Influence of the 1990 Ocean Climate Shift on British Columbia Steelhead (*O. mykiss*) and Coho (*O. kisutch*) Populations

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British Columbia steelhead trout (*Oncorhynchus mykiss*) populations showed coherent patterns of adult recruitment until the 1990s, when recruitment patterns diverged between northern and southern British Columbia rivers. From 1963 until 1990 the pattern of temporal change in adult steelhead recruitment was similar for rivers in all regions of British Columbia (Fig. 1).

A major increase in steelhead recruitment occurred in all regions of the province following the 1977 regime shift. Subsequently, an out of phase response occurred after 1990, indicating that the effect of the 1990 regime shift had both temporal and geographical structure. Steelhead entering the ocean from rivers located in northern regions of the province had increasing recruitment after 1990, while steelhead entering southern B.C. coastal regions have had sharply decreasing recruitment (Fig. 2).

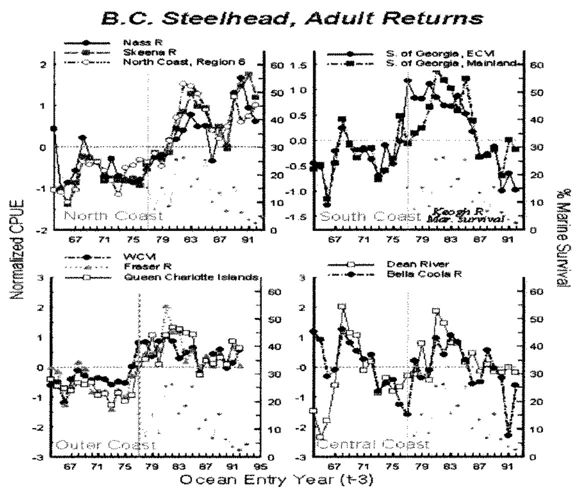

Fig. 1. Changes in normalized angler catch rates for wild adult steelhead caught in freshwater, 1967-96. The normalized abundance indices are grouped into four regions of the coast, with rivers with major steelhead populations shown separately, and rivers with minor populations aggregated. Following 1977 (vertical line) adult steelhead recruitment to all areas of the B.C. coast increased sharply. A period of high recruitment in the early 1980s is evident in all regions, as well as a smaller increase in the late 1960s. Steelhead recruitment increased again after 1990 for all rivers in northern B.C., while south and central coast populations show sharp declines; outer coast stocks show an intermediate response. Marine survival for the Keogh R. population is superimposed on each graph and shows the same pattern of increase in the early 1980s. The decline after 1990 is mirrored in the steelhead returns to essentially all rivers on either side of the Strait of Georgia and the central coast. The pattern of returns for North Coast stocks is quite different.

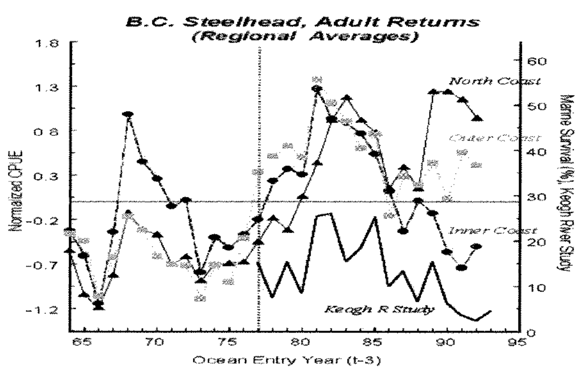

Fig. 2. Summary graph of the changes in B.C. steelhead by region. The pattern of change in Keogh River marine survival is superimposed, and matches the average recruitment response for all rivers in the south coast region.

In both the Keogh River steelhead population (located in southern B.C.; Fig. 3) and coho salmon (*O. kisutch*) in Oregon (Fig. 4), the evidence clearly indicates that the overall recruitment response since 1977 was primarily shaped by changes in marine (not freshwater) survival. These changes appear to occur both suddenly and show considerable persistence. A possible reason for the change is that ocean productivity declined in southern B.C. after 1990, reducing the marine growth of juvenile salmon.

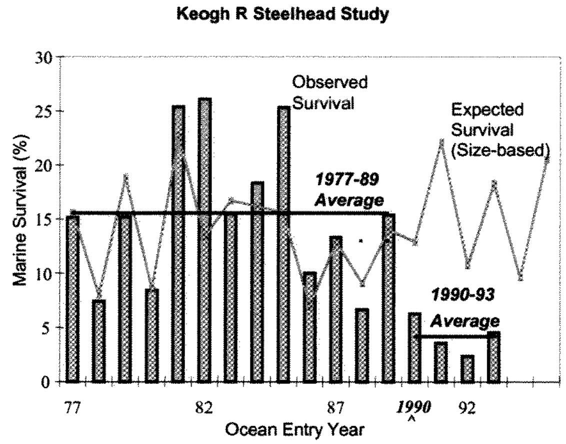

Fig. 3. Changes in marine survival of Keogh River (northern Vancouver Island) steelhead trout relative to year of ocean entry. From 1977-89 marine survival average 15.5% and deviations from this average were closely correlated with size of smolts at ocean entry; predicted deviations from mean survival prior to 1990 were positively correlated with size at ocean entry. Marine survival in 1990 and later years dropped to only one-fourth of its former average, and was no longer related to size at ocean entry. A broad scale pattern of change in marine survival is also evident, with survival increasing to a maximum in the early 1980s and then declining; however, the sudden decline in 1990 is the dominant feature of the time series.

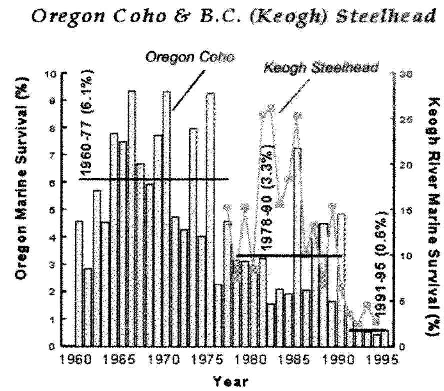

Fig. 4. Comparison of the changes in marine survival for Oregon coho salmon (bars) and Keogh River steelhead (line). The horizontal lines show the average marine survival for Oregon coho salmon for the three regime periods 1960-77, 1978-1990, and 1991-95. Note that the year defining the last period is one year later than the time of the sharp decline in Keogh River steelhead.

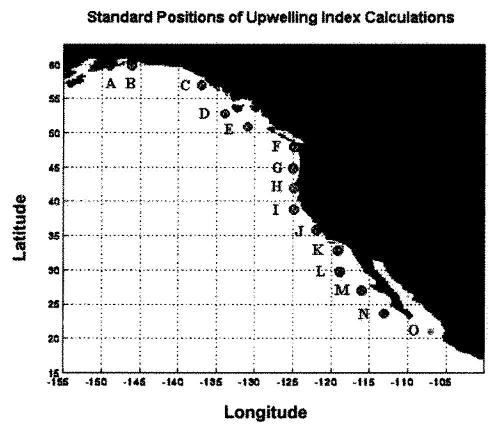

Fig. 5. Location of the standard positions for the Bakun wind indices used in the analysis.

Atmospheric winds show large scale patterns of geographic and temporal coherence. We examined the patterns of coherence in the upwelling favourable winds along the west coast of North America at 15 standard locations (Fig. 5) calculated by the NOAA Pacific Fisheries Environmental Group (*http://www.pfeg.noaa.gov/products/upwell.html*). The Bakun upwelling indices are based on estimates of offshore Ekman transport driven by geostrophic wind stress, and averaged to monthly values. They are expressed in units of cubic meters of upwelling per second per 100 meters of coastline. Monthly values of the Bakun winds were analyzed for the period January 1946 to March 1997. We conducted a hierarchical cluster analysis on the correlation matrix to examine the groups into which the months or regions clustered, in order to reduce the dimensionality of the dataset.

We first averaged the data over all 15 regions in order to obtain a single set of 12 monthly values for the upwelling indices in each year, and then performed a cluster analysis on the monthly time series to identify seasons of similarly varying winds for the whole coast. We then aggregated the monthly indices indicated by these clusters into three seasonal indices: winter (October-February), spring (March-June), and summer (July-September). We then separately compared the geographic clusters for each of the three seasons that resulted in order to identify regions of geographic coherence in the pattern of upwelling-favourable winds.

The clearest spatial clustering is for summer (Fig. 6), the period of strongest upwelling and also the season when juvenile salmon enter the ocean from the rivers. The results from the cluster analysis indicate that the summer winds fall into a series of internally coherent geographic regions. Stations in the northern Gulf of Alaska positively co-vary (A-E) and clearly cluster separately from Stations F-O lying to the south.

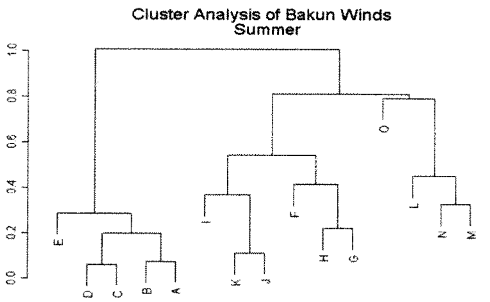

Fig. 6. Hierarchical cluster analysis of the pattern of geographic covariation in the Bakun winds.

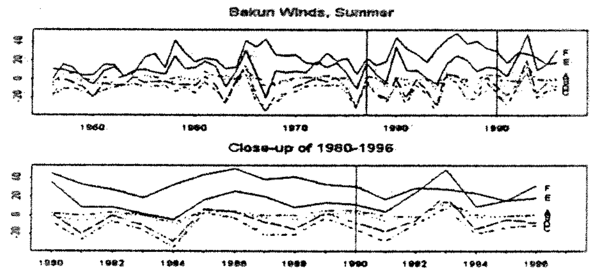

Fig. 7. Pattern of temporal change in the Bakun winds for the 6 northern-most stations along the west coast of North America. The times of the 1977 and 1990 regime shifts are indicated, and show only weak evidence for a change in upwelling favourable winds at this time.

Stations E and F are located near the northern and southern ends of Vancouver Island, respectively, and are near the coastal region that showed the sudden change in ocean survival after 1990. They fit into different clusters, indicating that the patterns of coherence in the Bakun winds are different between these regions. There is some indication for an intensification in upwelling favourable summer winds for Station F after 1977, but not for the regions to the north where most of the improvement in salmon survival actually occurred (Fig. 7). Following 1990 there is a weakening in the Bakun index for Station F and a somewhat reduced pattern of coherence of the pattern of change in the winds between Station F to the south and the wind patterns in Stations A-E farther to the north.

If the geographic pattern of wind flows changed after 1990 so that the coastal region indexed by Stations E or F now more strongly followed the wind pattern for regions to the south where steelhead survival decreased after 1977, this could explain the sudden change in the geographic pattern of survivals in southern British Columbia (Fig. 7). However, there is little convincing evidence for this change in the winds. Thus although there was a marked intensification of the Aleutian Low following 1977, the Bakun index shows little evidence of an influence on the degree of coastal upwelling.

Although the reasons for the sudden decline in ocean survival of coho salmon and steelhead are unclear, there is very good evidence that sudden climatic changes in the ocean have had a major impact on their productivity. A major effort is needed to try and establish why large regions of the ocean suddenly change and cause improved or decreased ocean survival at particular times.