Recent Changes in Atlantic (*Salmo salar*) and Pacific (*Oncorhynchus*) Salmon Stocks in the Context of Climatic Variations in the Northern Hemisphere

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The study is based on the analysis of spatial and temporal features of winter climate in the North Atlantic and the North Pacific during the last four decades. In each ocean several large-scale subdomains with the coherent sea surface temperature anomaly (SSTA) fluctuations were defined with the use Ward's hierarchical clustering method. SSTA variations in the northeastern and southwestern North Atlantic are opposite to those in the northwestern and southeastern parts. This quadra-pole structure is clearly associated with the features of the North Atlantic Oscillation (NAO). At the same time, the SSTA fluctuations in the central North Atlantic appear to be connected with the Pacific/North American (PNA) teleconnection pattern in the middle troposphere, while there are no significant relationships with the atmospheric teleconnection patterns over the North Atlantic.

The spatial structure of the SSTA fluctuations in the North Pacific is characterized by two independent patterns: changes in the SSTA in the eastern and central North Pacific, and those in the northwestern and southwestern parts, are out of phase. The SSTA fluctuations in the central and eastern North Pacific are related to the PNA pattern, while those in two western regions are associated with the Western Pacific (WP) teleconnection pattern.

Principal component analysis (PCA) was used to define objectively the most important patterns of common variability in 39 physical time series in the North Atlantic and the North Pacific. The first principal component (PC1) which explained 20% of the total variance is associated with the NAO and its temporal pattern shows four distinct regimes between 1957 and 2000: 1957–1971; 1972–1976, 1977–1988 and 1989 through (at least) 2000, with the most abrupt transition in 1989. The last decade is characterized by strong positive NAO values (except for 1995–1997). The second PC (17% of total variance) is associated with the Southern Oscillation and Pacific Decadal Oscillation (PDO) pattern and shows the rather prominent shift in 1977. The 1990–1999 decade was the warmest in both oceans compared with the previous three decades.

The results of PCA and correlation analysis give some evidence for strong relationships in SSTA variations between the oceans. Thus, the SSTA fluctuations in the Northwest Atlantic and Northwest Pacific are out of phase ($r = -0.69$), while those in the eastern North Pacific and central North Atlantic are characterized by a significant positive correlation ($r = 0.65$).

Climatic variations in the North Atlantic during the last 40 years were characterized by a second, interdecadal, mode of variability. From the 1970s to the 1990s there was an intensification and eastward shift of low- and high-pressure anomaly cells over the whole area south of 50°N and a general strengthening of zonal flow over the North Atlantic north of 50°N. This was accompanied by a gradual spreading of warming of the surface waters in the North Atlantic from the southwest to the northeast south of 50–55°N in accordance with the shift of the high pressure anomaly cell. The situation in the North Pacific was more uncertain. SST changes in the 1970s–1980s were, in general, consistent with the changes in the atmospheric circulation. At the same time, the signs of the northeastward propagating warming appeared in the 1980s, and in the 1990s the warming was observed over most of the North Pacific.

The interdecadal changes in the North Atlantic are characterized by a warming trend during the 1970s–1990s which in many aspects, resembled the warming of the 1920s–1930s described by Bjerknes (1964). In particular, there were inconsistent changes in SST and local winds north of 50°N. In the North Pacific the heat exchange at the sea surface contributed to SSTA changes at interdecadal time scale to a larger extent than in the North Atlantic. Thus, the effect of oceanic circulation in the North Pacific on interdecadal SST changes is seen only in the periods of general lessening of atmospheric circulation.

To consider if there is any relationships between the observed climatic variations and the recent trends in Atlantic salmon and Far Eastern Russian pink, chum and sockeye salmon stocks, we applied PCA to isolate the patterns of common variability in the 40 physical and 37 biological time series characterizing the Atlantic and Pacific salmon stocks. Scores for the first two PCs are shown in Fig. 1 and the loadings on these two PCs are given

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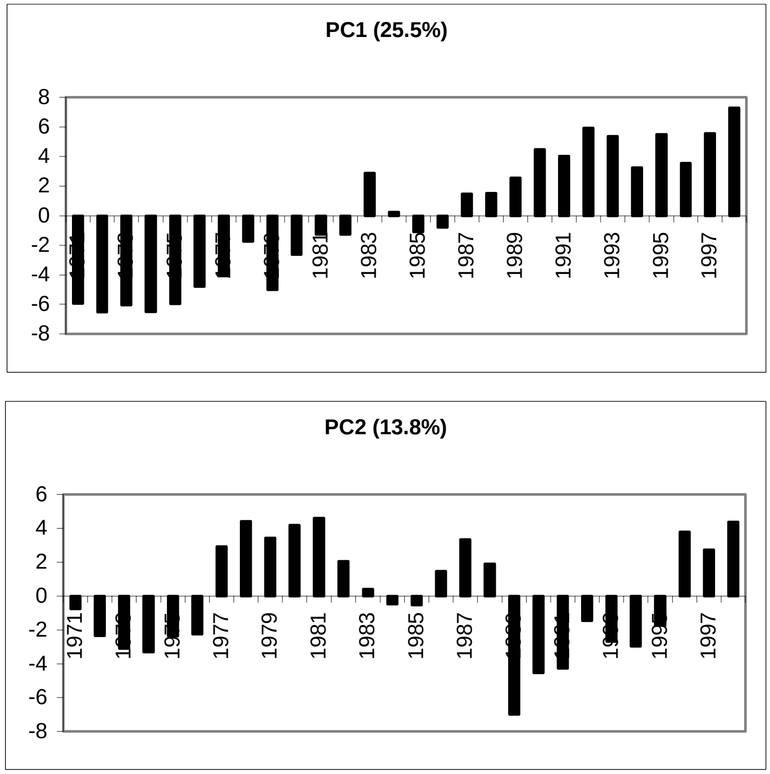
in Table 1. The PC loadings are correlations between individual time series and the associated PC score. Only statistically significant corrrelations are given in Table 1. The time series of PC1 illustrates an abrupt shift from negative to strongly positive values in 1987. High loadings (r > |0.4|) on PC1 occur for 6 of 9 time series for Pacific salmon stocks and for most time series of Atlantic salmon. All the Pacific salmon time series are positively correlated with PC1, while most Atlantic salmon stocks show the negative association with PC1. This indicates that the inverse reproductive patterns of the Pacific and Atlantic salmon stocks may be explained by these features of climate variations in the oceans under consideration.

The second principal component (PC2) shows three distinct regimes from 1971 to 1998, with abrupt shifts in 1977 and 1989 which are similar to climatic regimes defined in the North Atlantic, however, few biological time series have high loadings on PC2. There is a positive correlation between fluctuations of East Sakhalin pink salmon and Atlantic salmon in Labrador and Newfoundland areas.

Fig. 1. The first two principal component scores from a principal component analysis of the 77 climatic and salmon time series.



The analysis of the current tendencies in climatic changes in the North Atlantic and North Pacific allows some proposals regarding the situation with the salmons stocks in both oceans in the near future. In the North Atlantic, the recent period of warming appears to be close to its end and will be followed by a cool period. In this case, the state of most Atlantic salmon stocks will improve. In the Northwest Pacific, the cold regime that started in 1998 will result in decrease in abundance of pink salmon stocks in the western Pacific. At the same time, an abundance of West and East Kamchatka chum and sockeye stocks will not change essentially. This is associated with a weakening of the density-related dependence of these stocks on the stock of artificially propagated Japanese chum salmon, for which this cold period is unfavorable.

Table 1. Loadings on the first principal component from a principal component analysis of the 77 climatic and salmon time series. The loadings are correlation coefficient between each time series and the first PC score. Only statistically significant corrrelations are given.

Variable	Loadings
North Pacific	
Pacific Decadal Oscillations	0.47
Longitude of Aleutian Low	0.45
SSTA in Region 1P (eastern North Pacific)	0.78
Catches of pink salmon (West Kamchatka)	0.64
Catches of pink salmon (East Kamchatka)	0.84
Catches of pink salmon (East Sakhalin)	0.45
Catches of chum salmon (West Kamchatka)	0.46
Catches of sockeye salmon (West Kamchatka)	0.76
Catches of sockeye salmon (East Kamchatka)	0.60
North Atlantic	
Eastern Atlantic –Jet teleconnection pattern (TP)	0.55
SSTA in Region 5A (central North Atlantic)	0.87
North Atlantic Tripole	0.51
1 sea winter (SW) spawners (Northern Europe)	0.58
1SW returns (Salmon Fishing Area (SFA) 18, Northwest Atlantic	0.45
1SW returns (the Quebec rivers)	0.52
The Pacific Ocean	
SOI	-0.47
North Atlantic	
Catches of Atlantic Salmon (ICES area, I + IIab)	-0.82
1SW returns (Southern Europe)	-0.79
Multi sea winter (MSW) returns (Northern Europe)	-0.71
MSW returns (Southern Europe)	-0.74
1SW spawners (Southern Europe)	-0.74
Fishing-related mortalities as 2SW equivalents (Canada)	-0.94
Fishing-related mortalities as 2SW equivalents (Greenland)	-0.88
Fishing-related mortality as 2 SW equivalents (Northwest Atlantic)	-0.95
Weight of 1SW salmon caught at West Greenland (North American origin)	-0.61
Weight of 1SW salmon caught at West Greenland (European origin)	-0.81
Length of 1SW salmon caught at West Greenland (North American origin)	-0.48
Fork length of 1SW salmon caught at West Greenland (European origin)	-0.88
2SW recruitment (Labrador)	-0.90
2SW recruitment (Labrador + Newfoundland + West Greenland)	-0.93
2SW returns (SFA 15, Northwest Atlantic)	-0.66

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