The Regime Concept and Recent Changes in Pacific Salmon Abundance

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Key Words: Pacific salmon, climate indices, Aleutian Low, regime shifts, marine survival

In 1991, we reported a relationship between long-term trends in total Pacific salmon catches and the intensity of the Aleutian Low (Beamish and Bouillon 1991). A more complete version of the study was published two years later (Beamish and Bouillon 1993). Since then there have been a number of papers that have shown convincing relationships between decadal-scale climate trends and long-term trends in Pacific salmon production (i.e., Beamish 1995, Hare and Francis 1995, Mantua et al. 1997). However, others have reported that changes in salmon abundance could be explained entirely by fishing effects (Farley and Murphy 1997). The issue is not which explanation is correct, as both fishing and the environment can be important, but how fishing and long-term trends in the climate/ocean environment interact to regulate recruitment (Steele 1996).

An important component of this problem is the existence of trends in climate. If trends in climate are real, then the dynamics of aquatic ecosystems that are affected by climate will respond to these trends (Gargett 1997). We propose that there is evidence that indicates that trends in climate are real. We consider these trends or regimes to be a multi-year period of linked recruitment patterns in fish populations or a stable mean in a physical data series. A regime shift is characterized by synchronous and abrupt changes in the means of physical and biological data series.

We examined six well-known indices of Northern Hemisphere climate, the Aleutian Low Pressure Index (ALPI), the Southern Oscillation Index (SOI), the North Atlantic Oscillation Index (NAOI), the Atmospheric Circulation Index (ACI), the Length of Day (LOD), and the Northern Hemisphere Surface Temperatures (NHST). We standardized all indices (zero mean and unit variance). Intervention analysis on the standardized time series detected significant shifts in 1976-1977, which is a well-documented shift in several Pacific climate, environmental, and biological time series (Ebbesmeyer et al. 1991). The longer time series illustrated shifts in the late 1940s and mid-1920s that are consistent with dates reported by Mantua et al. (1997) and Minobe (1997). The time series can also be expressed as a cumulative sum (or CuSum), which is a form of integration that provides a visual method of studying trends (Fig. 1). We used the four pressure indices (SOI, ACI, ALPI, NAOI) to create a composite regime index (RI). This index can be shown to correspond closely to total salmon catches. The RI is also similar to the CuSum form of the Pacific Decadal Oscillation (PDO; Mantua et al. 1997). The inescapable conclusion is that climate indices in the Northern Hemisphere are closely linked and that there are synchronous shifts in the patterns (Fig. 1). We also propose that there is a common and as yet unknown factor that causes the shifts.

The ALPI remains as a reliable index of North Pacific climate trends. The changes in the CuSum of ALPI are consistent with the changes of RI and PDO. We use the ALPI as it has been associated with physical changes in the subarctic Pacific ecosystem (Gargett 1997), and, therefore, can be associated with physical and biological oceanographic processes, including salmon survival.

The ALPI changed in 1989-1990, when the Aleutian Low weakened. The trend to weak lows has now persisted for 10 years and is approaching the length of the 1977 to 1988 period of intense lows. Thus, we believe that there was a regime shift in 1989-1990, although the change was not to a pre-1977 state. In this respect, we propose that regime shifts are not cycles or oscillations but changes in states that can be multi-dimensional. Off Canada's west coast, in the Strait of Georgia, for example, the 1989-1990 change was from warm sea surface temperatures (SST) to even warmer SST, and was associated with more zonal winds in the winter, earlier spring freshettes, higher sea levels, and lower winter surface salinites.

If the associations between the intensity of the Aleutian Low and food production in the 1980s apply in the 1990s, it would be expected that a weakening of the Aleutian Low would be associated with a reduction in food production for salmon. The increasing temperatures would compound the impact on growth by increasing metabolic demands. If the hypothesis of Beamish and Mahnken (1998) that carrying capacity is determined by a late fall/winter mortality that is associated with growth rate during the summer is valid, the reduced food and

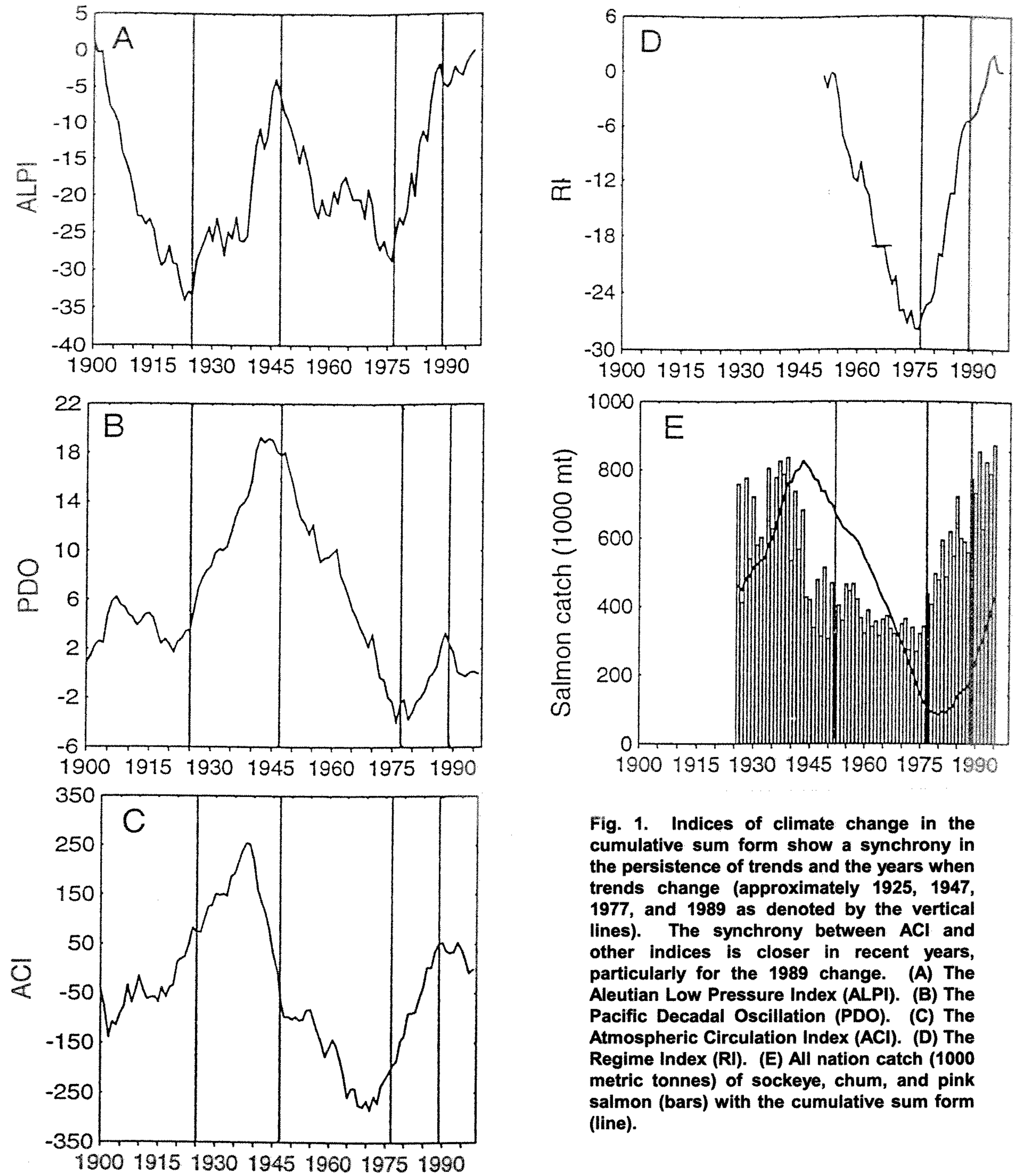

Fig. 1. Indices of climate change in the cumulative sum form show a synchrony in the persistence of trends and the years when trends change (approximately 1925, 1947, 1977, and 1989 as denoted by the vertical lines). The synchrony between ACI and other indices is closer in recent years, particularly for the 1989 change. (A) The Aleutian Low Pressure Index (ALPI). (B) The Pacific Decadal Oscillation (PDO). (C) The Atmospheric Circulation Index (ACI). (D) The Regime Index (RI). (E) All nation catch (1000 metric tonnes) of sockeye, chum, and pink salmon (bars) with the cumulative sum form (line).

increasing temperatures could increase marine mortalities in the first ocean winter. A dramatic example of the impact of the 1989 change can be seen in the synchronous decline in the marine survival of North American southern coho stocks. The return to weak Aleutian Lows in the 1990s and an even lower marine survival of coho at the southern limits of their distribution off North America, is an indication that changes in climate trends may not necessarily cause oscillations in salmon production such as proposed between northern and southern areas for chinook and coho stocks, but shifts in production among a number of possible levels.

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