Paleoclimate Variability in Ocean Conditions and the Production of North American Atlantic Salmon

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Climate regime shifts related to changes in circulation variations, nutrient upwelling and productivity have been shown to influence the survival success of young salmon at sea in the North Pacific (Mantua et al. 1997; Beamish et al. 1999). A similar relationship to climate and salmon production in the North Atlantic is less clear. While the ecology of young European salmon appears to be correlated with climate (Friedland et al. 2000) the only climatic link to North American Atlantic salmon is shown between winter thermal habitat and catch (Friedland et al. 1993). However, the relationship between the season in which this climatic link occurs suggests that the precise mechanism controlling salmon survival remains unknown (Friedland et al. 1993).

Principal Component Analysis of global multiproxy paleoclimate datasets and instrumental records reveal a 50–75 year multidecadal climate oscillation centered over the North Atlantic (Mann et al. 1998). The original dataset examined in this reconstruction (Mann et al. 1998) was compiled from 1,082 nearly continuous land air/sea surface instrumental temperature grid points from 1902 onward. An extensive set of proxy data was then calibrated against the records, extending the reconstruction over the past millennium. The multidecadal oscillation is best described by the fifth eigenvector of reconstructed global climate and is observed back to 1650.

Although observational data is lacking in spatial coverage, climate model simulations using two independent, naturally forced integrations of the Geophysical Fluid Dynamics Laboratory (GFDL) coupled ocean-atmosphere model, reproduce the observed multidecadal patterns of variability (Delworth and Mann 2000). They further demonstrate that in both the model and observational data, sea surface temperature (SST) appears to carry the signal. The simulations suggest that the observed multidecadal fluctuations are driven by variations in the intensity of the Thermohaline circulation (THC) (Delworth et al. 1997). An intensified THC increases northward warm water transport and is associated with reduced cold, fresh water export via the East Greenland Current. These changes are also related to large-scale salinity variations in the Arctic Ocean, suggesting interactions between the Arctic and the North Atlantic are forcing the multidecadal oscillation (Delworth et al. 1997).

North American commercial salmon landings, used in this study as a measure of stock production since 1908, appear to follow a similar multidecadal cycle (Fig. 1). This suggests that large-scale THC changes have played an important role in altering salmon abundance over the past century, and that salmon production is higher when SSTs in the North Atlantic are anomalously cold. The connection is interesting as the Labrador Sea, an important feeding ground in the late summer and early autumn for salmon, is also the site of deep-water convection driving the THC. Further evidence for a multidecadal climate signal in this region is indicated by tree-ring climate reconstructions from coastal Labrador (D'Arrigo et al. 1996).

In this study, an updated version of the Kaplan et al. (1998) monthly SST anomaly (SSTA) reanalysis dataset is examined for the Northwest Atlantic region (40–65°N, 70–40°W). Thirty, monthly, 5°x5° SSTA data grid point locations are examined over the last 100 years and three, ten-year average, SSTA maps are used to show the ocean climate conditions corresponding to the high-low-high catches for 1920–30, 1945–55 and 1965–75, respectively (Fig. 2). The cold-warm-cold multidecadal cycle is clearly evident from the approximately 0.5°C SST change between these three periods, supporting the inverse relationship to salmon production and Northwest Atlantic SSTs.

An attempt to isolate the catch signal to a specific location and time of year is made by using monthly SSTA data for each grid point and statistically comparing it to the North American commercial salmon catch since 1908. The highest correlation is obtained from the southern, Northwest Atlantic for the January prior to the salmon going to sea. To the north, in the Labrador Sea, SSTAs throughout the year show low correlations with salmon production. Taking the highest January SSTA and catch correlation values reveals a 10°x10° box located on and to the east of the Scotian Shelf (40–50°N, 60–50°W). We apply a ten-year running mean to the combined SSTA signal, taken from these four data point locations, and reproduce the cold-warm-cold signal of the multidecadal

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Fig. 1. North American commercial salmon landings (1908–1991) [black line] shown against the reconstructed principal component (RPC) 5 from Mann et al. (1998) [grey line] indicating approximately 300 years of multidecadal variability. The RPC5 is negatively correlated with salmon production.

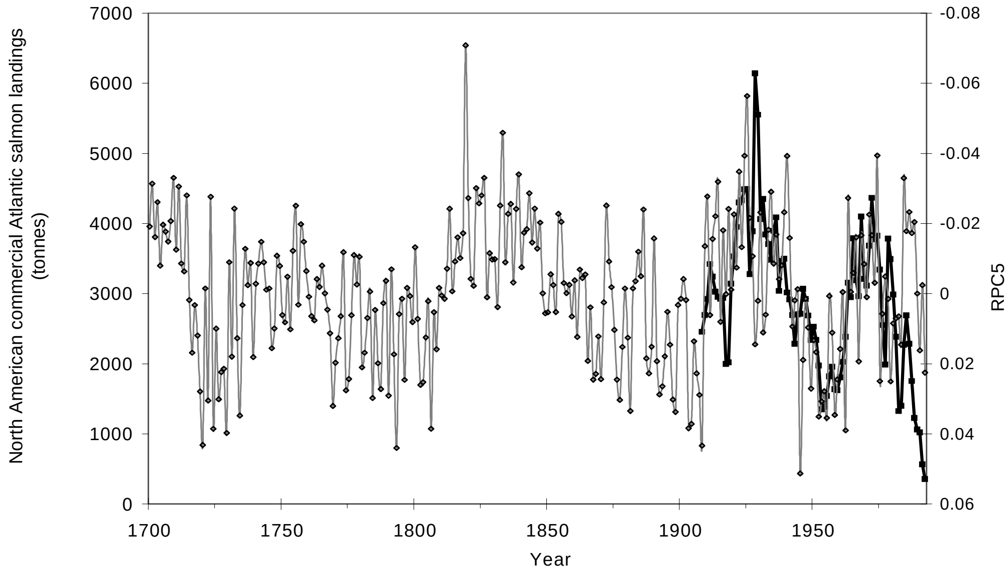
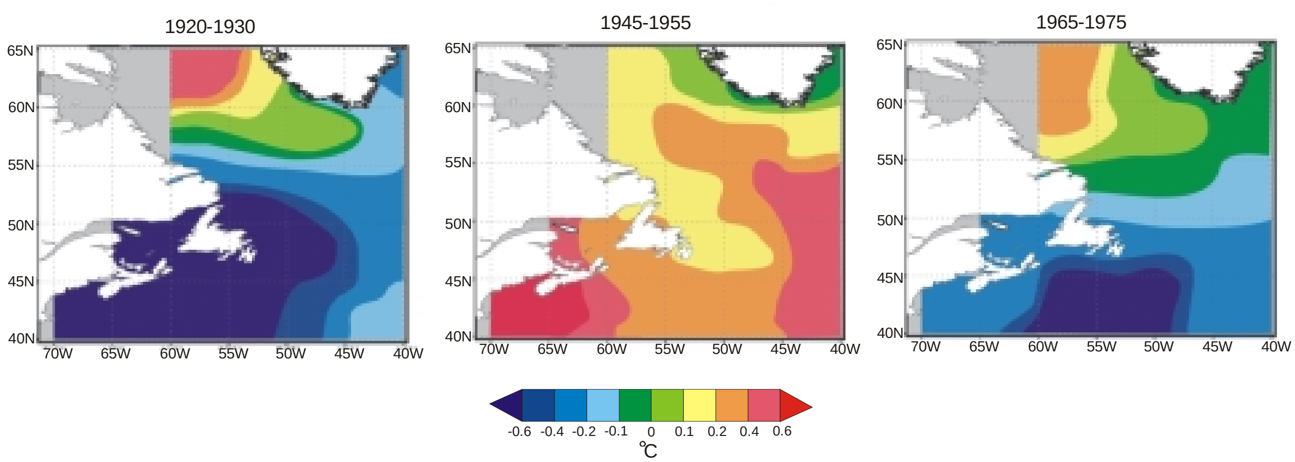


Fig. 2. 10-year average sea surface temperature anomalies showing the cold-warm-cold phase of the multidecadal cycle. The maps are drawn for time periods corresponding to high-low-high salmon production. The pattern shows that catch is negatively correlated with SST in the Northwest Atlantic.



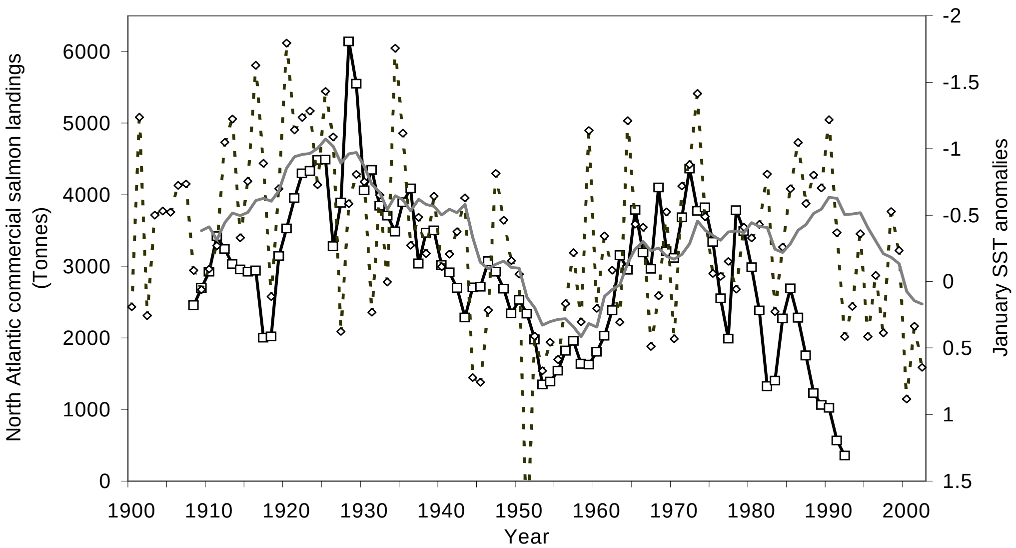
oscillation produced by principal component 5 over the past century. The correlation shows that salmon landings decrease (increase) when winter SSTs on and to the east of the Scotian Shelf are anomalously warm (cold) (Fig.3).

The results from this study suggest that large-scale multidecadal Northern hemisphere climate changes over the North Atlantic are negatively correlated with salmon production. The high correlation implies that climatic regime shifts, perhaps similar to those affecting North Pacific salmon (Mantua et al. 1997; Beamish et al. 1999) are also occurring in the North Atlantic. We can speculate that THC driven variations in the Greenland current and northward extent of warm water are altering the long-term climate of this region. However, a lack of investigation into changes in primary productivity and nutrient upwelling suggests we are still far from finding an oceanic link between the observed climate changes and those seen in salmon abundance.

Further investigation has revealed that the multidecadal signal can be traced over one hundred years of Northwest Atlantic SSTs, and can be isolated to a specific region in the winter months. This further supports the contention that winter climate conditions are affecting North American Atlantic salmon. The issue of an underlying mechanism is also advanced, as the temperature effect is no longer distant to the salmon juvenile rearing areas (Friedland et al. 1993), providing support for a freshwater winter mortality. Despite this, an oceanic overwintering influence cannot be ignored until the statistical correlations are investigated further.

The long-term climate regime shifts observed in this study bring us a step closer to understanding how climate controls salmon survival. However, the observed January correlation does not exist for the past few decades, as shown by a downward trend in salmon production in the late 1980s, despite declining SSTs (Fig. 3). For this location the trend is suggestive that recent declines in salmon abundance are not completely climate-related. However, the findings from this limited domain highlight our lack of understanding of the impact of climate on salmon and raise further concerns over the effect of future climate stress and its impact on salmonid populations.

Fig. 3. North American commercial salmon landings [black line] shown against January SST anomalies located at 40–50'N, 60–50'W [dashed black line]. A 10-year running average is drawn through the SST data [solid grey line]. Salmon production shows a strong negative correlation with SST anomalies from 1908–1980. The decline in salmon production in the 1980s is not consistent with the negative relationship observed prior to this.



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