (Kaev 2010a). Pink salmon exhibit rapid growth, short life, and great variability in their abundance, so this species attracts the attention of researchers as a possible indicator of environmental processes. Southern areas of the Sakhalin-Kuril region are important because these areas have a high abundance of pink salmon and the longest continuous record of pink salmon biological data. For this analysis, stocks were analyzed from three southern areas in the region, southeastern Sakhalin, Aniva Bay, and Iturup Island (Fig. 1).

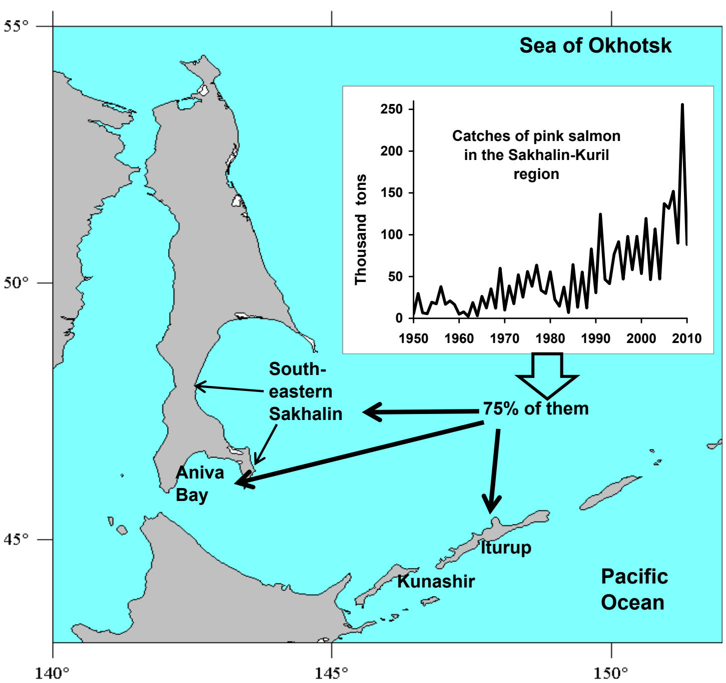

Fig.1. Study area of pink salmon biological characteristics in south-eastern Sakhalin and Iturup Island and catches of pink salmon in the Sakhalin-Kuril region (inset).

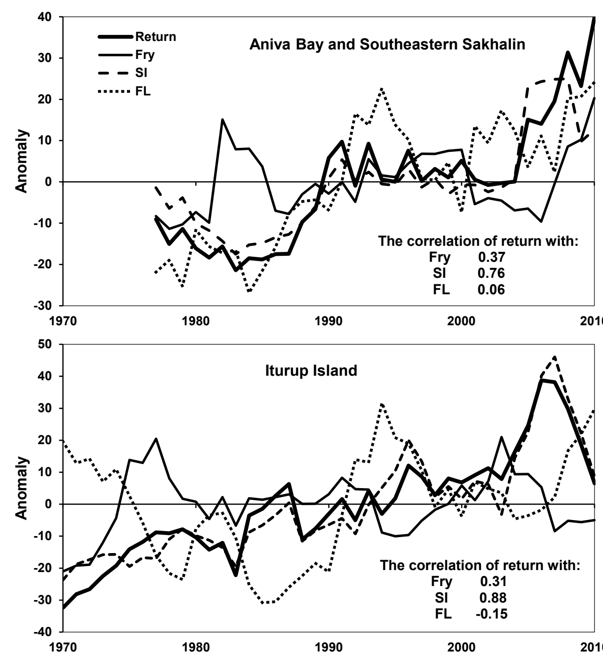

Fig. 2. Annual changes in fry abundance (Fry), adult returns (Return), marine survival (SI), and fish length (FL) for south Sakhalin and Iturup Island pink salmon, 1970-2010.

In the past 20 years, there has been a high abundance and large body size of pink salmon returning to South Sakhalin and Iturup Island (Fig. 2). For a better view of long-term changes, the data are presented as a 4-year running average because pink salmon have odd- and even-numbered year generations. High correlations should be expected between returns and a marine survival index, and low correlations expected between returns and fry abundance and fish length. Many researchers have compared changes in Pacific salmon abundance with global climatic indices. For example, a detailed report on chum salmon abundance related to climate was presented by Kaeriyama et al. (2009). I want to draw attention to environmental conditions as they relate to pink salmon abundance and biological characteristics.

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The following indicators were used for the analysis.

Reproduction Index (RI): Ratio between the number of downstream pink fry migrants and the number of pink salmon escapement for spawning (SakhNIRO data).

Survival Index (SI): Percentage of pink salmon returns to the total number of wild and hatchery fry migrants (SakhNIRO data).

Cold Type (CT): Number of "cold" decades in atmospheric processes over the Okhotsk and Japan Seas in October-March (TINRO-Center).

Pacific Decadal Oscillation (PDO): Pacific Decadal Oscillation (University of Washington: http://jisao.washington.edu/pdo).

Sea Surface Temperature (SST): Temperature in summer and autumn in the southern Okhotsk Sea (NOAA Earth System Research Laboratory: NCEP/NCAR Reanalysis Project).

Wolf number (W): Numerical index of the number of sunspots (The Solar Influences Data Analysis Center, SIDC).

Let's consider the correlation between changes in pink salmon indices and the "cold type" winter index (Table 1). I regard the reduction in generations that survived in cold winters as a casual coincidence in the general process of forming the abundance of pink salmon. The correlation between the number of cold winters and fry abundance is weak and has different signs for Iturup and Sakhalin. In addition, cold or warm winters have no significant effect on survival for the period between downstream migration and spawning (RI).

Table 1. Correlation between the number of "cold" decades in winter and pink salmon reproduction index (RI), abundance of pink fry migrants (Fry), and return of adult pink salmon to South Sakhalin and Iturup Island (Return).

Area	Actual values			Trends (related to 4 values)		
	RI	Fry	Return	RI	Fry	Return
South Sakhalin	-0.04	-0.08	-0.38	-0.23	-0.40	-0.64
Iturup Island	0.03	0.13	-0.17	-0.09	0.14	-0.30

Next let's consider the correlation between changes in pink salmon indices and the PDO (Table 2). Please note the following nuances. Correlation with the PDO is weaker for survival rates than for abundance of pink salmon returns. Clearly, pink salmon returns first depend on fry abundance and then on their marine survival. The relationship between the PDO and abundance and survival of pink salmon from the different areas vary, and the correlation with fish length is almost equal for the two areas. It is clear that similar changes in fish length reflect similar habitat conditions in the open sea. The index of survival seems to be more associated with the coastal lifespan, where local provincial factors are of great importance.

Table 2. Correlation between the PDO (winter-summer) and abundance of pink fry migrants (Fry), marine survival (SI), return of adults (Return), and pink salmon fork length (FL) of fish returning to South Sakhalin and Iturup Island.

Area	Actual values				Trends (related to 4 values)			
	Fry	SI	Return	FL	Fry	SI	Return	FL
South Sakhalin	-0.00	-0.25	-0.47	-0.18	-0.24	-0.53	-0.71	-0.48
Iturup Island	-0.03	0.07	0.05	-0.16	0.23	0.21	0.29	-0.44

Correlations between Sea of Okhotsk sea surface temperatures (SST) and pink salmon indices indicate the relationship with adult returns was higher than with survival (Table 3). The relationship between SST and the survival index was stronger than survival with cold winters (Table 1) or the PDO (Table 2), but the relationship between SST and survival was insufficient for reliable forecasting because of the large variance in some years (Fig. 3).

Table 3. Correlation between sea surface temperatures (SST) in the Sea of Okhotsk and marine survival (SI), return of adults (Return), and pink salmon fork length (FL) of fish returning to South Sakhalin and Iturup Island.

Areas	Actual values			Trends (related to 4 values)		
	SI	Return	FL	SI	Return	FL
South Sakhalin	0.44	0.59	0.19	0.58	0.79	0.60
Iturup Island	0.29	0.31	0.25	0.58	0.56	0.55

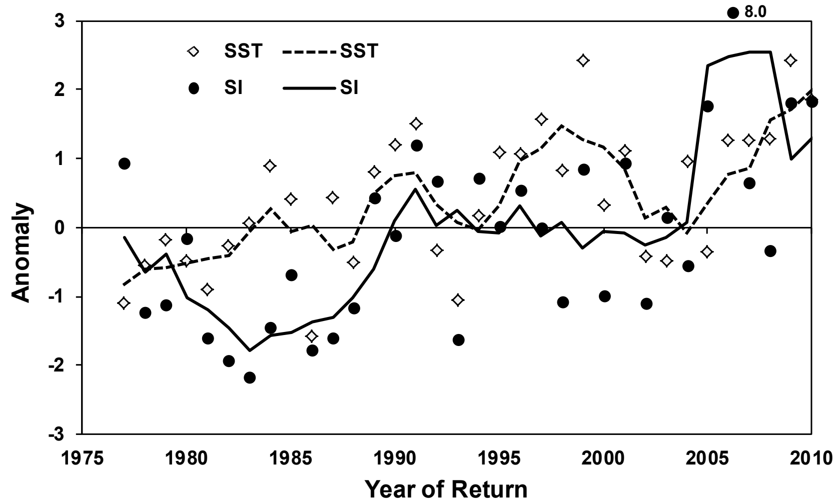

Fig. 3. Annual changes in marine survival (SI) of pink salmon from southern Sakhalin and sea surface temperature (SST) in the southern Okhotsk Sea, 1977-2010.

When compared with global climate indices, the same (positive or negative) changes in pink salmon from different areas are noted for fish length, which is explained by their living in similar conditions in the ocean. But changes in the timing of pink salmon approaches to the coast are worth considering. Changes in direction of long-term trends in pink length and migration timing occur more or less simultaneously for pink salmon in different areas. However, the coherence of changes in pink salmon migration timing in different areas is easily criticized because the correlation is much weaker (0.29) than the relationship between changes in fish length (0.79).

When studying these trends and relationships (e.g., Tables 1, 2, and 3), indices characterizing the whole stock of pink salmon are generally used. However, a stock of pink salmon is not uniform. In Eastern Sakhalin and Iturup Island, there are two forms of pink salmon: an early and a late migratory form that follow each other in return to freshwater. Until now, these forms have been most heavily studied in two areas: Aniva Bay and Iturup Island (Kaev 2010b). To identify the different forms, catch dynamics, proportion of males, and fish length are used. The appearance of the late form is usually accompanied by a significant increase in male size, while the length of females may remain unchanged. Pink salmon females of the late form have a lower fecundity per unit body length, but absolute fecundity may not change very much. The ratio of early to late forms in the migratory flow of pink salmon to Aniva Bay and Iturup Island may vary greatly by year (Fig. 4).

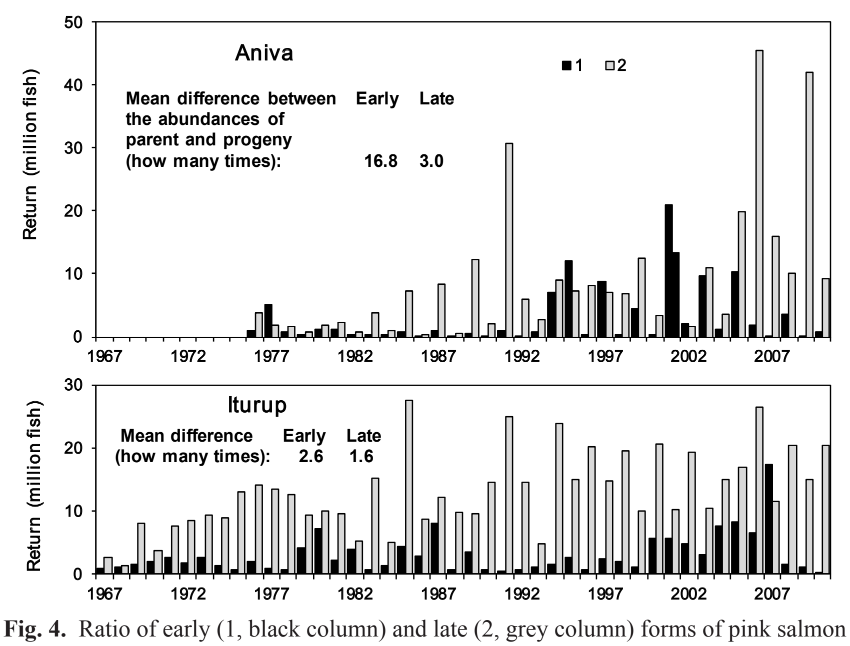

Fig. 4. Ratio of early (1, black column) and late (2, grey column) forms of pink salmon in Aniva Bay and Iturup Island, 1967-2010.

Annual changes in pink salmon length and migration timing for the two areas were calculated for the total run of fish and separately for the late form (Fig. 5). Regarding the late form of pink salmon, changes in fork length and particularly in migration timing have become more coherent in the two areas. Judging from the fact that mean abundance of the early form is lower and annual variability is greater (Fig. 4); the larger number of eggs produced by early-form females reflects a higher mortality. Long-term trends in abundance of both forms in Aniva Bay and on Iturup Island are weakly correlated with climatic indices and with area.

For a long time, it was not clear why researchers have failed to identify a pink salmon biological response to counteract worsening ocean feeding conditions, as has been shown for chum salmon. But this study of early and late forms of pink salmon has provided some interesting results on this subject. I observed that females become relatively larger than males when growth is slowed (Kaev 2010b). As there is a positive relationship between female length and fecundity, this feature may be a population response that supports reproduction when feeding conditions change for the worse.

Study of the early and late forms of pink salmon has yielded another result. Direction (positive or negative) of long-term fluctuations in the proportion of the two forms coincide with each other only for particular time periods in the areas studied (Aniva Bay and Iturup Island; Fig. 6). Fluctuations in abundance over time indicate the early form of pink salmon is less resistant to environmental change. A synchronous decline in the proportion of the early form in several areas can be viewed as a warning of a forthcoming reduction in the total abundance of pink salmon. During a previous synchronous decrease in the proportion of the early form, pink salmon abundance declined in the 1980s, especially on Sakhalin, and there was a change in the dominant pink salmon line on Iturup Island in 1993. Since 2005, a synchronous decrease in the proportion of the early form has been observed. This may forecast a future reduction in total pink salmon catches, and it seems that this process has already started.

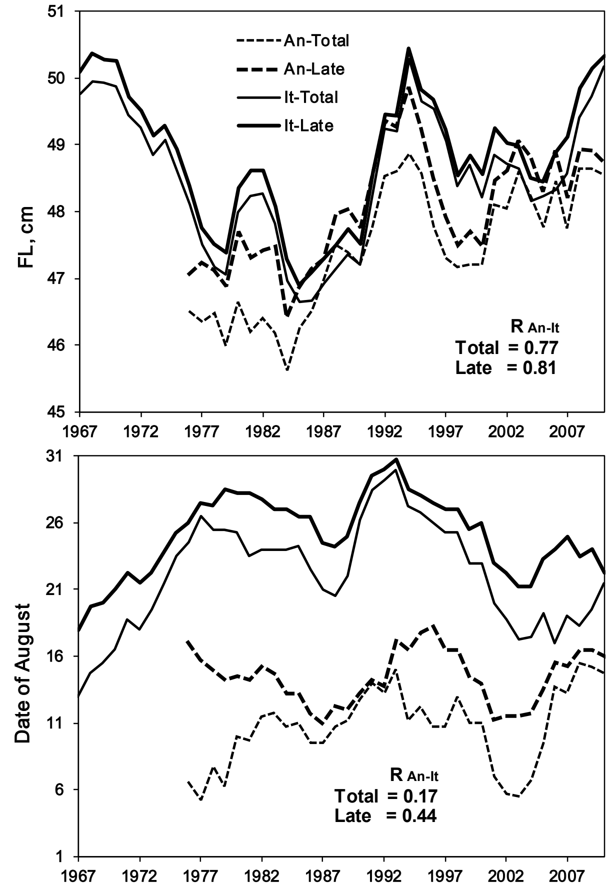

Fig. 5. Annual changes (smoothed as the 4-year running average) in the total run (Total) and the late form (Late) of pink salmon fork length (FL; upper panel) and migration timing (D: date of 50% capture; lower panel) in Aniva Bay (An) and Iturup Island (It), 1967-2010.

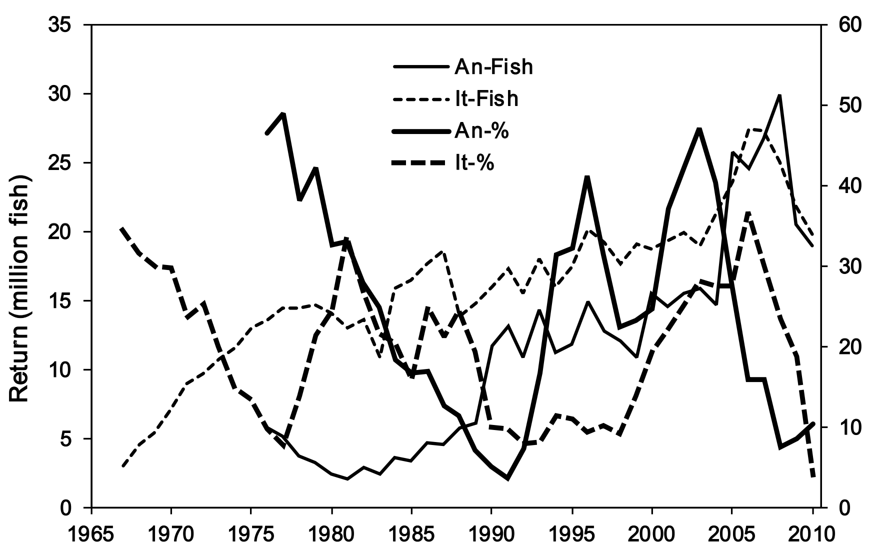

Fig. 6. Annual changes (smoothed as the 4-year running average) in return (Fish) and proportion of the early form of pink salmon (%) in Aniva Bay (An) and Iturup Island (It), 1967-2010.

According to some researchers (e.g., Sukhanov and Tiller 2000) the 11-year solar cycle is related to long-term changes in salmon abundance. As noted, there have been decreases in catch dynamics during which a short-term or periodic change in dominant lines has occurred that coincided with solar activity maxima (Fig. 7). The next-to-last decrease occurred during a decline in solar activity, and the last decline occurred during a solar activity minimum. I interpret this to mean there is no explicit synchronization between solar activity and pink salmon abundance in the southern Sakhalin area.

The magnitude of recent fluctuations in abundance between parent and progeny generations and between even- and odd-year lines is striking. These abrupt changes in catch are a sign of environmental instability that coincided with a subsequent synchronous decline in the proportion of the early form of pink salmon in different areas. If this hypothesis is true, the statistical evidence will not be available soon. Currently, this is only my intuitive sense of the link between the environment and pink salmon abundance. I proceed with the assumption that pink salmon respond to environmental processes earlier than we will notice these processes. After all, pink salmon experience and respond to the environment quicker than we can observe it with our standard research methods (Rachlin et al. 1987).

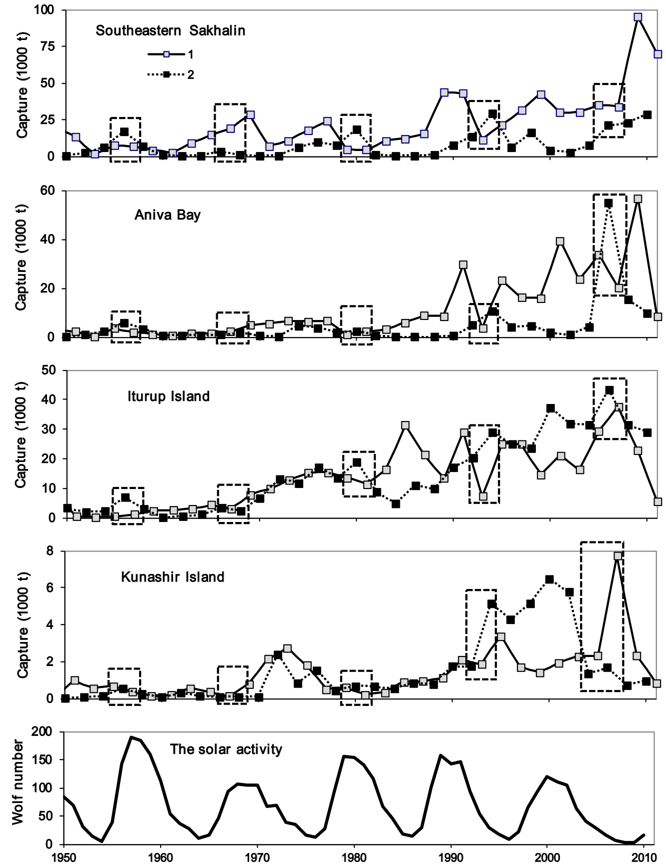

Fig. 7. Solar activity and dynamics of pink salmon catches in odd- (1, grey squares) and even- (2, black squares) numbered years in southern areas of the Sakhalin region, 1950-2011. Boxes highlight synchronous decreases and a shift in the dominant line of pink salmon.

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