The Association of Long-Term Changes in West Kamchatka Pink Salmon Catches with Climate Regime Shifts in the Northern Hemisphere

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In this study, an attempt was made to consider how multi-decadal changes in the state of Russian Far East salmon stocks are related to the leading large-scale climatic patterns in the Northern Hemisphere. As an example, we used information on pink salmon stocks originating from West Kamchatka (WK), and based our study on data from the 1951-2010 period. The data included monthly mean sea surface temperature anomalies (SSTA) from the ERSST v. 3b data set, geopotential heights at the 500-hPa surface from the NCEP/NCAR Reanalysis, monthly values of various climatic indices in the Northern Hemisphere, and catch statistics for WK pink salmon stocks.

During the 1950s, WK pink salmon catches dropped sharply from more than 100 thousand tons (in odd-numbered years) to a few thousand tons, and catches continued at a very low level until the early 1970s, when they started to increase (Fig. 1). The catches in odd-numbered years increased until 1983, when catches declined to very low levels. The period from 1984 to the present time is characterized by the predominance of pink salmon returning to West Kamchatka in even-numbered years. Catches of even-year pink salmon started to rise sharply in 1994, reached a maximum in 1998, and catches have remained at a high level until the present.

We separated our analysis into two periods: from 1951 to 1988, when odd-year generations were dominant, and from 1972 to 2010 when, in general, even-year generations dominated. Although the early part of the second period was dominated by odd-year returns, our selection for the year beginning the second period was made for two reasons. The first reason was to make the length of the pink salmon catch time series of both odd- and even-numbered years the same, and the second reason was that the correlation coefficient between the catches of odd and even years during 1971-1984 exceeded 0.90.

The most prominent feature of the correlation pattern between the WK pink salmon catches in odd-numbered years and the mean winter (January-April) SSTA field in the North Pacific and North Atlantic was the existence of a pronounced meridional dipole east of the North American coast, with the centers along 50°N and 30°N (Fig. 2a). In the North Pacific, the correlation pattern was characterized by an extensive domain of positive correlations stretching from the southwestern part of the ocean to the northeastward, which was surrounded by areas of negative correlations to the north, east, and southeast. However, these correlations were generally weaker as compared to the correlations calculated for the North Atlantic. The centers of positive and negative correlations in the southwestern North Pacific and the southern Sea of Okhotsk, respectively, might be considered as a dipole similar to that for the North Atlantic, but with inverse polarity.

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Fig. 1. West Kamchatka pink salmon catches for fish returning in odd-numbered and even-numbered years, 1951-2011.
The described pattern corresponds to the EOF2 (10% of total variance) of the combined North Pacific and North Atlantic SSTA field, but with the opposite sign (Fig. 2b). The North Atlantic dipole was expressed rather well. In the North Pacific, the correlations were generally stronger, as compared to those in Fig. 2a. However, the dipole in its western part of the North Pacific was weaker. Instead, there was evidence of opposite SSTA variations between the central North Pacific and the Gulf of Alaska. This resembles the North Pacific Gyre Oscillation pattern (NPGO; Di Lorenzo et al. 2008) in its negative phase.

The EOF2 pattern in the North Atlantic can be further interpreted as the four-pole structure described by Krovnin (1995) on the basis of his cluster analysis of data from the 1957-1991 period. In his study the correlation coefficient between the first principal component (PC) of the two time series representing the anomalies averaged over the northwestern and southwestern regions in the North Atlantic and catches in odd years was -0.58 (p<0.05).

The time series of EOF2 PC scores and WK pink salmon catches in odd-numbered years in 1951-1988 indicated that catches started to increase after 1973, following the shift of the EOF2 phase from negative to positive (Fig. 3).

![Fig. 2. Correlation pattern between West Kamchatka pink salmon catches in odd-numbered years and the mean winter (January-April) SSTA field in the North Pacific and North Atlantic (a, upper panel); pattern of the corresponding EOF2 (10% of total variance) of the SSTA field (b, lower panel) during the 1951-1988 period.](image)

![Fig. 3. Time series of PC2 scores that represent 10% of the total variance (a, upper panel) and West Kamchatka pink salmon catch (tons) in odd-numbered years, 1951-1988 (b, lower panel).](image)
The correlation pattern between the WK pink salmon catches in even-numbered years and the SSTA field for the 1972-2010 period was characterized by high positive correlations covering most of the North Atlantic (positive phase of the Atlantic Multidecadal Oscillation (AMO); Fig. 4a). In the North Pacific, a tongue of high positive correlations stretched from the Asian coast eastward in the area south and southeast of Japan. Domains of strong and weak negative correlations were located to the northeast and southeast, respectively, of the area of high positive correlations. A comparison of the map with the patterns of the leading EOFs of the combined SSTA field showed almost complete coincidence with the EOF1 pattern, which explained 29% of the total variance (Fig. 4b).

The combined analysis of the EOF1 pattern and correlation pattern between the EOF1 PC and geopotential heights at the 500-hPa surface for the 1972-2010 period showed that the EOF1 was associated with simultaneous development and following establishment of the positive phases of the Atlantic Multidecadal Oscillation (AMO) and North Pacific Oscillation (or NPGO-like SSTA mode).

Fig. 4. Correlation pattern between West Kamchatka pink salmon catches (even-numbered years) and the SSTA field in the North Pacific and North Atlantic (a, upper panel); pattern of the leading EOF1 (29% of total variance) of the SSTA field (b, lower panel) during the 1972-2010 period.

Fig. 5. Variations in the Atlantic Multidecadal Oscillation (AMO) index, 1856-2009 (a, upper left panel); West Kamchatka pink salmon catches in even-numbered years, 1952-2010 (b, lower left panel); correlation coefficient between cumulative sums of total Russian Far East pink salmon catches and the AMO index, 1971-2010 (c, right panel).
The positive and negative phases of the AMO index for the 1856-2009 period are demonstrated in Fig. 5a. The present positive phase was established in 1995, and the sharp increase in salmon catches was observed between 1992 and 1994, i.e., at approximately the same time (Fig. 5b). Moreover, the correlation coefficient between the cumulative sums of the AMO index and anomalies of total catch of all Russian Far East pink salmon stocks during 1972-2010 was 0.91 (Fig. 5c). Thus, the change in phase of the large-scale mode of SSTA variability in the Northern Hemisphere resulted in changes in state not only of West Kamchatka pink salmon stocks, but also of other Russian Far East pink salmon stocks independent of the predominance of odd- or even-year generations.

The important question is how long the current period of high Russian Far East salmon catches will continue. Our analysis showed that high catches coincided with the simultaneous development of positive AMO and NPGO-like phases in the North Atlantic and North Pacific, respectively. Though the values of correlation coefficients between the WK pink salmon catches and SSTA during 1972-2010 were stronger in the North Atlantic, it is obvious that the AMO cannot directly affect Far East salmon stocks. Rather, the correlations may be considered an indicator of large-scale climate variations. The stocks are affected by the physical processes existing in the North Pacific, and the beginning of a climate regime shift there may not coincide with a shift in the North Atlantic. Analysis of the SSTA field for 2011 provides evidence of a change in the dominant mode of SSTA variability in the North Pacific with establishment of a negative PDO-like pattern, while the positive AMO phase in the North Atlantic will continue (as expected) until the mid 2020s. Apparently, observed changes in the North Pacific may lead to a sharp decrease in Russian Far East salmon catches in the coming years.

REFERENCES