CLIMATE-OCEAN CHANGES AND THE IMPACTS ON YOUNG SALMON IN THE STRAIT OF GEORGIA

R. J. Beamish and C. Neville
Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, BC Canada V9R 5K6

The climate event that occurred in the winter of 1976-77 resulted in changes in the ocean that altered the productivity trends of a number of commercially important fishes. The effects were particularly noticeable in salmon stocks. The productivity of pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), and sockeye (*O. nerka*) salmon stocks that reared in the subarctic Pacific increased, while the productivity of coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon stocks in the Strait of Georgia and probably off the coasts of Washington and Oregon decreased. The synchrony of the changes and the use of hatchery reared smolts to maintain the total production of smolts leaves little doubt that the marine changes were largely responsible for the declines in productivity of these coastal stocks.

Catches of chinook salmon in the Strait of Georgia began to decline in 1979 (Fig. 1). Synchronous with this decline was an abrupt and precipitous decrease in marine survival from an average of 4.8% from 1974 to 1977 (year to sea) to 0.7% from 1978 to 1988 (year to sea). If overfishing was the major cause of the decline, there would be a gradual reduction in smolt production at the time of the decrease in catch and marine survival. However, the total number of wild and hatchery reared chinook salmon smolts produced after the declines actually increased from a yearly average of about 30 x 10^6 from 1974-76 to about 82 x 10^6 in the early 1990s (Beamish et al. 1995).

There was a decline in coho salmon survival shortly after the decrease occurred for chinook salmon (Fig. 2). Although the average catch of coho salmon in the Strait of Georgia remained about the same, there was an increase in smolt production from about 15 x 10^6 before the change in survival to about 25 x 10^6 smolts in the early 1990s. Because the marine mortality for hatchery reared and wild coho salmon is about equal, it is clear that the addition of smolts to the Strait of Georgia did not increase the total abundance of post-juvenile fish over the pre-1977 levels.

The changes that occurred in the abundance and survival of chinook and coho salmon in the Strait of Georgia were coincident with several key physical changes that in turn were coincident with other major climate-ocean changes that occurred in the winter of 1976-77. The common factor affecting both of these ecosystems was the Aleutian low pressure system. The intensification of the low in the late 1970s increased production of salmon species resident in the offshore areas, possibly through increases in mid-ocean upwelling. The linkages with the ecosystem in the Strait of Georgia are not well understood, but they involved decreases in the snowpack and subsequently in the annual flows of the Fraser River. At the same time that the trend in flows started to decline, there was an increase in the bottom and surface temperatures in the strait. The reasons for the increases in temperatures are unknown as are the relationships with the production of coho and chinook salmon; however, it is clear that the changes would affect the Strait of Georgia ecosystem. It is also clear that the message for fisheries management is that it is necessary to understand both the natural and human factors affecting coho and chinook salmon abundance.

Beginning about 1989, there was another change in the climate-ocean system. In the tropical Pacific, the change appeared as a persistent and strong negative anomaly of the Southern Oscillation Index that was associated with higher sea surface temperatures (Trenberth and Hoar 1996). In the subarctic Pacific, sea surface temperature anomalies indicated that some warming in the central subarctic Pacific had occurred (Deser et al. 1996) and there were changes in the trend of the Aleutian low pressure system and other large-scale climate indices (Beamish et al. in prep.).

In the Strait of Georgia, there was continued warming of the surface and bottom layers. There also were larger discharges in April from the Fraser River than occurred in the past (Fig. 3). These larger spring discharges are important because they affect the timing of the spring plankton bloom. Associated with the change in the pattern of the April flows was a trend for coho salmon from the Strait of Georgia to move out of the strait (Fig. 4) and rear off the west coast of Vancouver Island. This is noteworthy because coho salmon fishing in the Strait of Georgia supports one of the most important recreational fisheries in Canada. For example, in past years at the same time of this meeting, there would be a rather substantial fishery for juvenile coho salmon. Our recent studies for this year indicate that there are virtually no coho salmon in the strait.

We suspect that the ecosystem in the Strait of Georgia changed again when the physical indices changed about 1989-90. We observed increases in the survival and abundance of Pacific hake (*Merluccius productus*) as well as observing that large numbers of chum salmon remained in the strait longer than they did in the past. There also is an indication that Pacific herring (*Clupea pallasi*) are in high abundance. In association with our colleagues, we are carrying out a 3-year study of the physical and biological factors that cause these regime shifts.

Regimes are a new and important concept in the management of Pacific salmon. A productivity regime can be considered to be the level of production within a particular ecosystem. While it is this level of production that is important for fish stocks, it is the change in regimes that is an important reference point for managers. It has been assumed in the past that the survival of salmon in the ocean is either without a long-term trend or that the highest, historic levels of production represent the upper limits of the possible marine production. The concept of regime shifts in which the equilibrium level of production abruptly increases or decreases has, in general, not been considered to be an important part of Pacific salmon management.

For fish populations, a regime shift is a change in production that is coincident with climate-ocean changes that result in a response that is synchronous for a number of species (or stocks), usually over a relatively large area. According to this definition, it is an abrupt change in equilibrium production that is important and not a reversal in a fluctuating trend.

The changes in both 1976-77 and 1989-90, although different, would be regime shifts according to our definition. In general, the 1976-77 shift included a temperature reversal and a change (increase) in the intensity of the Aleutian low. The 1989-90 change appeared as a change to higher temperatures in some areas as well as a change (decrease) in the intensity of the Aleutian low pressure system.

It is now 20 years after the 1976-77 event occurred and there is still no explanation of the cause of the event. There is growing acceptance of the impact on fishes and increasing evidence linking the climate trends in the tropical Pacific to the changes observed in the ocean, but there is no explanation of the mechanisms involved. Although the events cannot be controlled as we attempt to do for fishing effects, the effects of the regime shifts have profound impacts on regional economies. For example, it is clear when one looks at the history of the total catches of all Pacific salmon in British Columbia (Fig. 5) that the recent low catches and resulting economic hardships are in some way associated with climate effects. There are also associated impacts on the effectiveness of government expenditures and programs and on the credibility of fisheries studies. The most serious impact, however, may be in relation to our ability to detect and adapt to the effects on our fisheries caused by a general warming of our climate.

Citations

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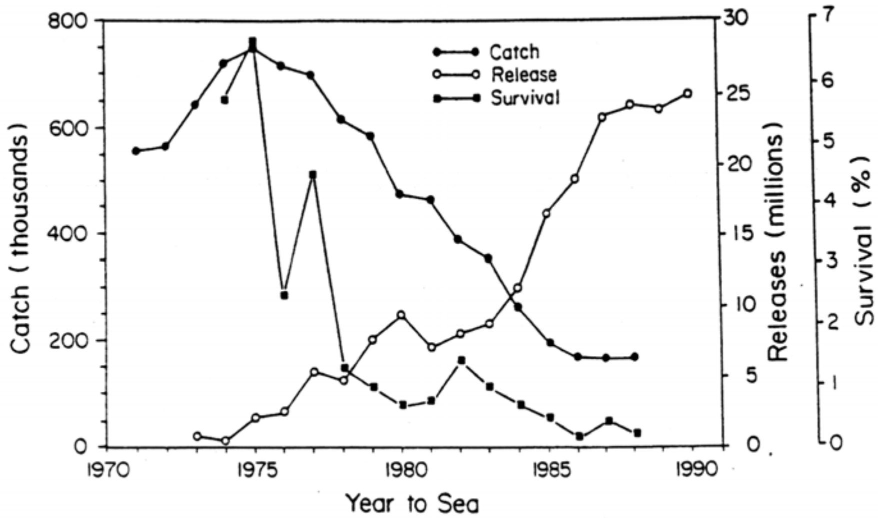

Figure 1. Commercial and sport catch of chinook salmon in the Strait of Georgia showing a declining catch beginning in 1976. The decline in hatchery survival occurred at about the same time. The releases from Strait of Georgia increased as the catches declined.

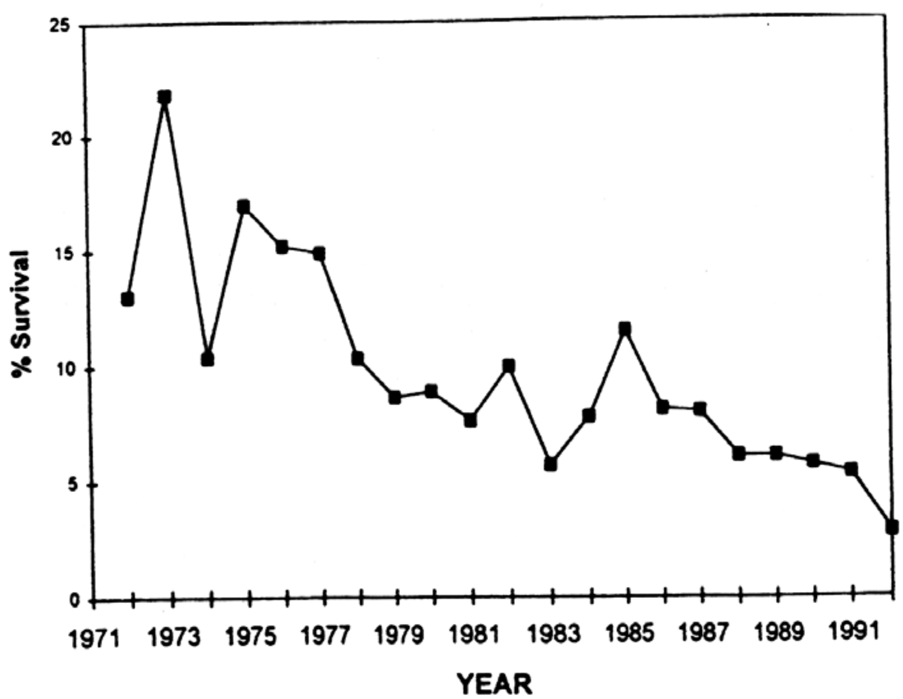

Figure 2. Survival of coho salmon from the Strait of Georgia and Fraser River hatcheries. There was a decline in average survival about 1978, approximately the same time as for chinook salmon.

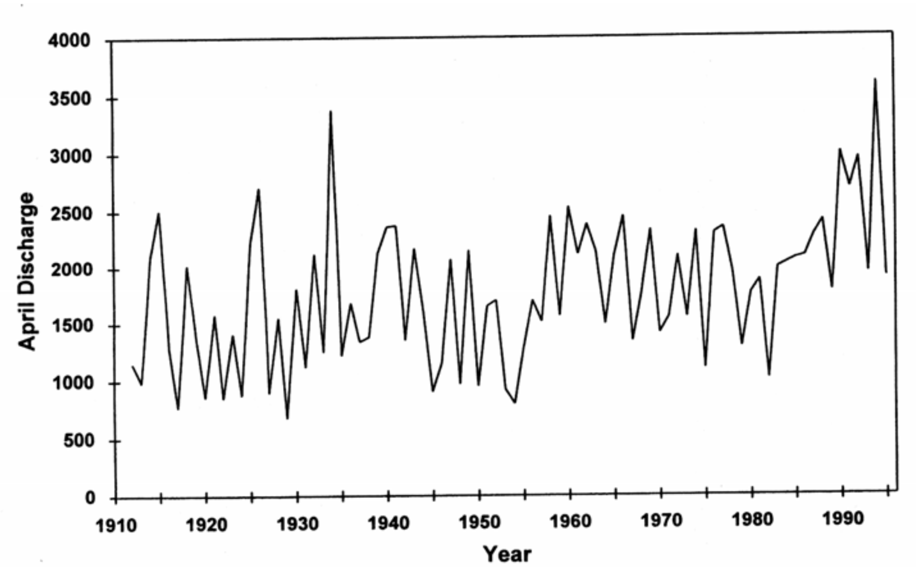

Figure 3. Average daily discharge of the Fraser River at Hope for April from 1910 to 1995. Note that since 1990, April discharge has on average been the highest in the time series.

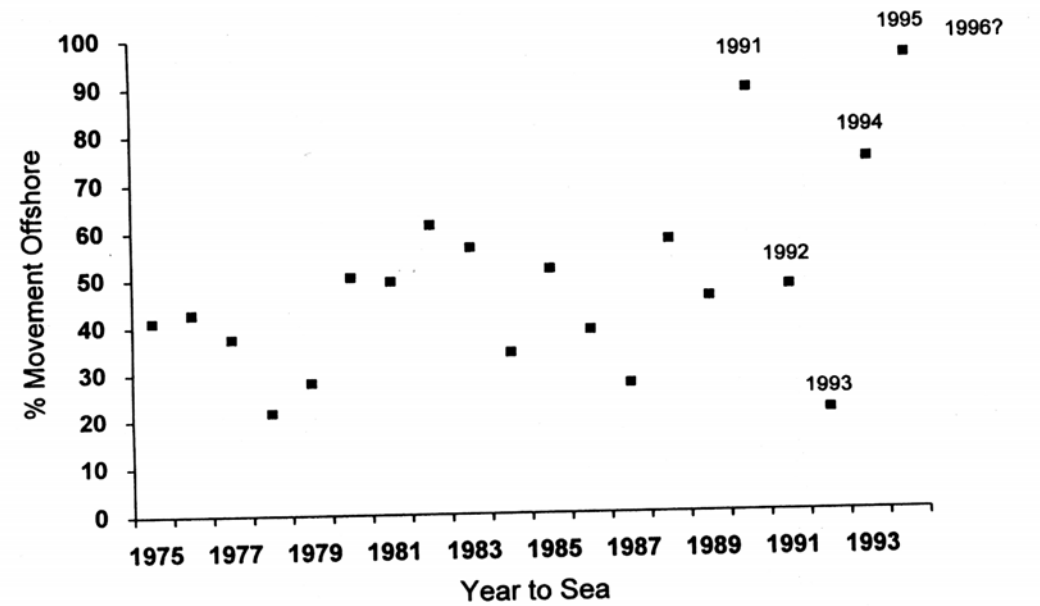

Figure 4. Percent of coho salmon caught in waters outside the Strait of Georgia that were released from hatcheries in the Strait of Georgia and Fraser River. Years written on figure are catch years. Note that since 1991 the majority of the coho salmon are moving out of the strait. The value for 1996 is an estimate but is not expected to be lower than indicated.

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Robert L. Emmett and Michael H. Schiewe

National Marine Fisheries Service
Northwest Fisheries Science Center
Coastal Zone and Estuarine Studies Division
2725 Montlake Blvd. E.
Seattle WA 98112-2097
(206) 860-3270

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