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GLOBAL CLIMATE CHANGE AND EFFECTS ON PACIFIC NORTHWEST SALMONIDS: AN EXPLORING CASE STUDY

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OUTLINE

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I. Introduction

Recently, a number of papers have addressed global warming and freshwater fisheries. Meisner, Rosenfeld, and Regier (1988) described how increased groundwater temperatures could affect survival and growth of salmonines (salmon, char, and trout) by altering temperature and dissolved oxygen in redds (nests). Areas having optimal summer conditions could shrink at low altitudes and latitudes and expand at high altitudes and latitudes.

The recent report to Congress by the U.S. Environmental Protection Agency (Smith and Tirpak 1988) included an analysis of potential effects of global warming on fisheries of the Great Lakes, California, and the Southeast. In California, the report stated that salinity increases in the San Francisco Bay could enhance the abundance of marine fish species, while anadromous species could be adversely affected.

The prediction of climate change impacts on fisheries (especially marine fisheries) is crude at this time, relative to more well-studied sectors such as agriculture, for several reasons: the physical changes in habitat (e.g., water temperature and circulation patterns) are less predictable at this time than are air temperature and precipitation; fisheries, other than aquaculture, combine elements of both managed resources (i.e., economics, catch limits, and harvest technology are all important factors) and unmanaged ecosystems; and basic life-history and population-dynamics information is often inadequate because of the vastness of the seas and sampling difficulty. It is also difficult to anticipate how abiotic conditions in inland waters could be affected by global climate change because it is not yet possible to relate the output from GCMs, with their coarse spatial resolution and crude approximation of surface hydrology, to the flow, water temperature, and water quality information needed for fisheries assessment.

A recent symposium on climate change and fisheries (Regier 1988) explored a wide array of methodologies for forecasting the effects on marine and freshwater fish species and communities. The use of computer data bases on fish thermal tolerances, bioenergetic models, early response indicator species, and large-scale experimental studies were among the forecasting approaches discussed. There was a consensus that there are long and complex causal chains linking climatic change with ultimate effects on fisheries stocks (e.g., DeAngelis and Cushman 1989). A combination of methodologies can provide a range of possible futures but cannot be viewed with confidence as a source of "predictions."

II. Background

The Northwest Power Planning Council Fish and Wildlife Program forms the basis for much of the salmon and steelhead planning in the Pacific Northwest. In support of this plan the President's budget request for FY 1991 includes $15 million support for a program of repairs to several mainstream Columbia River dams that are projected to double the survival of downstream-migrating juvenile salmon. Concurrence among regional power and fish authorities in 1987 led to an expedited schedule for these repairs by 1994. About $28 million has been appropriated by the Congress to date for the mainstream dams (Crow 1990).

In addition to the mainstream dams, a significant effort has gone into upstream restoration projects on the various tributaries of the Columbia. One of the more ambitious programs has been launched on the Yakima River. In recent years, thanks to many changes in the river system stemming from irrigation diversions and practices, blockages from historical spawning areas, heavy fishing pressure, predators, and losses at mainstream dams during migrations, among other causes, the salmon and steelhead runs in the Yakima have fallen to a small fraction of their former size. For example, best current calculations suggest that the Yakima system may be producing about one quarter of the Spring Chinook that it is capable of producing. This capacity does not count those tributaries that are currently inaccessible to fish.[1] The Yakima Subbasin Plan represents a basis for reversing some of the damage.[2] A major hatchery would be constructed, a number of river obstructions are to be removed, water flows maintained during migration, irrigation diversions screened properly, etc. The combined total costs of all of the individual strategies in the Yakima Subbasin Plan, if fully implemented, has been estimated at over $ 157 million.[3] A summary breakdown of costs by species is shown below.

- Spring Chinook: $136.9 million
- Summer Steelhead: Spring Chinook work, plus $8.9 million
- Fall Chinook: Spring Chinook work, plus $11.4 million
- Summer Chinook: Spring Chinook work, plus $0
- Coho: Spring Chinook work, plus $0

The bulk of the restoration effort, especially for big ticket items such as the planned hatchery at $81.2 million, are charged against Spring Chinook restoration in these cost estimates, even though they might benefit other species.

All of this restoration effort, however, implicitly assumes a continuation of current climatic conditions in the Pacific Northwest. Under conditions of changed climate brought on by global warming due to the "greenhouse effect", a continuation of current climate conditions cannot be assured. Lettenmaier and Scheer, in their analysis of the Sacramento-San Joaquin River Basin of

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1 Northwest Power Planning Council, Draft Yakima River Subbasin Salmon and Steelhead Plan, June 20, 1989, p. III-37.

2 Northwest Power Planning Council, Draft Yakima River Subbasin Salmon and Steelhead Plan, June 20, 1989.

3 Ibid., Appendix B.

northern California, found that at the elevated temperatures expected under a doubling of atmospheric CO_2, the computer-simulated flow regime of tributary streams in the Sierra Nevada Mountains would shift radically (Lettenmaier 1989). A far greater percentage of annual precipitation was expected to fall as winter rain, exacerbating both winter flooding and summer low flow conditions. California's relatively small water storage reservoirs, because they are designed for within-year storage and depend on snowpack for much of their water storage capacity, are not adequate to the task of evening out this altered flow regime (Smith and Tirpak 1988, Chapter 4). The Pacific Northwest shares California's situation of having reservoirs that primarily reshape the annual hydrograph. However, because Pacific Northwest catchments are for the most part at lower elevations, the potential exists for more serious flow shifts and the same problems with reservoirs inadequate to the task. Thus, even if annual precipitation is left unchanged, there could be flow problems in Pacific Northwest rivers.

It is not expected that annual precipitation will remain constant, however. Recent work suggests that annual precipitation in the Columbia Basin may be reduced if the climate warms. Under conditions present during the mid-Holocene period, approximately 6 to 8 thousand years ago, the average annual temperature in the Columbia Basin was about 1 to 2°C warmer than under modern conditions. During that period, paleoclimate records suggest that average annual precipitation may have been 30% below current averages--comparable to the more extreme drought years in the Pacific Northwest under modern conditions. Furthermore, the evidence suggests that precipitation probably fell more as winter rain or as rain-on-snow, resulting in more winter flooding and drier summer streams. Salmonids were not nearly as plentiful.

Although global climate model (GCM) results for the Pacific Northwest suggest that precipitation would increase under an elevated temperature regime, it is not possible to dismiss a warm-dry scenario. Because of their coarse grid scale, GCMs do not include key atmospheric features such as frontal systems and key topographic features that influence precipitation such as the Cascade and Olympic Mountains. In addition, the GCMs disagree seriously among themselves concerning even the direction of change in regional precipitation patterns. THe paleorecord suggests that under warmer climatic conditions, the storm systems that bring most of the precipitation to the Pacific Northwest will tend to track farther to the north, leaving the local climate more like that of modern-day northern California.

III. Methods

As a test of the implications of climate change on salmonids in the Pacific Northwest, we simulated the impacts of climate change on Spring Chinook production in the Yakima Sub-basin using a computer modeling system developed for the Northwest Power Planning Council (NPPC). The system consists of two models, the Tributary Parameter Model (TPM), and the System Planning Model (SPM).

In a typical planning exercise for a river subbasin using the NPPC modeling system, the TPM is used to develop average values of key subbasin biological parameters that the coarser-scale SPM requires as input. The TPM takes data on each reach in a sub-basin as input. It then aggregates these input values into an entire sub-basin value, which is basically a weighted average of the individual reach values. The SPM requires data on a much wider level: some data is input for the Columbia Basin as a whole, other data is input for a particular sub-basin.

The Tributary Planning Model

The TPM models any sub-basin of the Columbia River basin as a system of the component reaches of the sub-basin. The Yakima River sub-basin, for example, is modelled as a series of 214 reaches. Model users can specify biological parameters for any of the modelled species, for any of the reaches of the system. Four parameter values are required for each reach: egg to smolt survival rate, smolt to smolt survival rate, pre-spawning survival rate, and smolt capacity. Smolt capacity is not input directly, but is calculated as a function of smolt density, which the user must provide. (A third NPPC model, the Smolt Density Model (SDM), can be used to calculate smolt densities. The SDM was not used in this simulation). The TPM weights the value of each of the survival rates by the relative smolt capacity of a reach, and calculates the sub-basin level weighted average values. The smolt capacity of each reach is summed to generate a sub-basin level smolt capacity. The TPM is documented in "Tributary Parameters Model (TPM) Ver 4.65 Users Guide", dated April 3, 1989, published by the NPPC.

The System Planning Model

The SPM simulates salmonid production in the Columbia River basin as a whole. Users specify parameters describing the Columbia River, its dams, and the characteristics of a specific sub-basin, in this case the Yakima sub-basin. The SPM allows the user to specify stock size and characteristics for natural and/or hatchery stocks, harvest rates at various life-cycle stages, survival rates at various life-cycle stages, survival rates associated with a number of aspects of hydropower projects, and the characteristics of individual hydropower projects in the Columbia Basin. The SPM is then run, simulating annual Chinook production for up to 100 years. A number of output variables can be obtained: total adult production was used to simulate the impacts of climate change. The model estimates production for each year of the simulation, but the model's outputs should be viewed as an indication of the production level the species under consideration would converge to if allowed to reach an equilibrium, and not as accurate estimates of annual run size. See the NPPC document "Technical Discussion Paper: Columbia River Basin Fishery Planning Model", dated June 3, 1986, for a more detailed description of the SPM model.

The NPPC modelling system was used to simulate the potential Spring Chinook production in the Yakima sub-basin, where potential runs refer to the runs that would exist in the absence of harvesting. Potential runs were simulated for two pairs of scenarios. The first pair of scenarios simulate the Yakima sub-basin as it currently exists, while the second pair assume that the NPPC is successful in implementing the fishery enhancement projects outlined in the NPPC's "Columbia Basin System Planning Preliminary System Analysis Report", dated March 15, 1989. The first scenario in each pair simulates current climate conditions, while the second scenario in each pair assumes a climate change induced degradation in the fish habitat.

The model input parameters needed to simulate current conditions and conditions after the NPPC enhancement program, in the absence of climate change, were obtained from the NPPC and the Yakima Indian Nation Fisheries Management office. Climate change impacts were simulated by changing specific reach values of the four parameters in the TPM. Table 3.1 contains the values of these parameters used int the SPM to simulate each case.

TABLE 3.1 Parameter Values Used to Simulate Climatic Impacts

	Existing Conditions		NPPC Enhanced Conditions	
	Current Climate	Climate Change	Current Climate	Climate Change
Natural Production Parameters				
Pre-spawning survival	0.8000	0.7987	0.9000	0.8825
Egg-smolt survival	0.2121	0.1976	0.2345	0.2167
Smolt-smolt survival	0.4876	0.4101	0.7145	0.5585
Smolt capacity	2.46 mil	1.65 mil	3.84 mil	2.45 mil
Hatchery Production Parameters				
Pre-spawning survival	NA	NA	0.9000	0.8825
Egg-smolt survival	NA	NA	0.6480	0.6480
Smolt-smolt survival	NA	NA	0.7145	0.5585
Smolt capacity	NA	NA	1.65 mil	1.65 mil

Note: There is currently no spring chinook hatchery in the sub-basin.

IV. Results

The results of the simulations are shown in Figure 4.1, in terms of total adult production of spring chinook. As shown in Figure 4.1, our climate change scenarios decrease spring chinook production by 54% in the unenhanced scenarios and by 46% in the enhanced scenarios. Given the results of this simulation, it would be necessary for considerable improvements to be undertaken in the yakima sub-basin in order to keep up with the potential habitat degradation climate change could cause. At the same time, climate change could go a considerable ways towards undoing any improvements made by the NPPC.

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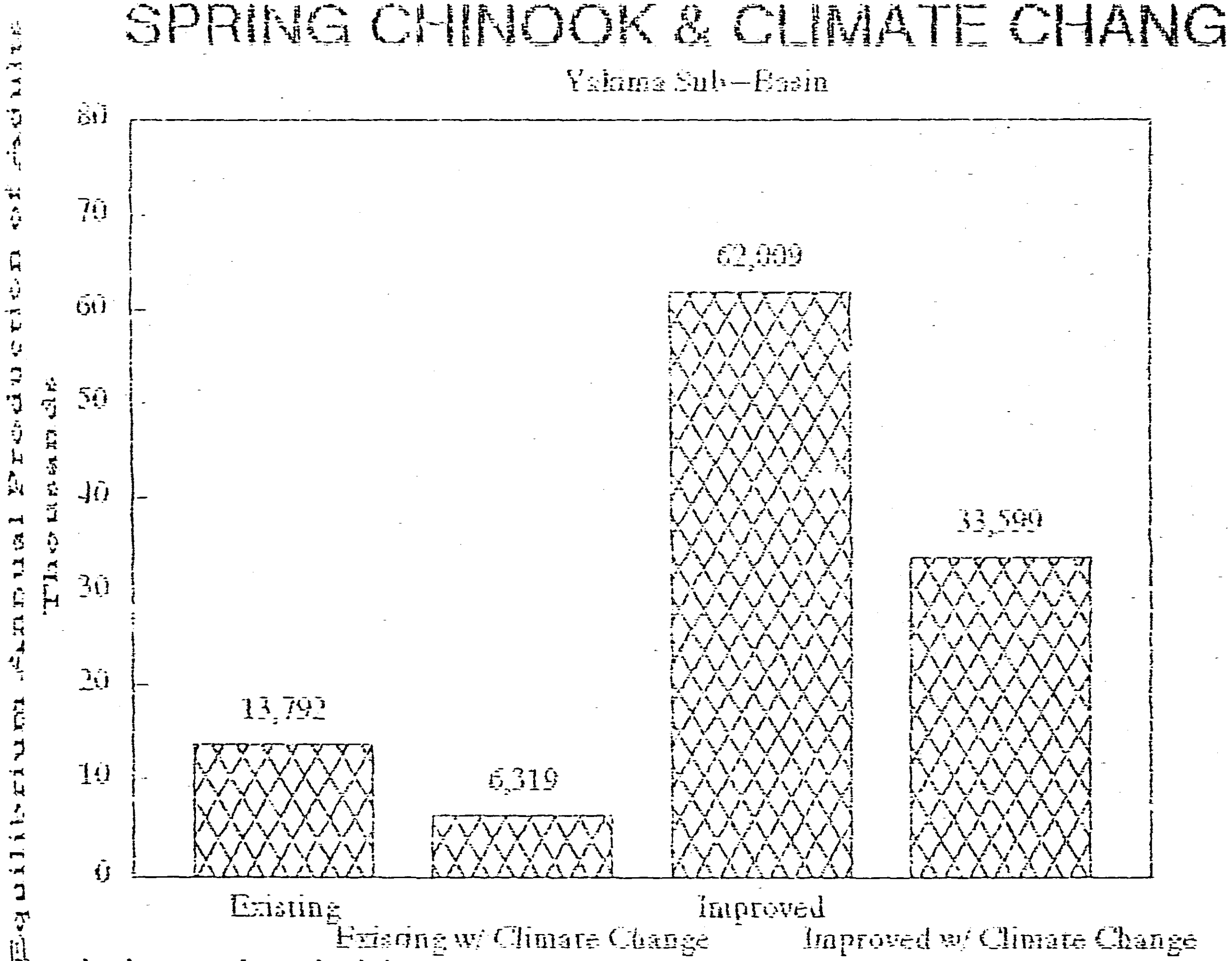
SPRING CHINOOK & CLIMATE CHANGE

Yakima Sub-Basin



Reach-by-reach methodology

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