DECADAL SCALE CLIMATE PATTERN AND SALMON SURVIVAL: INDICATORS, INTERACTIONS AND IMPLICATIONS

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ABSTRACT

The influence of decadal scale climatic variations on the decline of Columbia River salmon was not realized until recently. I evaluate the implications of this omission using a stock recruitment model with climatic and anthropogenic factors. I conclude that fisheries managers over the past century have misinterpreted the anthropogenic impacts on Columbia River salmon. In particular, I suggest three major events have been misinterpreted: 1) managers overestimated the significance of harvest on the catch decline after 1920 by not accounting for climatic changes that lowered ocean survival at this time, 2) managers under -represented the detrimental effects of the hydrosystem by not accounting for the contribution of good ocean survival during the years of hydrosystem development and, 3) managers underestimated the success of stock rebuilding measures in the last two decades because the concomitant poor ocean survival was not accounted for. I also suggest that the fisheries community is now evolving an ecosystem approach that considers both environmental and anthropogenic impacts on salmon.

Introduction

Over this century management strategies have been unsuccessful in halting the salmon decline in the Columbia River system. Through the failures, an understanding of the processes affecting the fishery has evolved an ecosystem perspective in which both anthropogenic and natural factors are considered. In this paper I illustrate how this history has evolved using a stock-recruitment model that represents the assumptions and projections through three management periods, each one an adaptive management experiment with unique problems and a management paradigm. In recent years this cycle has been coined adaptive management, where learning is achieved through management actions (Lee 1995).

Adaptive management involves a number of basic steps outlined in Figure 1. An action taken on a resource is based on a prior prediction of its effect. The actual effect is monitored, either by exploitation of the resource or through a specific monitoring program, and the results are evaluated through comparison with the prior prediction. Discrepancies between the predicted and observed effects are used to modify the

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management paradigm and develop new actions and predictions.

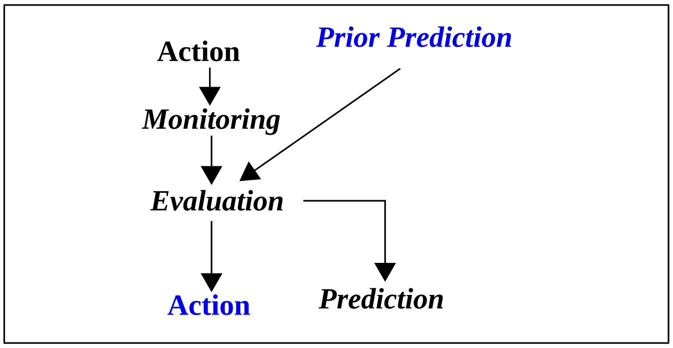

Figure 1. Steps in an adaptive management experiment.

Model

To illustrate how the management paradigm can change between experiments consider a Ricker type stock-recruitment model that contains mortality associated with hydrosystem passage, harvest, habitat loss, and changes in ocean/climate conditions. The model assumes a generic chinook stock with a fixed maturation at age four. For each cohort the model first removes harvest, second generates recruits, and third updates the population. The algorithm is

$$S_i = S_i - harvest_i * S_i$$

$$R_i = f * habitat_i * S_i * \exp(- passage_i - climate_i - b * S_i)$$

$$S_{i+1} = S_i + R_i$$

where for generation i, S_i is the harvestable population, R_i is recruitment, $habitat_i$ is a measure of spawning habitat, f is egg production per adult, $passage_i$ is hydrosystem mortality, $climate_i$ is mortality attributed to climate-induced changes in survival, b is a density dependent mortality rate, and $harvest_i$ is the harvest rate. These factors are set to represent the beliefs during each management period or experiment. Factors not accounted for in an experiment are held constant.

Important trends in the Columbia River history, representing basic paradigm shifts, fall into three adaptive management experiments: 1) harvest experiment (1866-1932); 2) hydro development experiment (1932-75) and 3) fishery rebuilding experiment (1975-95). The periods are illustrated with chinook harvest, hydro development and hatchery output in Figure 2.

Adaptive Management Experiments

The harvest experiment began with the Columbia River commercial fisheries (1860) and ended with the construction of the first mainstem dam (1932). The industry quickly expanded and stabilized between 1890 and 1920. In addition to harvest, salmon production was affected by a cumulative loss of habitat due to farming, grazing, timber harvest, irrigation, and mining (Lichatowich and Mobrand 1994). These losses were largely ignored and unregulated. Ocean and climate effects were unknown.

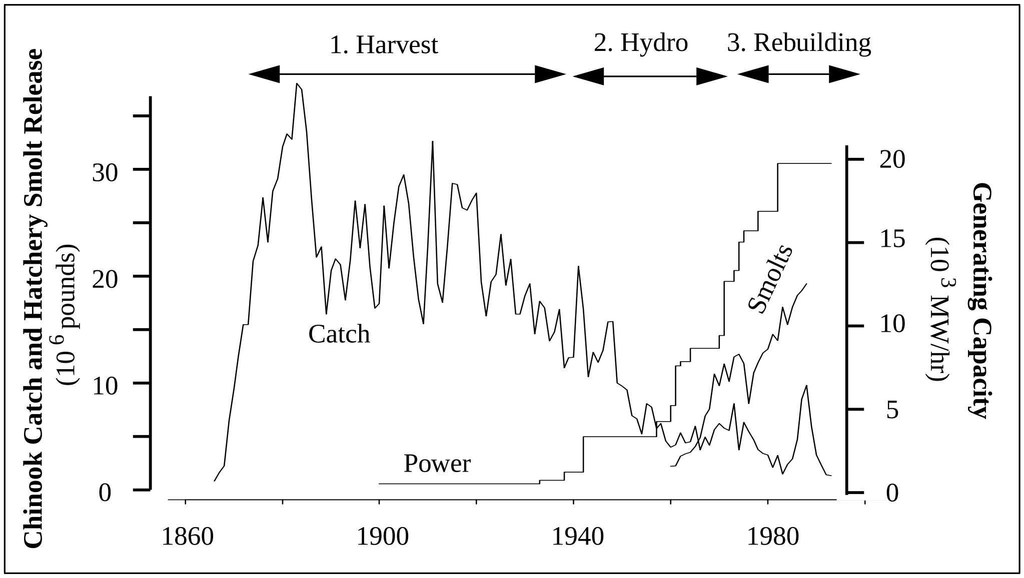

Figure 2. The history of the Columbia River has three major adaptive management experiments: harvest, hydrosystem development, and fishery rebuilding.

During the harvest experiment managers assumed that overharvest was the major reason for the catch decline and the solution was to regulate fishing. The stock recruitment model illustrates that, assuming all other factors constant, harvest reductions should have stabilized the fishery (Figure 3). Since catch was relatively stable between 1890 and 1920 there was no compelling reason to believe that limited harvest restrictions were not effective. The decline accelerated after 1920 which motivated the banning of stationary fishing gear in 1934.

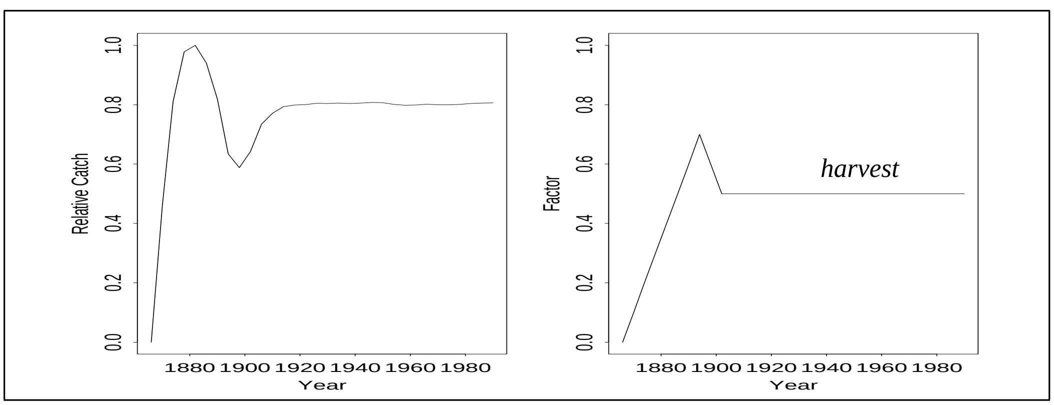

Figure 3. The harvest experiment strategy was to limit harvest rate.

A hydrosystem development experiment followed between 1932 and 1975 when nineteen major dams were build on the Columbia and Snake Rivers and many more were built in the tributaries. It was ineluctably clear that the dams destroyed spawning habitat and degraded river passage. To deal with adult upstream passage, fish ladders were installed on the mainstem dams below Chief Joseph and Hells Canyon dams but the problem of juvenile downstream passage was not addressed. To replace lost habitat hatcheries were constructed and by 1975 the biomass of hatchery smolts released into the Columbia River Basin equaled the adult catch (5 million pounds) (see Figure 2). Expressing these assumptions in the model, catch would have increased by about 1950 and a significant reduction in the harvest rate would not be required (Figure 4).

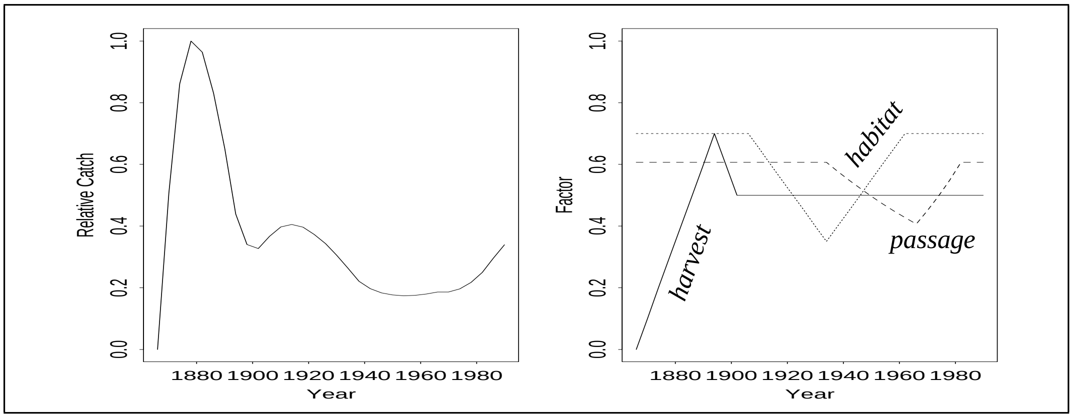

Figure 4. Management actions in the hydro development experiment included adult passage ladders and replacing lost habitat with hatcheries.

Mitigation through hatcheries and fish ladders was unsuccessful and so a third cycle of adaptive management, the stock rebuilding experiment, commenced with a program including monitoring, evaluation and models. The focus was in four areas; harvest, habitat, passage and fish production. In particular, smolt migration was identified as a problem and actions were taken to improve downstream passage survival. These included a water budget to speed smolt migration, juvenile bypass facilities and spill to divert smolts from turbines, and a program to collect and transport Snake River smolts to below Bonneville dam. In addition, since gains made in smolt passage could be lost in harvest, additional fishing regulations were implemented. With the rebuilding program assumptions represented in Figure 5 the stock decline should have been halted in the 1980s.

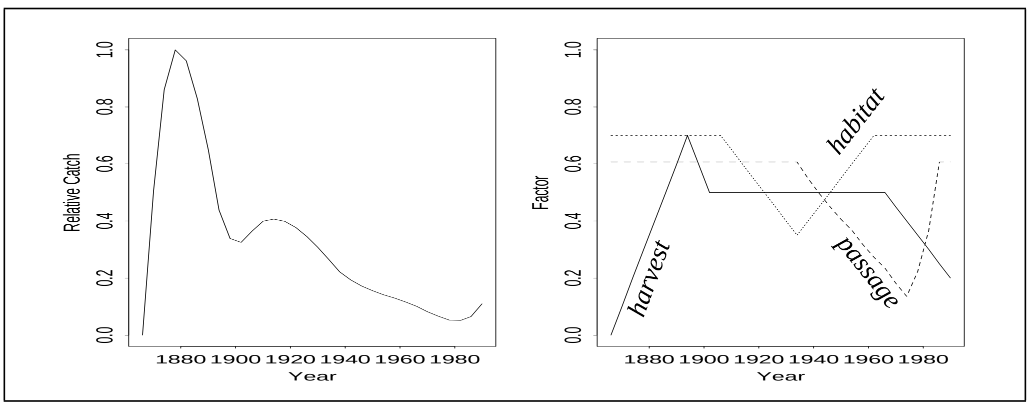

Figure 5. The fishery rebuilding experiment involved new actions including harvest restrictions and improved juvenile passage. The model indicates the stock would improve beginning about 1980.

These management actions did not stop the decline which has again brought managers to question the underlying assumptions on which the actions were based. As a result the research/management community is moving into a fourth adaptive management experiment the focus of which is to understand the fisheries through an ecosystem approach. In particular, the new focus examines the effect of decadal scale climatic and oceanic variation on fish survival. Earlier management paradigms ignored this factor.

To represent the effect of climate and ocean conditions consider the Pacific Northwest Index (PNI), which consists of air temperature, rainfall and snowpack data from the Northwest (Ebbesmeyer and Strickland 1995). The PNI pattern is similar to other climate indicators which show relationships to fish abundance and catch over the North Pacific (Beamish 1995). Of particular importance, all the climate indicators have a pronounced shift in 1976-77 when the North Pacific changed from a cool regime to a warm regime. The cool regime was favorable to West Coast salmon stocks and the warm regime was favorable to Alaskan stocks.

To illustrate the potential impact of climate, the stock recruitment model assumes the PNI is directly related to the salmon ocean survival rate (Figure 6). During hydrosystem development the PNI was high, while during the stock rebuilding phase the PNI was low. If ocean survival followed the same trend, the negative impact of the hydrosystem during its development would be masked by the concomitant favorable ocean conditions. Also, the large replacement of lost habitat with hatcheries postulated in earlier management experiments (Figure 4 and Figure 5) is not required. Otherwise the stocks would have significantly increased during the rebuilding experiment.

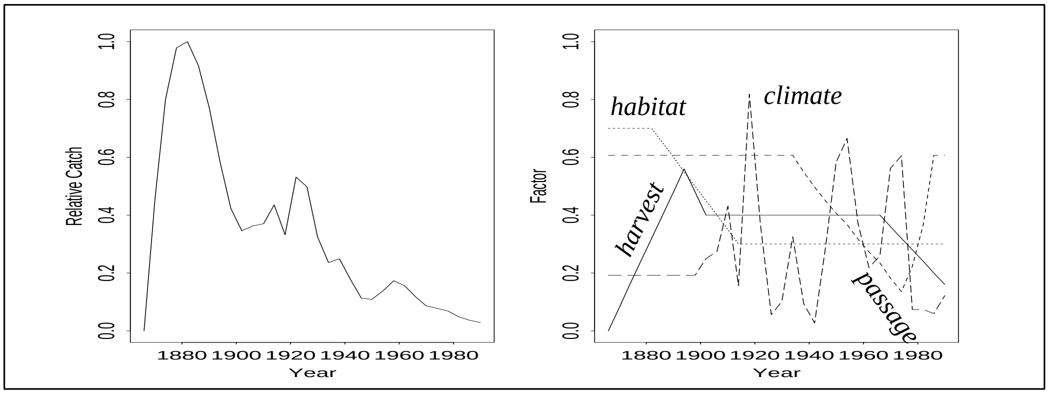

Figure 6. The ecosystem adaptive management experiment includes climate factors and downgrading of the effectiveness of habitat actions.

The 1975-76 ocean regime shift, producing in unfavorable conditions for fish, complicates the interpretation of the effectiveness of hatchery actions. Coronado-Hernandez (1996), in an analysis of salmonid hatchery survivals from the West Coast and Alaska, concluded that ocean conditions were partially responsible for the decline in hatchery productivity while disease and genetic changes were not significant factors. Previously, declining hatchery productivity was generally attributed to such factors.

The ocean regime shift also complicates the interpretation of efforts to improve smolt passage after 1976. Of particular importance is the transportation program. One hypothesis, which ignores the ocean effect, attributes the Snake River wild chinook decline to fish transportation. The evidence offered is a correspondence in the decline of survival expressed as a smolt to adult ratio (SAR) (Schmitten, Stelle and Jones 1995) to the percent of Snake River fish that were transported. Figure 7 suggests that survival went down when transportation increased.

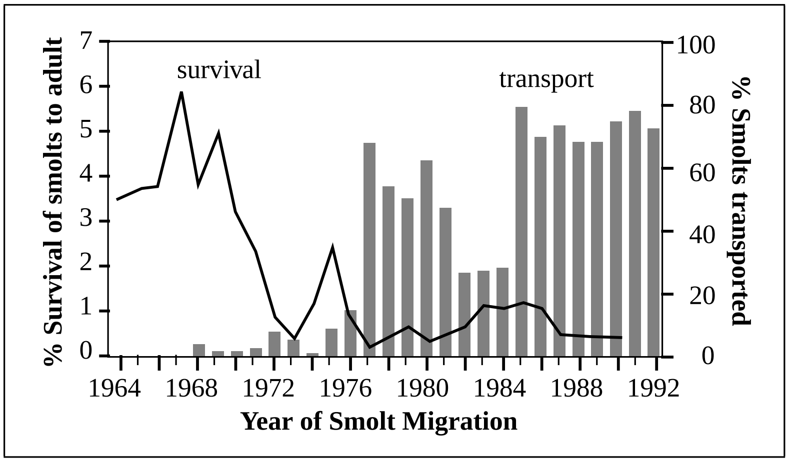

Figure 7. Snake River spring chinook smolt to adult survival and percent of the run transported.

An alternative hypothesis assumes that in-river survival has improved and fish transportation has been effective (survival of transported fish greater than 80%), but passage survival improvements were negated by poor ocean conditions. This hypothesis is supported by studies indicating high smolt survival through the Snake River (Iwamoto et al. 1996) and estimates generated from the CRiSP1.5 mainstem passage model (Anderson et al 1996), which show improving smolt passage survival since the early seventies. The improvement is attributed to reduced gas bubble disease, improved dam operations (Williams and Mathews 1995), and the transportation program, which was initiated in 1977. The contention that climate change negated passage improvements is supported in Figure 8 which shows a negative correlation between the PNI climate index and CRiSP estimated in-river survival between 1966 and 1990. Furthermore, prior to 1975 the smolt to adult survival followed the CRiSP in-river survival pattern suggesting that the poor passage conditions during the construction of the lower Snake River dams was a significant factor in lowering SAR survival between 1966 and 1975. After 1975 the SAR followed the PNI, which switched to the regime unfavorable to West Coast salmon. This suggests that poor ocean survival was a major contributor to the low SAR after 1975.

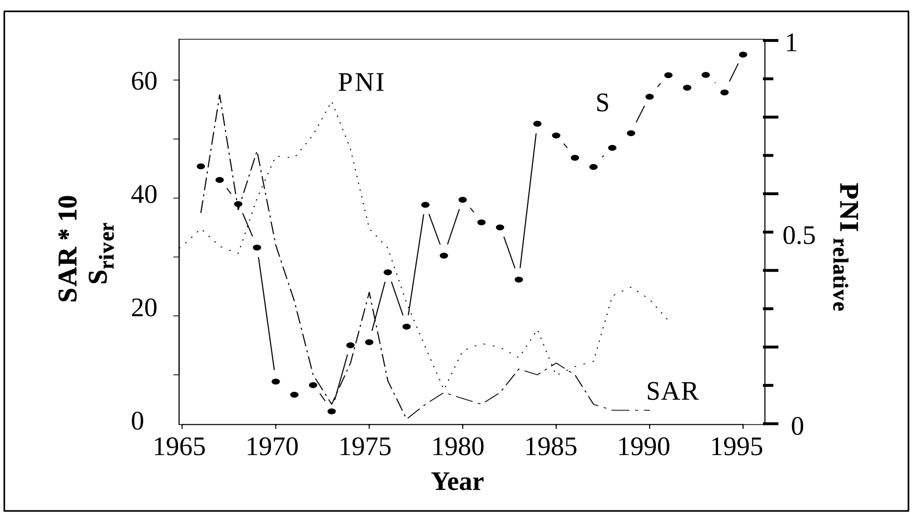

Figure 8. PNI climate indicator and juvenile passage survival estimate (S) move in opposite directions and result in declining smolt to adult survival (SAR).

Conclusions

Climate clearly has had an impact on the decline of Columbia River salmon and compels a reinterpretation of the anthropogenic impacts; principally harvest and the hydrosystem. The significance of climate is suggested in the patterns of the PNI, the hydrosystem generating capacity and Columbia River chinook catch (Figure 9). Three features are noteworthy: 1) the catch decline in 1920 corresponds with PNI change from a cool/wet regime to a warm/dry regime; 2) hydrosystem development, starting in the 1940s, was concomitant with the PNI switching back to the cool/wet regime; 3) the stock rebuilding effort, beginning in 1976, occurred with the PNI returning to the warm/dry regime.

The start of the catch decline in 1920 is possibly the result of a change in climate conditions and an inability of the harvest restrictions at the time to fully compensate for the environmental change (compare Figure 3 and Figure 6). The fact that the catch decline did not steepen during the hydrosystem development is likely the result of a return to favorable ocean conditions which compensated for the adverse effects of the dams (compare Figure 4 and Figure 6), and the failure of the stocks to increase with the rebuilding efforts in the 1980s (compare Figure 5 and Figure 6) was likely in part the result of unfavorable ocean conditions, which have counteracted improvements in smolt passage survival.

This revised interpretation for the Columbia River stock decline may never be fully supported, because of the lack of long term historical data on fish survival. In any case, it is clear that the coincidence of major natural and anthropogenic events did occur and that the fishery decline cannot be explained by anthropogenic factors alone. Realizing that natural and anthropogenic processes interact over decadal scales the community of Columbia River scientists and managers has embarked on a new ecosystem system perspective for managing the resource. The current focus is on the effects of the climate, but as an ecosystem perspective expands, including such factors as fish physiology, behavior and genetics, a more realistic understanding of the limitations and opportunities available to improve the Columbia River will evolve.

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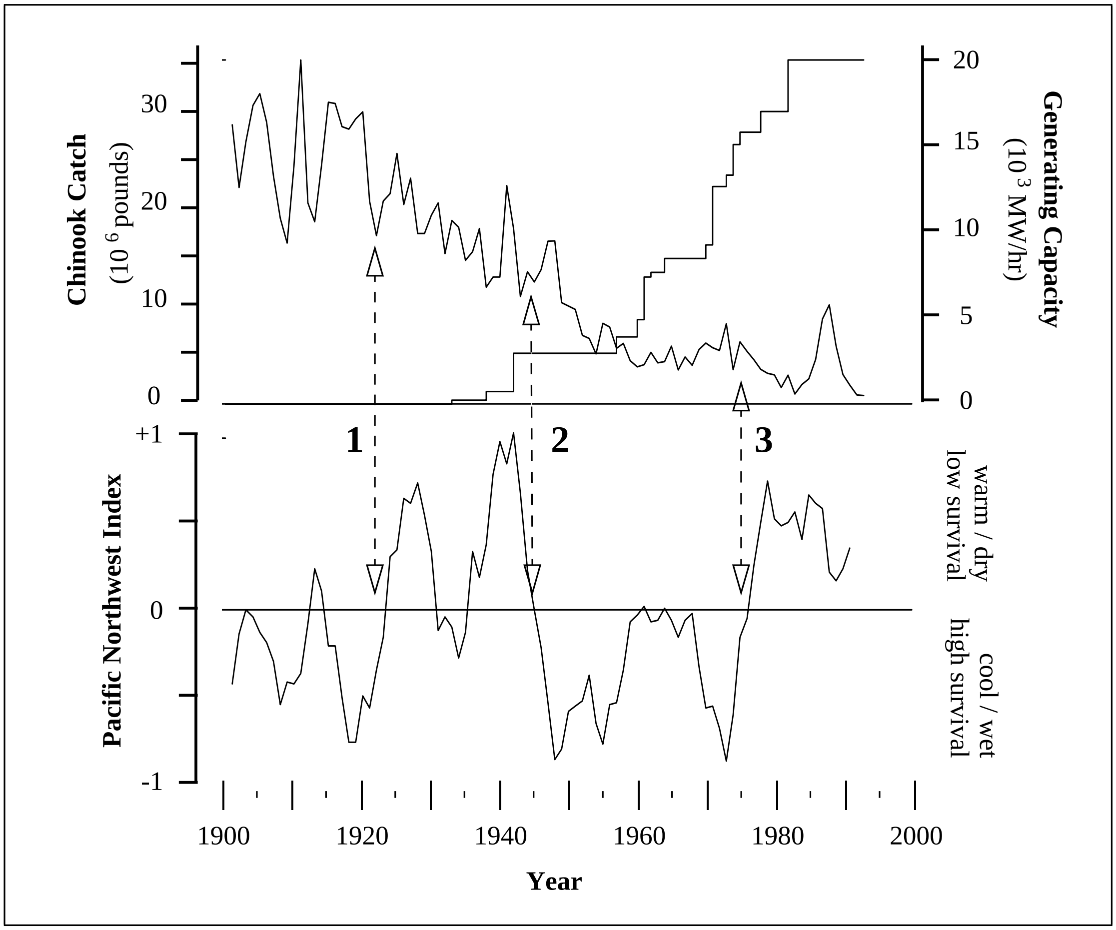

Figure 9. Major changes in the PNI climate indicator were concomitant with changes in harvest (1),the beginning of hydrosystem development (2), and the beginning of the fish transportation program.