Long-term Climate Change and Pink Salmon Stock Fluctuations

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Klyashtorin, L.B., and F.N. Rukhlov. 1998. Long-term climate change and pink salmon stock fluctuations. N. Pac. Anadr. Fish Comm. Bull. No. 1: 464-479

Northern Hemisphere surface air temperature anomaly (dT) and Aleutian Low Pressure Index (ALPI) are highly variable and have not reliable correlation with Pacific salmon and Pink salmon abundance for the period 1920-1995. Atmospheric Circulation Index (ACI) by G. Wangengeim method correlate closely with Pacific salmon, Pink salmon and a number of Pacific commercial stock dynamics (Japanese , Californian and Peruvian sardine, Alaska Pollock and others).

This allows us to suppose a principal cause of long-term fluctuations in Pacific salmon and pink salmon abundance is oceanic climate conditions. The close relationship was observed between high- and low abundant pink salmon generation in Asian and not American stock. The new approach is proposed on this basis to forecast inter-annual pink salmon stock fluctuations for Kamchatka and Sakhalin regions and for Asian pink salmon as whole.

INTRODUCTION

Pacific salmon catches fluctuated throughout this century with highest catches registered in the late 1930s and early 1990s and lowest ones in the period from 1950-60s. At the same time there were large changes in abundance in three sardine populations in the Northern and Southern Pacific oceans (Kawasaki 1992 a,b, 1994). Recent studies (Beamish & Bouillon 1993; Francis & Hare 1994; Klyashtorin & Smirnov 1995) have shown that fluctuations of Pacific salmon stocks correspond to long-term change in Global Climate. Following Beamish and Bouillon (1993) we believe that salmon catch statistics in vast region reflects, in general, salmon stock dynamics. An important problem still remains to be answered, however, which is to find a relative method of predicting long term changes in the stock dynamics of Pacific salmon in general and pink salmon in particular. For pink salmon, sharp inter-annual variations in catches are well known feature of its stock dynamics (Heard 1991).

The purposes of the study therefore are the following: 1. To identify climatic variables that can be reliably correlated with long-term salmon stock dynamics. 2. To demonstrate a way to predict long-term fluctuations of total Pacific salmon and pink salmon stocks. 3. To outline new approaches for prediction of inter-annual changes in pink salmon abundance.

DATA AND METHODS

Reliable commercial statistics for Pacific region are-available since 1920s. Main sources of statistical data used in this paper are: F.A.O. Yearbook of Statistics (1957-1994), Statistical collected volume (1989), and Klyashtorin & Smirnov (1992). Global data on air surface temperature anomaly (dT) were taken from (Halpert et al. (ed.) 1994). Aleutian Low Pressure Index (ALPI) is used as a characteristic of historical weather over the North Pacific Ocean. ALPI is calculated as the area (mln. of square kilometres) of the North Pacific Ocean covered by Aleutian Low Pressure system enclosed by the isobar of 100.5 kPa. Annual values of ALPI since 1900 were taken from Beamish & Bouillon (1993). The index of the general circulation of the westerly winds, or the Atmospheric

Circulation Index (ACI) in the Atlantic-Eurasian region was determined by the method of Wangengeim-Girs method (Girs 1971). The indices of temperature anomaly (dT) and Aleutian Low (ALPI) are quite common climatologic characteristics, but the ACI is less well-known one.

The founder of the ACI -- George Wangengeim is a well-known climatologist in Russia. The so-called Wangengeim-Girs classification of atmospheric circulation is a basic idea in the modern school of Russian climatology (Girs 1971). According to this method, all patterns of westerley winds in the Northern Hemisphere are combined in 3 main forms: Western (W), Eastern (E) and Meridional (C). Each day the analysis of atmospheric pressure charts of the Northern Atlantic-Eurasian region identified the dominant form. The number of days of each circulation form observed (W, E or C) is expressed as "days" for a year and the dominant form for the year results in the year being classified as that type. Annual sum of days of all forms is obvious to be equal to 365. The observation series for the atmospheric circulation forms have been maintained continuously since 1891.

The forms of the atmospheric circulation can be conveniently displayed in the form of anomalies (deviations from time series average for each form) rather than plain "days". It is even more informative to present data as consequent summation of anomalies. The resulting integral curve demonstrate the long-term trend of Atmospheric Circulation change for each circulation form: W, E or C (Girs 1971). The integral of the sum of (W+E) or the ACI exhibits long-term (about 30-years) regular oscillations, called "circulation epochs". The epoch of meridional (C) circulation dominated in the periods 1890-1920 and 1950-1980. The epoch of combined (W+E) circulation dominated in the periods 1920-1950 and 1980-1990s (Girs 1971). Current (W+E) epoch is not completed yet. The recent pattern is similar to the climatic phase of 1940-50s and probably will close in the first decade of next century.

The ACI for 1900-1995 were kindly placed in our disposal by directorate of Russian Federation Arctic and Antarctic Institute (AARI) in St. Petersburg. The full catalogue of the forms of atmospheric circulation has been maintained by the staff of this institute since 1891.

RESULTS AND DISCUSSION

The fluctuations of Pacific salmon and pink salmon total catches (Fig. 1) are in phase. The maximum catch occurred in late 1930s, followed by depression in 1950-1960s and recent maximum in the early 1990s; the trends are tightly correlated ($r=0.89$, $p<0.001$).

The similar long-term catch dynamics was observed for a range other major commercial species in the Pacific Ocean. Catches of Japanese and Californian sardine (Fig.2) fluctuated in phase with Pacific salmon maximum in late 1930s, followed by

Fig. 1 Total Pacific salmon and pink salmon catch 1920-1994. Correlation coefficient between total and pink salmon catch is: 0.89, p<0.001.

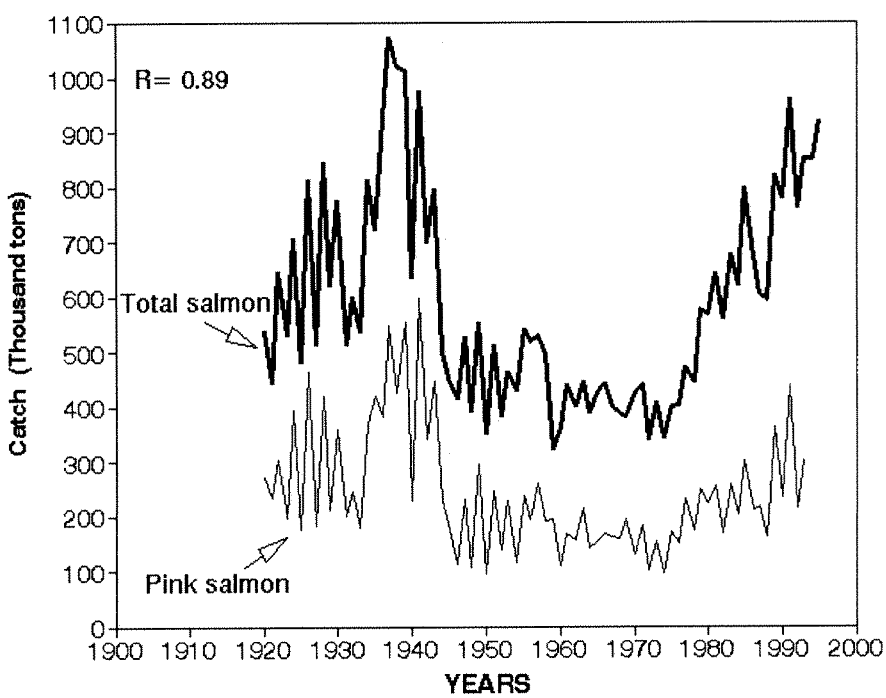
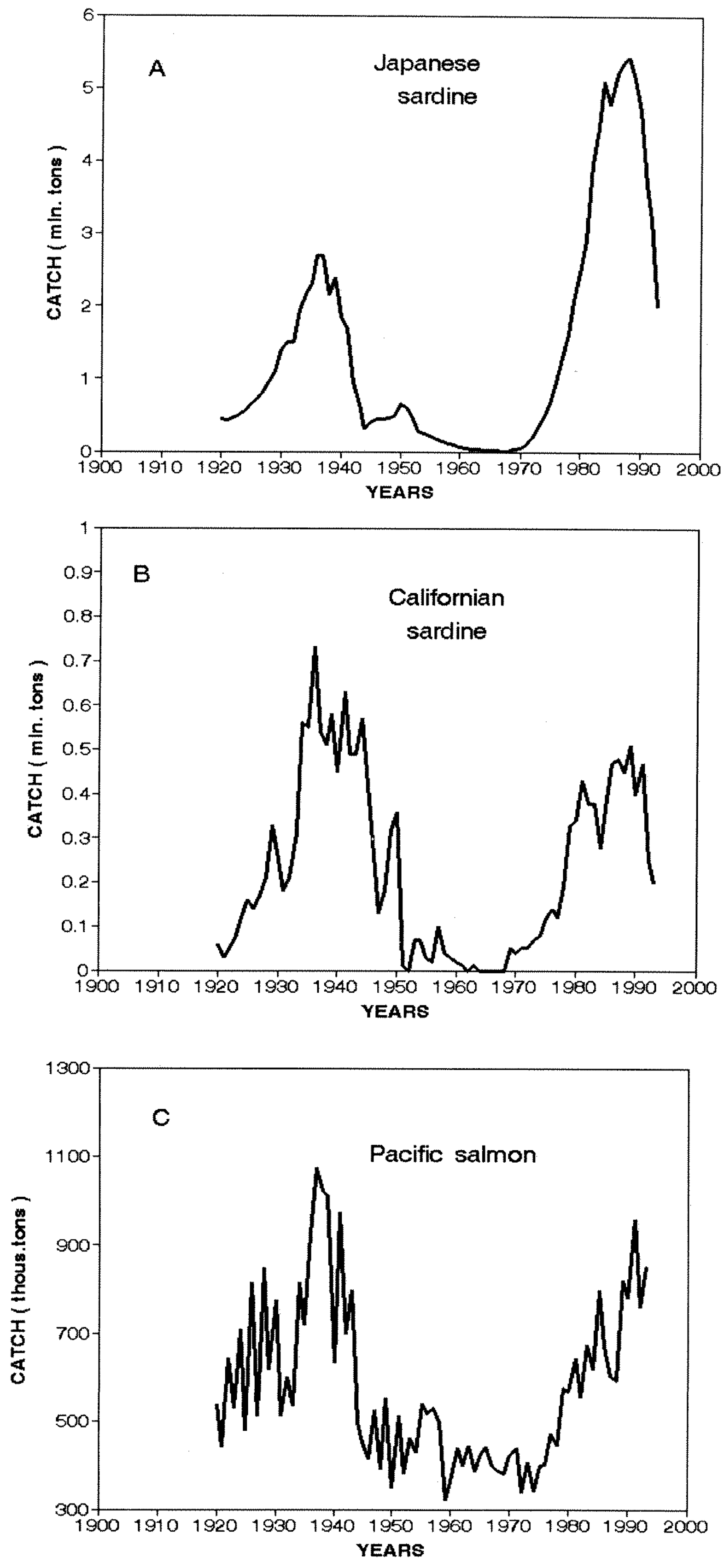


Fig. 2 **Total catch of Japanese sardine (A), Californian sardine (B), and total Pacific salmon (C), 1920-1994.**



the depressions in 1950-1960s and maximum in late 1980s-early 1990s. The synchronous fluctuations of Japanese and Californian sardines and Pacific salmon are likely caused by long-term Global Climate changes (Klyashtorin & Smirnov 1995).

If there is a common factor affecting the abundance fluctuations of Pacific salmon and sardines which climatic index corresponds to the catch trends best and which can be used to predict the simultaneous fluctuations of above mentioned species abundance?

The trends of dT and ALPI are highly variable and this indices hardly satisfy F-criterion of statistical significance(Fig. 3). The 13-year smoothed curves of dT and the ALPI can demonstrate general direction of the climatic changes; however, they are less reliable forecasting tools because of the large variance.

In contrast, ACI variability is substantially less and the ACI trend is in a good agreement with smoothed trends of dT (global climatic characteristic) (Fig.4) and the ALPI (main climate forcing factor of the Northern Pacific (Fig.5).

General curves for dT, ALPI and ACI have rather similar general shape: a maximum in the 1930s, minimum in the 1950-1960s and a new maximum about 1990.

The ACI curve correlates tightly with long-term dynamics of other important commercial species in the Pacific such as: Japanese, Californian and Peruvian sardine, Alaska pollock, Chilean jack mackerel and others. It is believed that ACI long-term dynamics, although measured in Atlantic - Euro-Asiatic region, reflects Global climate changes (Klyashtorin & Sidorenkov 1996).

A good correlation is observed between ACI and total Pacific salmon catch ($r = 0.81$. $p < 0.001$) (Fig. 6). The curve for Pacific salmon catch dynamics has a "saw-like" form because of the interannual alternations of pink salmon abundance. Smoothing of curve of pink salmon catches with 3-year averaging increases the correlation coefficient to 0.92 (Fig 7).

The correlation coefficient (r) between pink salmon catch (unsmoothed) and ACI is rather moderate ($r=0.64$) because of natural inter-annual stock fluctuations (Fig 8). To improve the relationship the pink salmon catch was smoothed by 3 year running averaging. Even such slight smoothing results in significant increase of correlation coefficient to 0.84 ($p<0.001$) (Fig.9)

Variation of Pacific salmon harvest throughout this century can be defined as two sequential natural climate-governed production cycles with large catches in the late of 1930-s and early 90s. The latter (current) cycle is not completed yet but is going into final descending phase (late 1990s-early 2000s), that corresponds to the one of 1940-1950s and associated with similar climatic phase.

Total stock of pink and Pacific salmon are now at their highest levels. However, we expect gradual decrease of their stocks as early as late 90s, in accordance with the descending ACI trend. Similar fluctuations in stock dynamics have been observed for more climate sensitive species: Japanese, Californian, and Peruvian sardine (Kawasaki 1992 a, b).

The similar stock dynamics of ecologically different species (including Pacific salmon), suggests that the similar climate-governed oceanic mechanisms can be responsible for the long-term fluctuations of total productivity over the whole Pacific (Klyashtorin & Sidorenkov 1996). Mechanisms of climate impacts on the marine ecosystems productivity are not clear yet. Some authors suppose that the most probable reason is the changes in the character of the global atmospheric and water mass transportation (Bakun 1990, Kawasaki 1992, 1994, Hsieh & Boer 1992, Ware & Thompson 1991, Ware 1995).

The stock fluctuations of main species of pelagic fish in the Pacific can be considered in its turn as a sensitive indicator of oncoming climate change. "In many instances biological organisms are integrators of environmental variables and may be more sensitive to low frequency climate events than physical time series" (Polovina et al.1994).

It is commonly accepted in North America that pink salmon abundance fluctuates between odd and even runs, however the persistence of these fluctuations can be questioned if the observations are extended over a number of years. The magnitude and regularity of the odd-even year alternation of high and low abundant generations differ in various regions (Heard 1991).

For example, catches of pink salmon from North America (Fig. 10) do not exhibit annual alternation. Since 1920 the reverse of "odd-even" generation dominance has been observed 31 times for 74 years period (Fig. 11). Ricker (1962) suggesting that dominance exist when one generation line is at least twice the size of the other, and this condition persist for at least four generations. In this respect the phenomenon of even-odd catch alternating is questionable for "Total American" pink salmon.

The reversal of the dominance has occurred much less in the Asian pink salmon population (Fig.12). In contrast to "American" pink salmon, "Asian" pink salmon catch exhibits clear and regular inter-annual alterations. A characteristic feature of "Asian" pink salmon dynamics is rare occurrence of dominance change: regular odd-even alternation was broken only once in 74 years (Fig.13).

Let us follow the history of high- and low abundant pink salmon generations separately. Figure 14 demonstrates that the curves of high- and low abundant generations of Asian pink salmon have a similar shape and correlate rather tightly ($r=0.76$, $p<0.001$). "American" high- and low abundant lines

Fig. 3 The run of climatic index curves 1900-1994. A. Global air surface Temperature Anomaly (dT); B. Aleutian Low Pressure Index (ALPI) (thin line — annual fluctuations, thick line — smoothed by 13-years averaging); C. Atmospheric Circulation Index (ACI) — integral curve of combined (W+E) circulation form (unsmoothed).

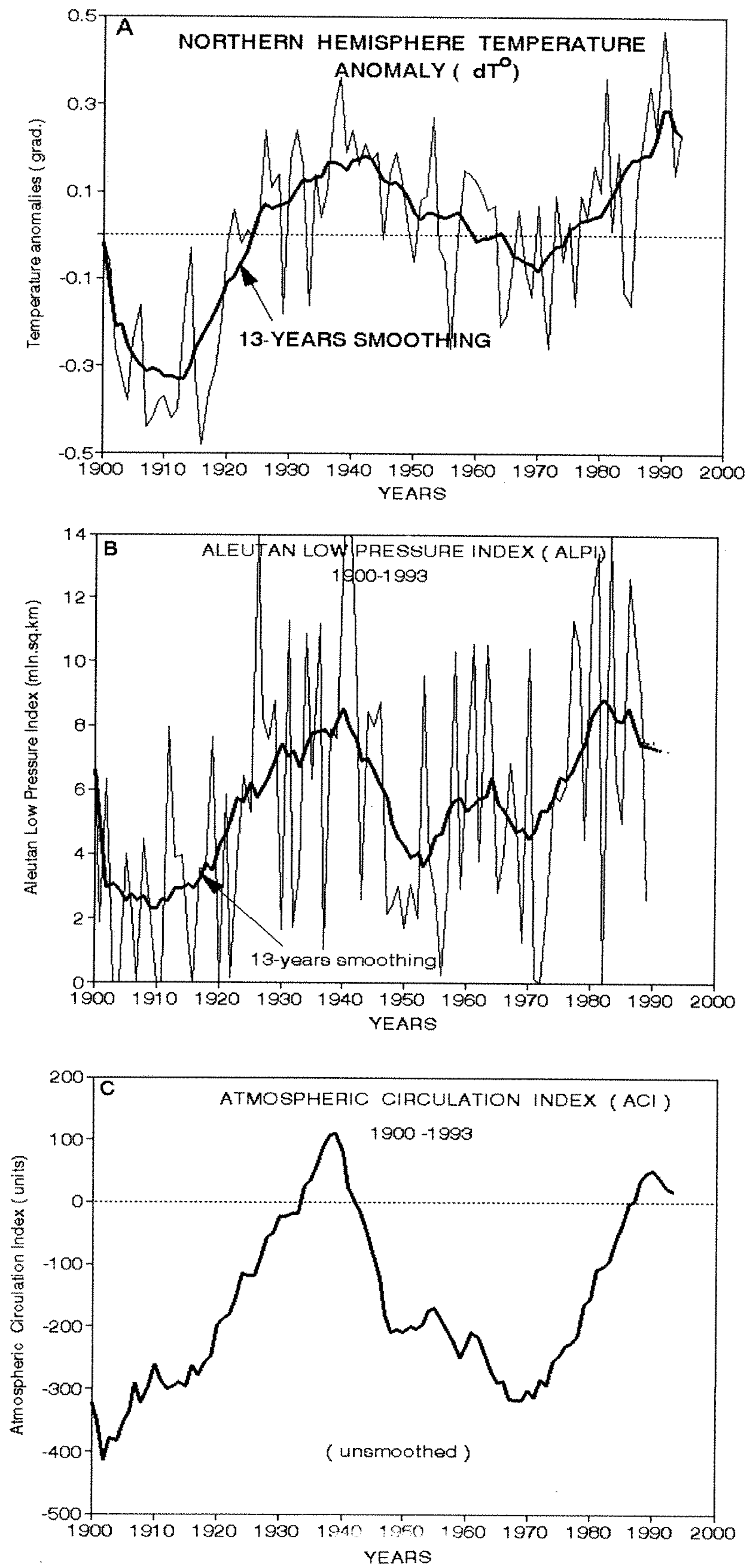


Fig. 4 **Long-term run of temperature anomaly (dT) and Atmospheric Circulation (ACI) curves 1900-1994. Thin line — ACI (unsmoothed), thick line — dT (smoothed by 13-years averaging).**

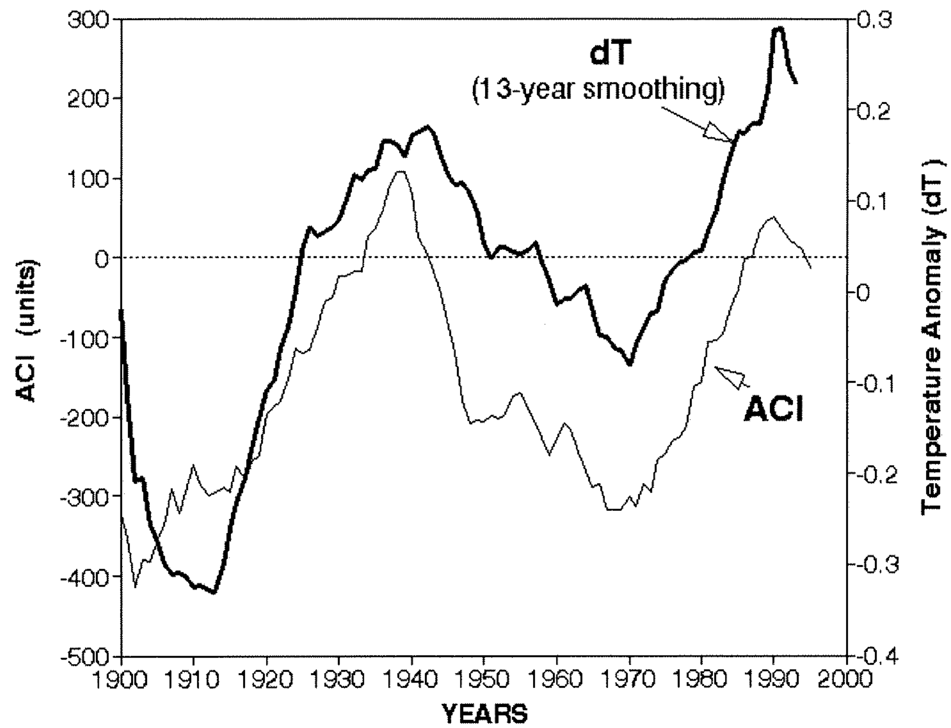


Fig. 5 **Long-term run of Atmospheric Circulation Index (ACI) and Aleutian Low Pressure Index (ALPI).**

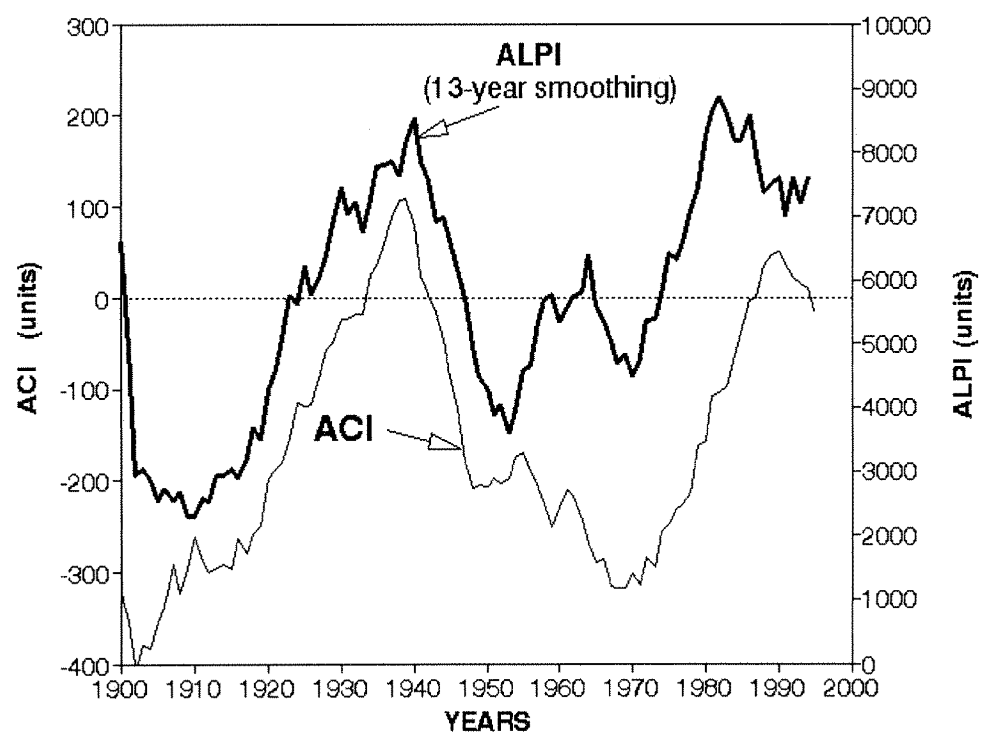


Fig. 6 **Total unsmoothed Pacific salmon catch and Atmospheric Circulation Index (ACI) 1900-1994. Correlation coefficient between ACI and catch curves is: 0.81, p<0.001.**

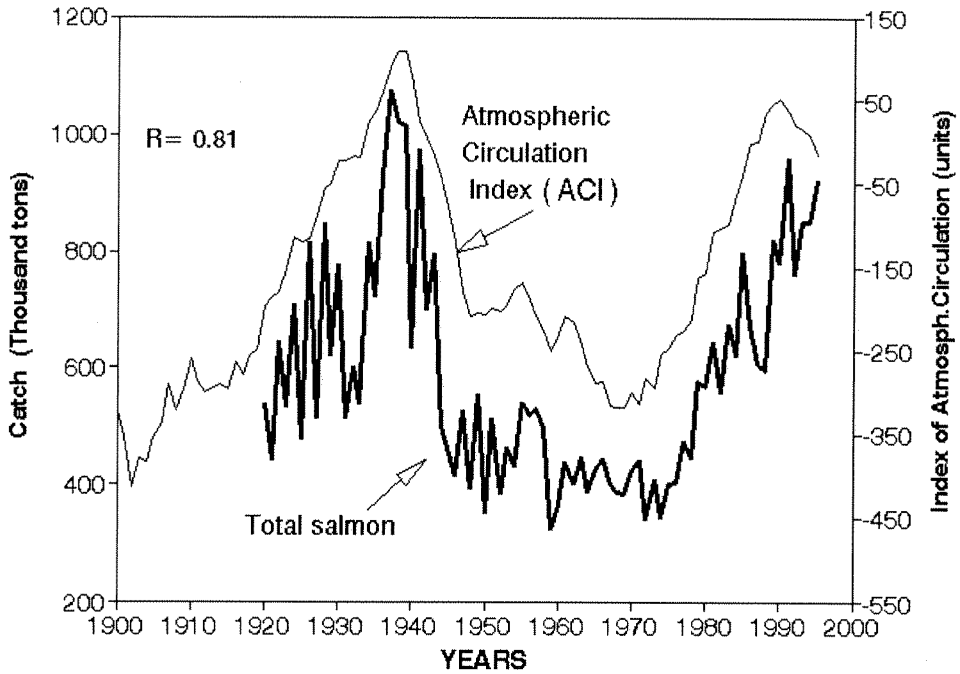


Fig. 7 **Total 3-year smoothed Pacific salmon catch and Atmospheric Circulation Index (ACI) 1920-1994. Correlation coefficient between ACI and the smoothed catch is: 0.92, p<0.001.**

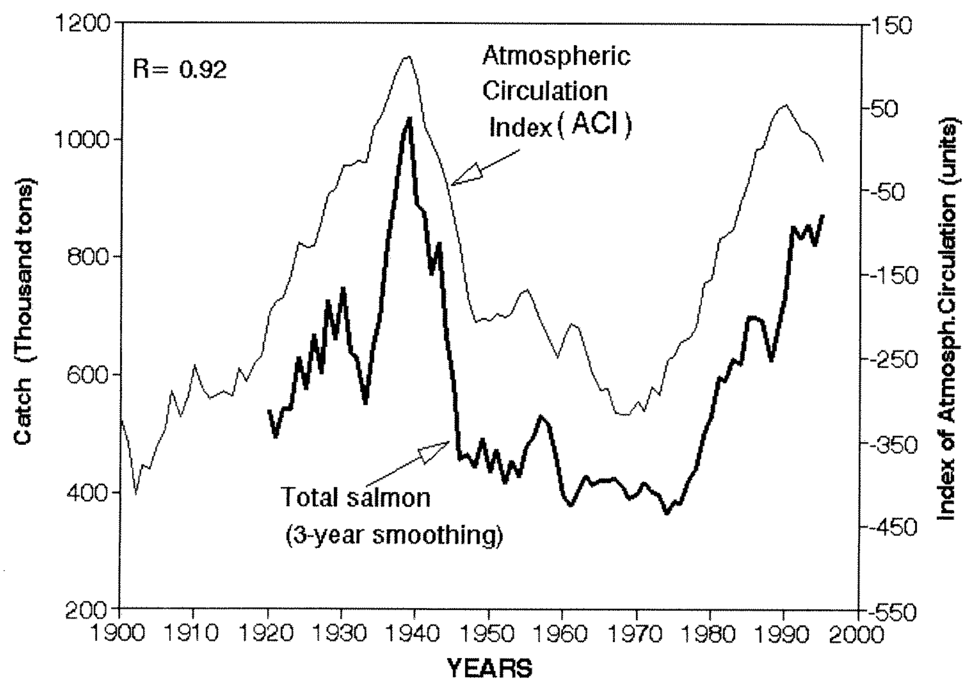


Fig. 8 Total unsmoothed pink salmon catch and Atmospheric Circulation Index (ACI) 1920-1994. Correlation coefficient between ACI and the catch is: 0.64, p<0.001.

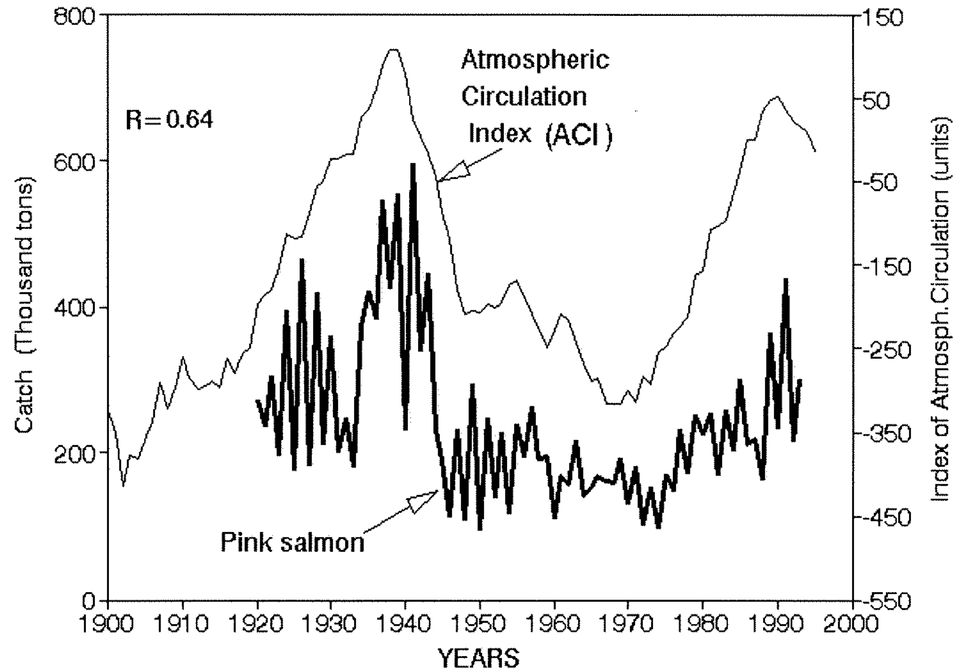


Fig. 9 Total 3-year smoothed pink salmon catch and Atmospheric Circulation Index (ACI) 1920-1994. Correlation coefficient between ACI and the smoothed catch is: 0.84, p<0.001.

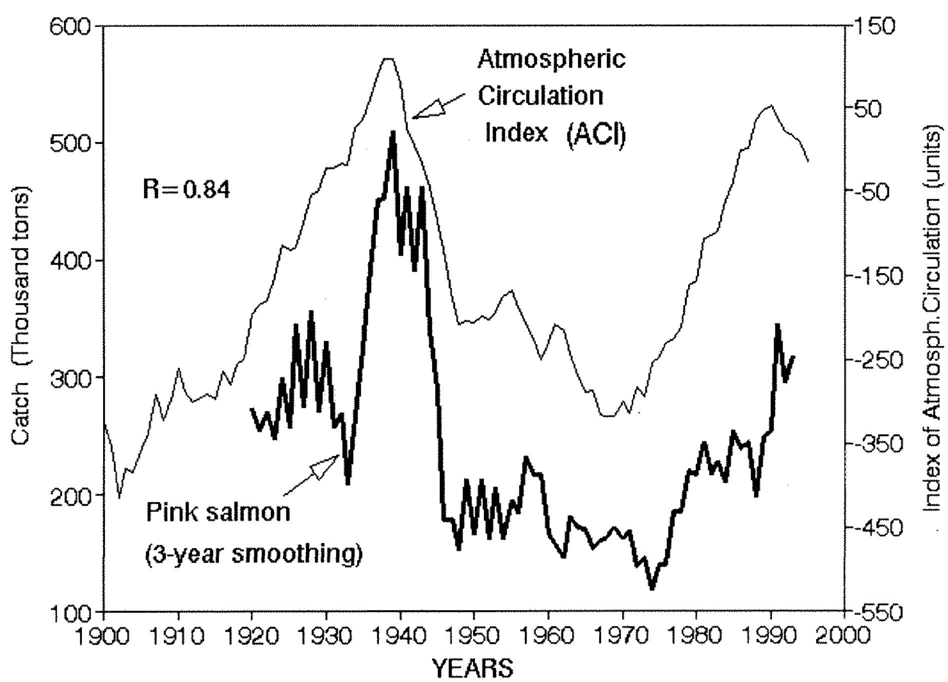


Fig. 10 Total American pink salmon catch, 1920-1994.

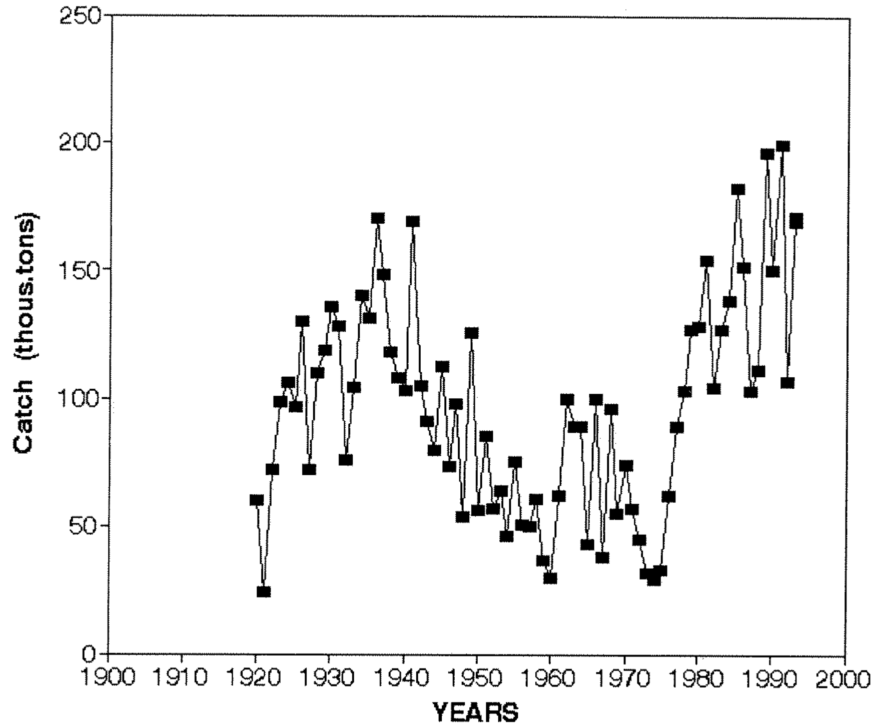


Fig. 11 American pink salmon of even- and odd year catch 1920-1994. Bars indicate the year of dominance change.

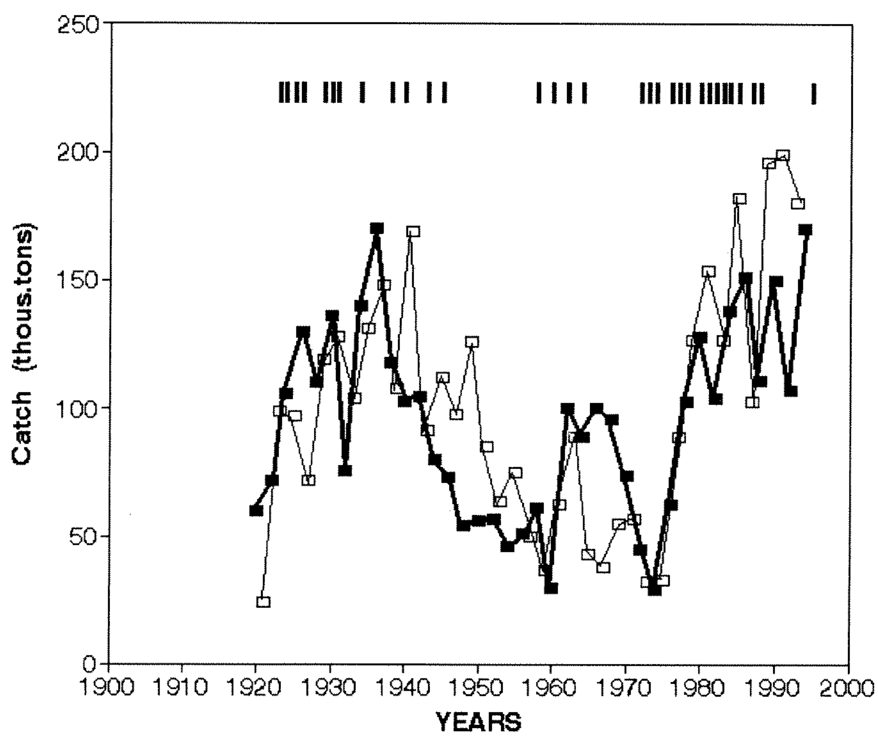


Fig. 12 **Total Asian pink salmon catch, 1920-1994.**

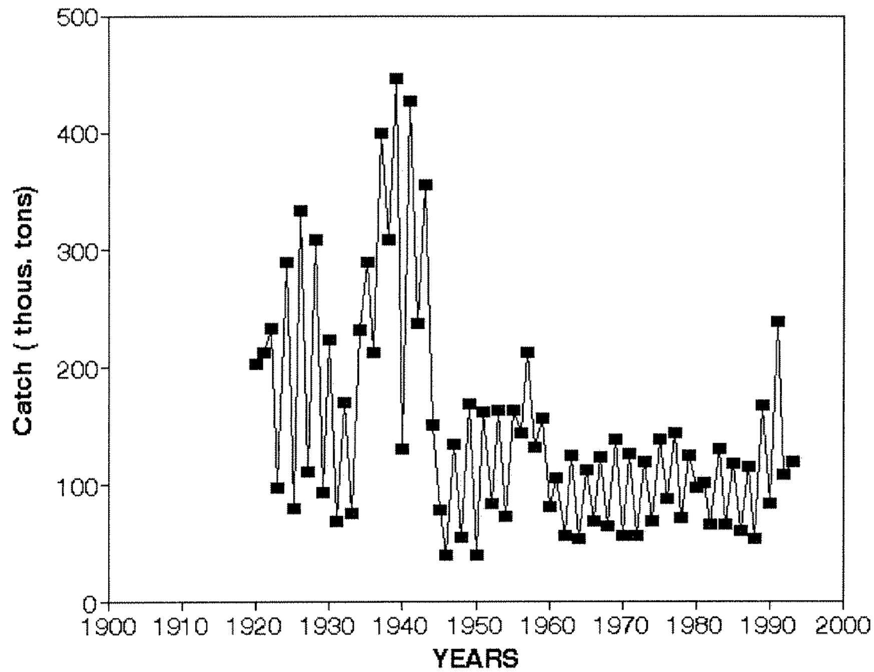


Fig. 13 **Asian pink salmon of even- and odd year catch. Bold line — even year generations, thin line — odd year generation. Bars indicate the year of dominance change.**

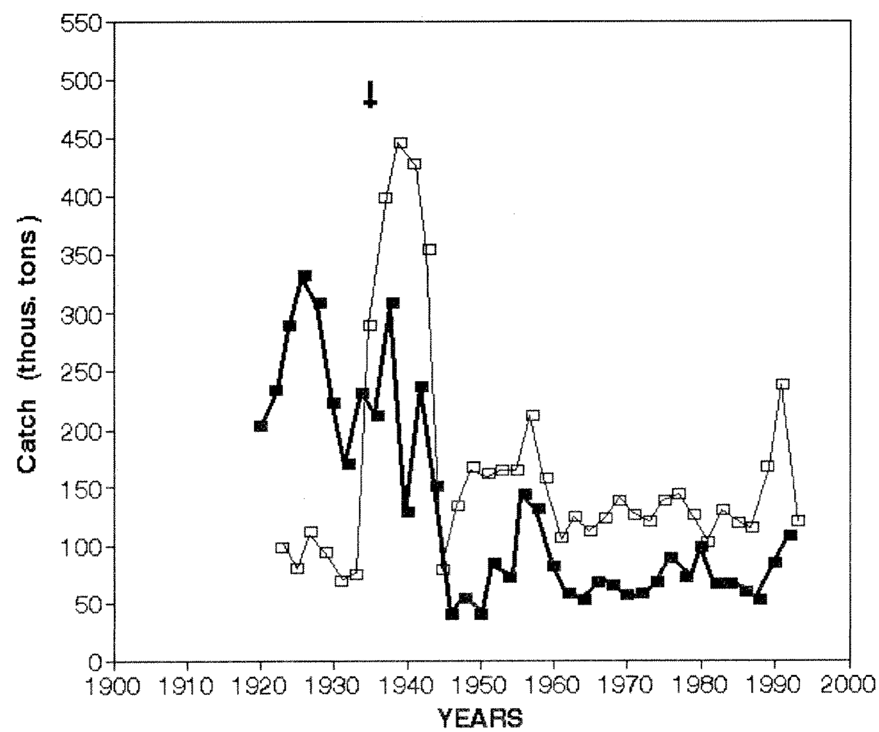
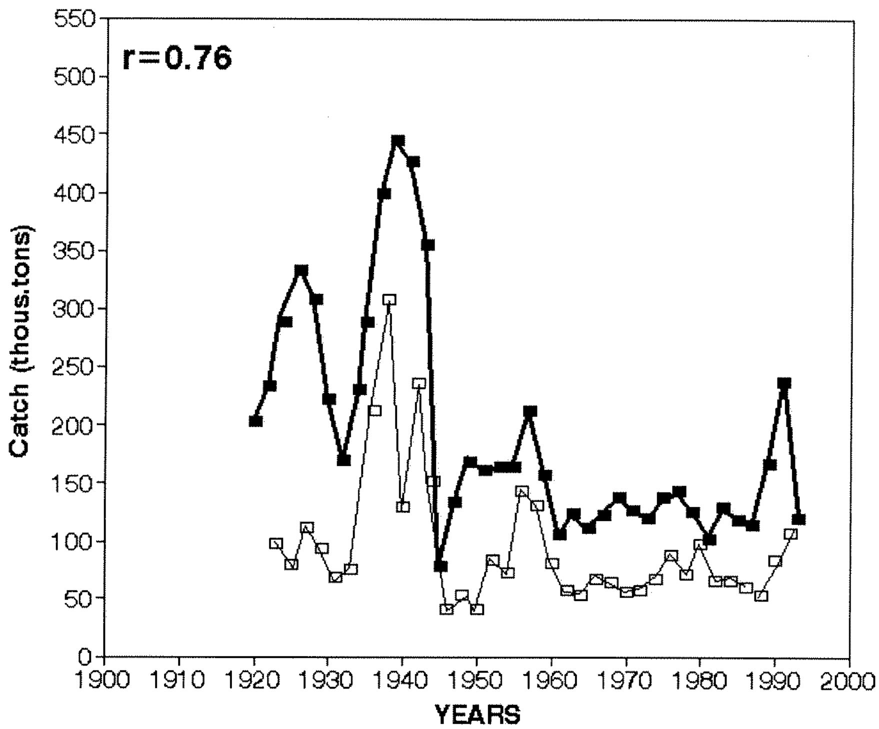


Fig. 14 Asian pink salmon high- and low abundant generations. Bold line — high abundant generations, thin line — low abundant generations. Correlation coefficient between high-and low abundant lines is: 0.76, p<0.001.



also exhibit similar dynamics (Fig. 15), but it is difficult to calculate correlation between these two lines because of a numerous "intermediate" catch points. It is interesting to note that the "intermediate" pink salmon catches demonstrate similar dynamics to the catches of high and low abundant lines.

Impressive results were obtained in Kamchatka and Sakhalin regions. In Kamchatka strong inter-annual alteration was observed for pink salmon catches (Fig. 16). The change of the dominance was observed only three times for the 74-year period 1920-1994 (Fig. 17). Close correlation ($r=0.92$, $p<0.001$) was revealed between dynamics of high- and low abundant generations of Kamchatka pink salmon (Fig.18).

Fig.19 illustrate the dynamics of Sakhalin pink salmon catch. The change in dominance for Sakhalin pink generations was observed 8 times during 74 year period 1920-1994 (Fig.20). The correlation between high- and low-abundant generation trends (Fig.21) is rather moderate ($r=0.70$, $p<0.001$). Nevertheless the general dynamics of Sakhalin pink salmon catch were similar to ones observed over Kamchatka and Asian region on the whole.

It is significant that both high- and low abundant pink salmon generations demonstrate similar long-term dynamics closely related to the ACI trend. At the same time, the dynamics of high and low abundant pink generation is in general agreement with dT and ALPI dynamics. This suggests that climate change influence high and low abundant pink salmon stocks in the same way.

The close correlation between the trends of high and low abundant pink generations makes it possible to calculate roughly the abundance of next year populations based on previous one. This procedure can be applied to Asian pink salmon populations only, since the latter exhibit more or less regular alternation of even-odd generations. The long-term change of both lines of pink salmon stock correspond to long-term trends of global and hemisphere climatic indices, first of all to ACI dynamics.

The proposed approach is under way now and preliminary results are hopeful.

CONCLUSIONS

There is a close association between the dynamics of some global climatic indices (dT, ALPI, ACI) and long-term fluctuations of Pacific salmon and pink salmon abundance.

ACI is the most reliable climatic index of all indices analyzed. Close agreement in long-term stock dynamics of Pacific salmon, Japanese, Californian and Peruvian sardines and a range of other Pacific commercial species suggest that some climate-

Fig. 15 American pink salmon high- and low abundant generations. Bold line — high abundant generations, thin line — low abundant generations.

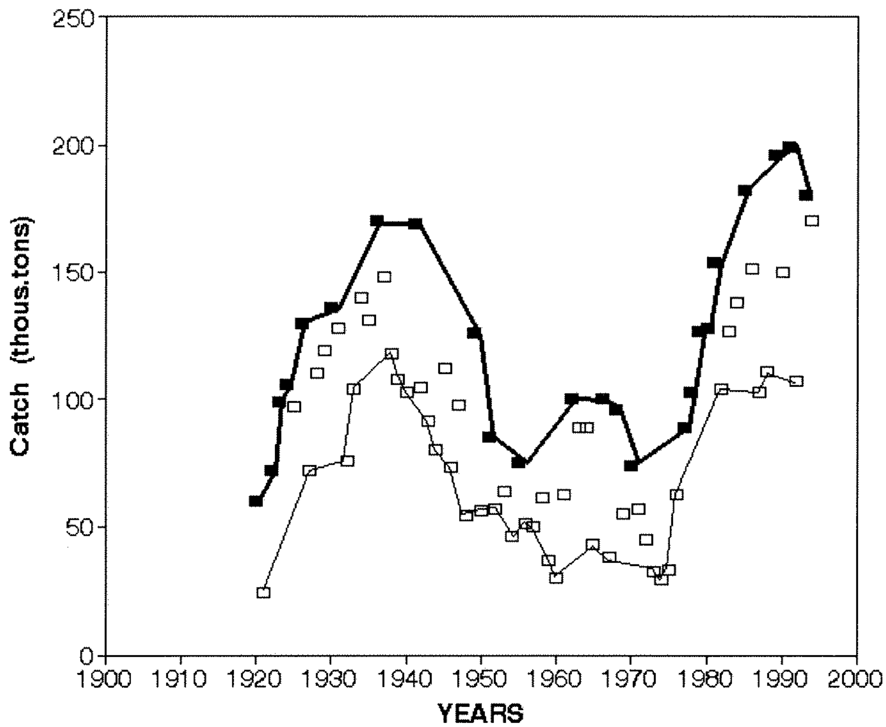


Fig. 16 Kamchatka pink salmon catch, 1920 - 1994.

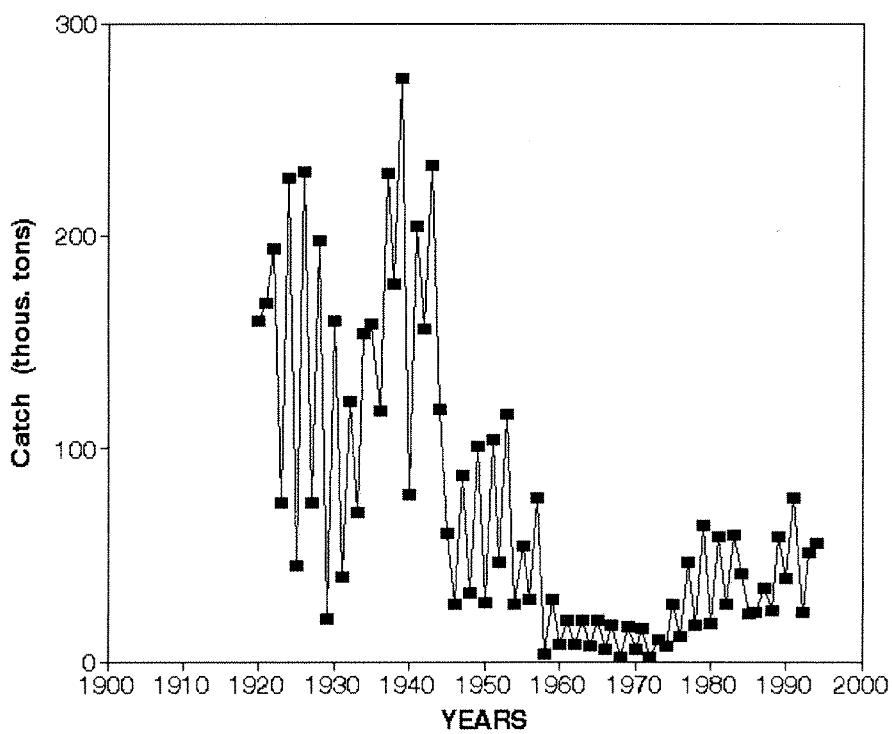


Fig. 17 Kamchatka pink salmon of even- and odd year catch. Bold line — even year generations, thin line — odd year generations. Bars indicate the year of the dominance change.

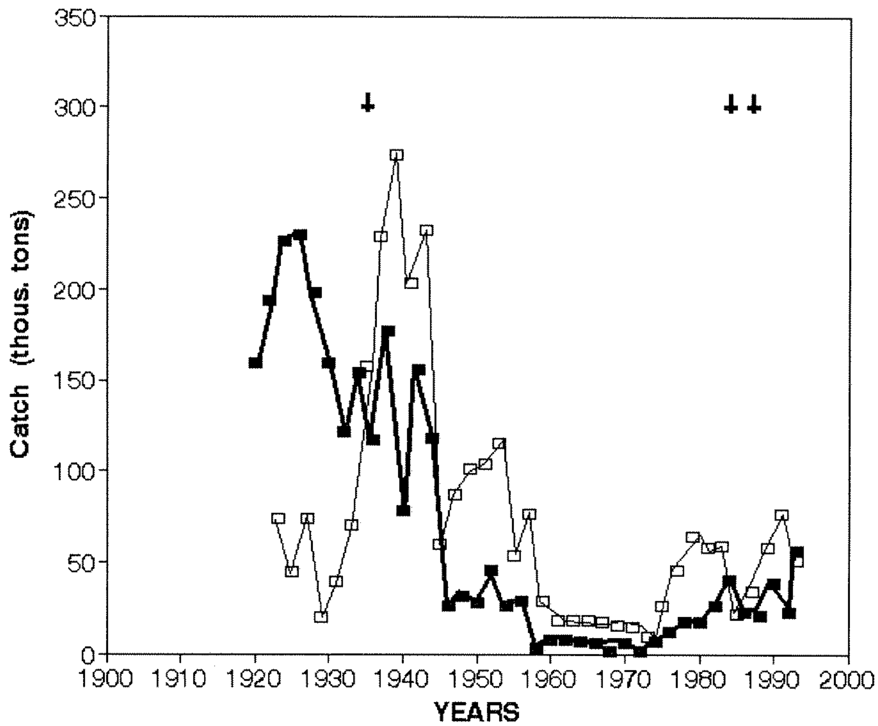


Fig. 18 Kamchatka pink salmon high- and low abundant generations. Bold line — high abundant generations, thin line — low abundant generations; correlation coefficient between high and low abundant lines is: 0.92, $p<0.001$.

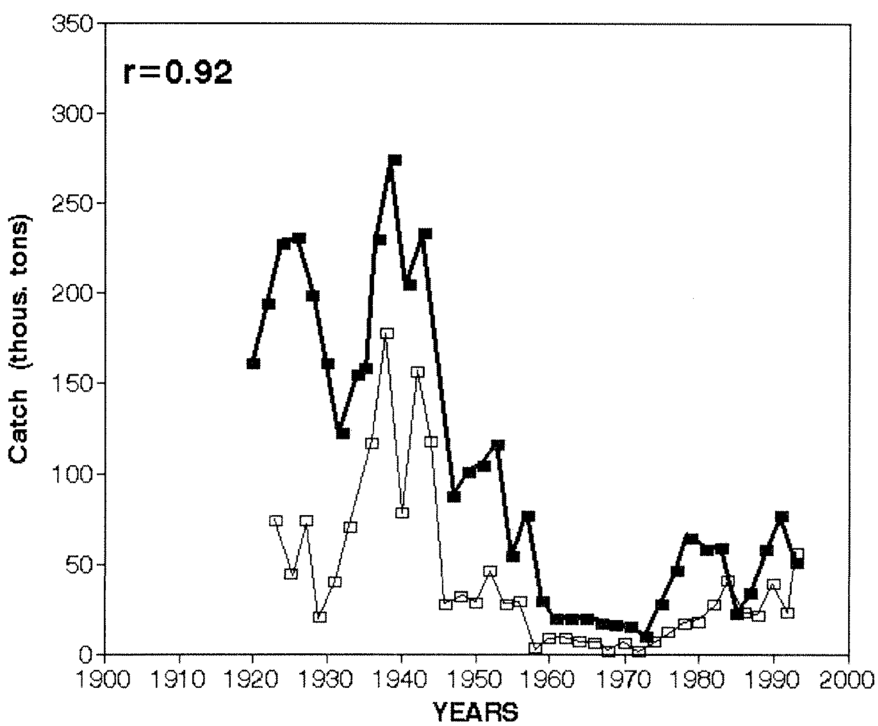


Fig. 19 Sakhalin pink salmon catch, 1920-1994.

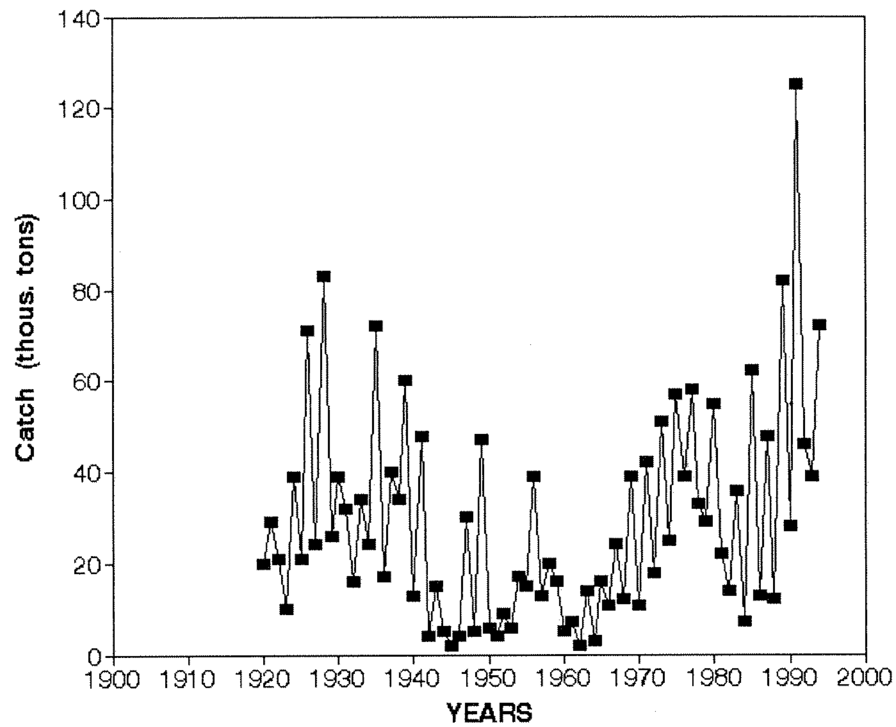


Fig. 20 Sakhalin pink salmon of even- and odd year catch. Bold line — even year generations, thin line — odd year generations; bars indicate point the year of the dominance change.

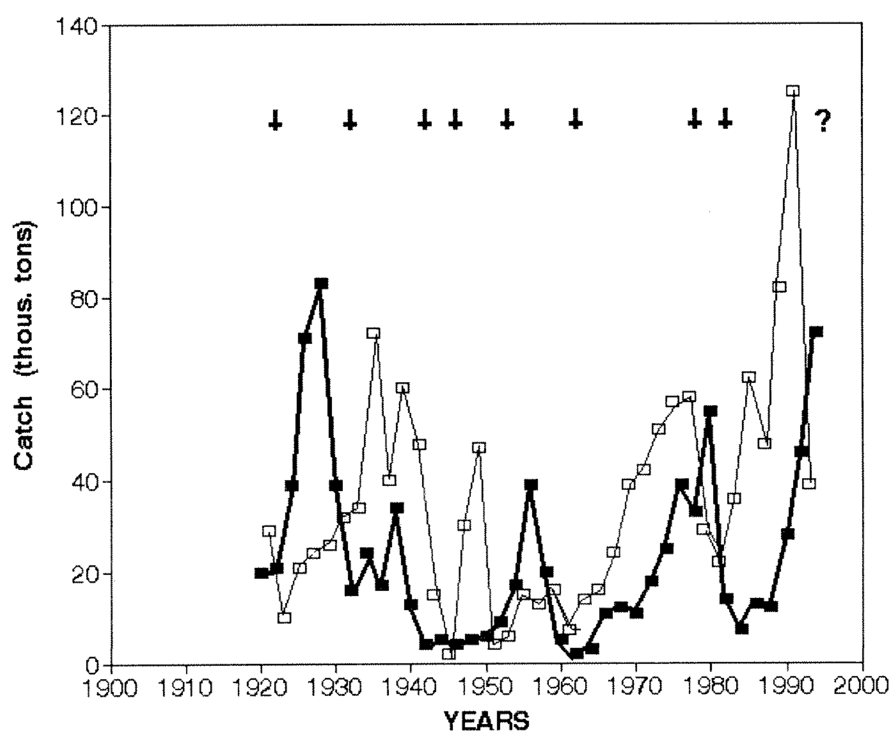
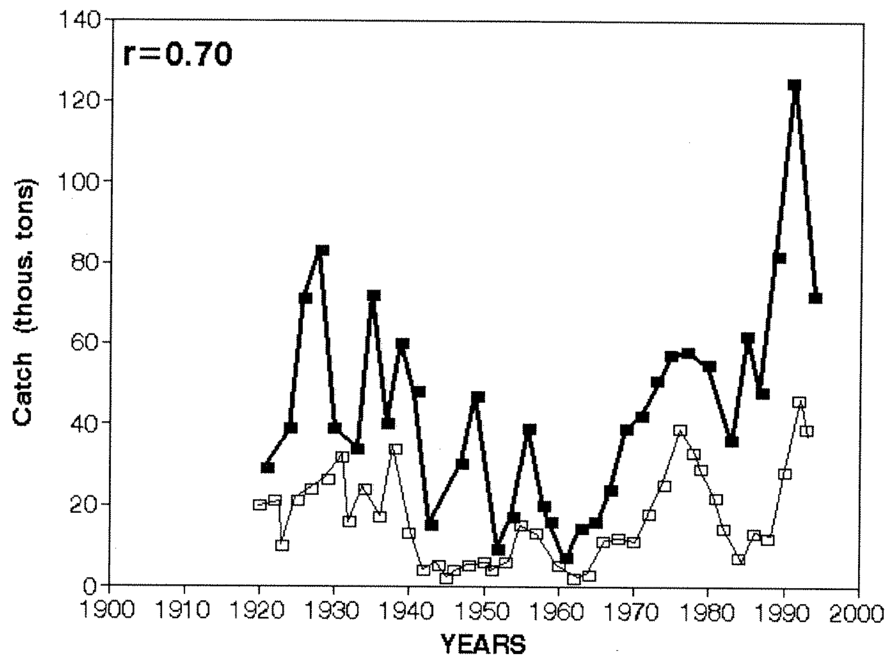


Fig. 21 Sakhalin pink salmon high- and low abundant generations. Bold line — high abundant generations, thin line — low abundant generations; correlation coefficient between high and low abundant lines is 0.70, p<0.001.



governed oceanic factors are first responsible for long-term fluctuation of Pacific salmon and pink salmon stocks.

As for the long -period inter-annual dynamics of pink salmon population, general curves of high- and low abundant generations of Asian pink salmon are similar in shape and demonstrate a tight correlation.

A new approach can be outlined on this basis to forecast Asian pink salmon abundance one year ahead.

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