Salmon Climate and Ecosystems Strategic Research Plan 2005

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Executive Summary

Currently we are undergoing a global shift toward warmer climates and various models suggest the earth will warm from 1 to 6^{o}C over the next century. We know that physical parameters and ecosystems respond to and are highly coupled to climate variability. These effects are particularly acute in the Pacific Northwest which lies between cooler (northern) and warmer (southern) climate regimes where ocean productivity, snow pack, and river hydrology respond quickly to climate change, and where these ecosystems supports a large number of highly valuable commercial and recreational fisheries. A critical gap in our knowledge is the ability to predict how these important commercial species of fish will respond to climate change and how to improve our management of the fisheries by incorporating climate warming into management scenarios. Salmon occupy both freshwater and marine environments during their life cycle and comprise a highly valuable commercial and recreational fishery. We will use Pacific salmon (*Oncorhynchus* spp.) to investigate the impacts of climate variability on freshwater and marine ecosystems and develop models and forecasting tools that incorporate the role of climate change into the management decisions for commercially valuable fisheries supported by the northern California Current ecosystem and the conservation and restoration of freshwater rearing habitats of the Pacific Northwest.

Introduction and Background

Considerable research during the past decade demonstrates a clear link between climate-driven conditions in marine environments and the productivity of marine and anadromous fishes, including salmon in the Pacific Northwest. Many studies have shown clearly that interannual variations in winds, upwelling and transport are correlated with growth and survival of fishes, although a biological linkage between physical variability, biological responses in the ecosystem, and managed marine fish populations has yet to be shown. In particular, for salmon, the relationship between climate forces affecting both the freshwater and marine environment may magnify the effects of deleterious or beneficial changes in survival. For freshwater systems, where salmon spend up to half of their life, we have established long-term recovery and strategic plans to aid recovery of depressed stocks. However, we presently lack studies investigating the impacts of climate variability on freshwater ecosystems and associated salmonid productivity.

What is lacking is long term data sets capturing the physical and biological conditions throughout the marine and freshwater landscape that salmonids occupy, identification of relevant trophic interactions, and an empirically-supported suite of modeling and forecasting tools to assess the sensitivity of various ecosystem attributes that influence the productivity of salmon and predict impacts from changing climate scenarios. This lack of data is problematic for National Oceanic and Atmospheric Administration (NOAA) scientists and managers because: (1) continued climate change will likely have dramatic and predictable impacts on both marine and freshwater ecosystems, and (2) changes in freshwater productivity account for fully one-half of the year-to-year variability in the population dynamics of Pacific salmonids. Moreover, even fewer studies have attempted to examine how the simultaneous interaction between climate effects in both the freshwater and marine life stages will affect salmonid populations.

We will establish an initiative to support maintenance of fledgling long-term data sets of the physical and biological structure of the California Current ecosystem, study the combined effects of climate change on the oceanic and freshwater habitats of Pacific salmon, and develop models and forecasting tools to support management decisions to address the role of climate change on salmon in the Pacific Northwest and coupling to the northern California Current ecosystem. Specifically, we will determine how interannual and decadal variations in climate affect the coupled coastal ocean and freshwater ecosystems. These proposed efforts have never been studied in such a holistic manner, thus our success will depend on collaborations between freshwater, ocean and atmospheric scientists.

Mission and Expertise

The Northwest Fisheries Science Center (NWFSC) researches links between fluctuations in climate and freshwater and oceanic processes that affect distribution, abundance, growth, and survival of salmonids in Pacific Northwest watersheds and marine waters. The abundance of salmon is related to variations in climate conditions, but this relationship is poorly understood. By focusing on ecosystem studies, we are able to examine the causal connections among components of the freshwater, estuarine, and marine ecosystem (habitat characteristics, climate-driven estuary and ocean conditions, plankton production, and fish community structure). Through these studies, we expect to gain a better understanding of the factors that control salmon production through the entire salmon landscape, make better predictions of resource status, and better assess the effects of human management on these systems.

From the perspective of the freshwater environment, we will strive to understand how salmonid populations are influenced by current climate conditions with the goal of predicting how they will respond to future changes. We will initially focus on salmonid ecosystems in the Salmon River basin in central Idaho for several reasons: first, we have long-term data on these populations and experience working with them; second, since they are high-elevation streams, they are susceptible to changes in hydrology resulting from reduced snowpack; and third, they are in close proximity to the University of Idaho and its resources.

NOAA has identified climate, ecosystems and weather and water as critical mission elements to meet its mandates. NOAA Fisheries has revised its mission statement and strategic plan to address NOAA's overarching mission. Since this proposed project is cross cutting in nature, we propose to develop three Research Teams: the **Climate** Goal Team (to include Program Component 1: Observations, Component 3: Climate Predictions and Assessment, and Component 4: Climate and Ecosystems), the **Weather and Water** Goal Team and the **Ecosystems** Goal Team. We will also integrate our efforts with IOOS/PaCOOS (International Ocean Observing System/Pacific Coast Ocean Observing System) and the California Current Large Marine Ecosystem programs as they develop.

Moreover, because this must be a collaborative cross cutting effort among NOAA elements and our academic partners, we anticipate the effort will involve scientists from NOAA Fisheries, the University of Idaho, the University of Washington, Oregon State University, and the University of Maryland. Each of these partners possesses unique qualifications vital to the success in implementing this strategic plan. In addition, considerable value will be added if we involve modelers from NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), data and data management support from NOAA's National Climate Data Center (NCDC), and the Decision Support efforts centered at the NOAA Office of Global Programs.

A critical factor in the ability to succeed is the expertise to mark fish to obtain the necessary information to derive climate related impacts to fish populations. We (NOAA Fisheries) have PIT-tagged juvenile Chinook and steelhead in up to seventeen streams per year in the Salmon River basin in central Idaho since 1988. These data yield information on migration timing and survival of juveniles. The streams represent a variety of conditions along elevation, productivity and anthropogenic impact gradients. In addition, we have conducted detailed monitoring of stream primary productivity and nutrient levels in these same streams for the past three years. We also have developed age-structured population viability models that incorporate climate effects and can analyze fish otoliths to estimate how juvenile growth rates vary with changes in climate and habitat.

The University of Idaho (UI) College of Natural Resources has expertise in physiological ecology, fish population dynamics, community, and landscape ecology. The College of Natural Resources houses the equipment infrastructure to address nutrient dynamics with two mass spectrophotometers and expertise in watershed analysis and stable isotopic approaches to ecosystems. In addition, UI owns and operates the Taylor Ranch field laboratory on pristine Big Creek in the Frank Church Wilderness, which also has served as a field site for the ongoing NOAA Fisheries research. The site has residences for scientists, a meteorological station, and direct access to salmonid spawning/rearing habitat that is relatively undisturbed (although heavily impacted by forest fires). Thus, this site offers an outstanding opportunity for detailed studies on the interactions between climate variability and freshwater ecosystems.

The Climate Impacts Group (CIG) at the University Washington has developed physical models of freshwater hydrology in the Pacific Northwest. In higher elevation streams, snowpack is a major driver of seasonal stream flow and water temperature patterns. The CIG has developed predictive models of how snowpack will decrease with global warming. For example, the CIG estimates that snowpack may decrease by 50% in the next 50 years, which will consequently alter the timing and volume of stream flows vital for salmon spawning and rearing.

Scientific Approach

Following guidance presented in NOAA's recent Program Baseline Assessment for the "Climate Program Component 4: Climate and Ecosystems", we will initiate this strategic plan by developing a **demonstration project** in the Pacific Northwest that will serve as a proof of concept for how a team of NOAA and academic scientists and resource managers can work together, using NOAA's unique set of scientists and tools, to produce an assessment of the potential response of Pacific salmon in freshwater and coastal ecosystems to a common set of climate forcing functions variations in winds and weather patterns related to the El Niño/Southern Oscillation (ENSO) cycle, the Pacific Decadal Oscillation, and interactions between the two.

To accomplish our goal of linking the “climate forcing” part of the NOAA community (the push) with the “ecosystem response” and “living marine resource management” part of NOAA (the pull), we will need to expand greatly our ability to do the following:

- Continuously **monitor** changes in freshwater, coastal and marine ecosystems through a network of in-situ and remote observing systems, following IOOS protocols;

- Develop regional-scale coupled physical-biological **models** that incorporate climate variability for ecological forecasts, and apply to assessments, and “ if…then…” scenario analyses. This work would be done in collaboration with University of Washington Climate Impacts Team, the NOAA/University of Washington RISA (Regional Integrated Science Assessment), modelers associated with the U.S. GLOBEC program at Oregon State and modelers from NOAA GFDL;

- Conduct process **research** focused on gaining a better understanding of **linkages** between climate forcing and ecosystem response. Our chief hypothesis is that climate-driven variations in coastal transport results in planktonic community types that are result in lipid-rich food chains (during cool water conditions) or lipid-poor food chains (during warm water El Niño and El Niño-like conditions). The linkage to fish is that fat, lipid-rich juvenile salmon will have higher probability of surviving winters at sea, and fat adult salmon will have a greater probability of surviving their migration back to and into freshwater and reproducing in their natal streams;

- Produce a suite of **physical climate and ocean indicators** and **ecological indicators** based on modeling, observations, and on our understanding of salmonid habitat requirements that will help determine and index the current and future status of how climate variables will influence freshwater and coastal marine ecological systems;

- Produce and distribute annual **assessments** of the Status of the Northern California Current and Pacific Northwest watersheds, and the freshwater, coastal and marine ecosystem contained therein.

- Assess the role of lipids associated with **prey resources** as the linkage between physical variability and fish population dynamics. We envision the following sequence of events: cold ocean conditions lead to lipid-rich food chains which in turn lead to greater fish survival, whereas warm ocean conditions lead to small and lipid-depleted copepods that ultimately result in lean fish that are less able to survive winter-time conditions, or if they do survive, they are likely to have a less successful migration to their natal streams.

- Enhance **hydrology models** in the Salmon River basin to operate on a finer geographic scale and to include features, particularly stream temperature. This will be coupled with field studies to investigate the integral role that Pacific salmon play in their surrounding freshwater and terrestrial ecosystems. We will continue with their field studies to PIT tag juveniles and to monitor stream nutrients. In addition, we will use empirical data from these studies, and future climate scenarios from CIG, to parameterize population viability models.

- Through **viability modeling**, predict how salmon populations will respond to future climate change and predicted changes in hydrology. The life-cycle modeling approach will allow us to contrast the effects of changes in freshwater productivity with changes in survival throughout the life cycle. The field studies will yield a better understanding of the mechanisms underlying the interactions between salmon populations and their freshwater ecosystems and how changes in climate will affect these interactions. This may ultimately lead to more efficient management of river flow.

- Develop **parallel research programs** in a variety of salmon stream types, such as those in the Puget Sound region and on the Oregon coast.

<u>Rationale</u>: Our ultimate goal is to be able to predict the probable consequences of global climate change on ecological systems and their living resources, and to deliver to fisheries managers the knowledge and tools needed to incorporate climate variability into the management of living marine resources, using Pacific salmon as a demonstration project. NOAA has made large investments towards understanding the physical climate system and describing the mechanisms that govern climate variability and climate change. However, very little work has been done to understand the impacts of climate variability or the implications of future climate change on coastal and marine ecosystems, and the response of living marine resources and coastal communities to climate forcing. We intend to build a bridge between "physical forcing" and "ecosystem response" through observations, modeling, and research, that lead to a better understanding of the critical factors that link climate variability and ecosystem response.

Organization

The organizational structure of the effort in support of the salmon climate and ecosystem theme at the NWFSC (Figure 1) reflects the focus areas outlined above. We have three Divisions that contain programs that are aligned with key research themes within the NWFSC:

1) Fish Ecology – monitor ocean ecosystem, ocean process studies, ocean indices, physical-biological models
2) Environmental Conservation – monitor freshwater ecosystem, freshwater process studies, hydrology model development
3) Conservation Biology – viability modeling

These research themes require interdisciplinary and interrelated activities, with expertise drawn from different Divisions. The effort requires coordination among programs within and between Divisions. Moreover, interdisciplinary and broad-scale research of this nature cannot be conducted without cooperation and collaboration from other agencies and organizations throughout the region. A role of the Center directorate is to assure that we are collaborating within and outside the agency, conducting cutting edge research, and not duplicating research being conducted by other organizations. Each Division has a lead to assure that we meet science, technical support, and outreach needs. The organization also provides the structure necessary to conduct research efficiently and provides for continued Program evolution or expansion.

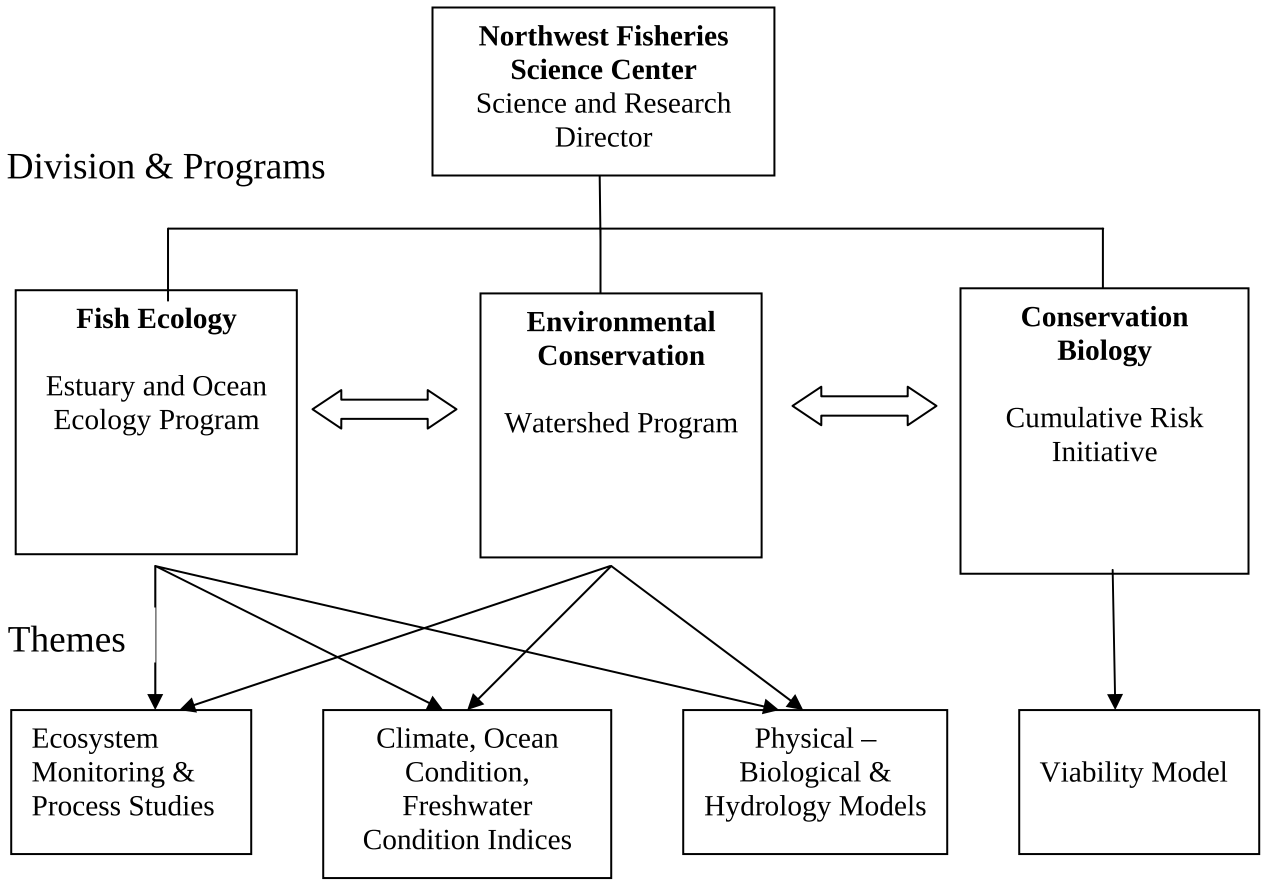

Figure 1. Organizational structure of the Salmon Climate and Ecosystem Theme team at the Northwest Fisheries Science Center.

Prioritizing Research and Allocating Resources

The research needs and questions under each of the three research teams are periodically updated and prioritized. We have gone through an internal planning and development effort to define pressing research needs. We have plans to include meeting with NOAA Fisheries regulatory staff and with stakeholders to define our research direction over the next several years.

Below we briefly summarize our initial high priority research direction over the next 3 to 5 years.

Climate and Ocean Conditions—

- Maintain long-term ocean monitoring programs (the Newport Line and the BPA transects)
- Develop an index of ocean condition incorporating physical and biological metrics
- Identify role of lipid quality of food resources on improved salmon survival
- Produce an annual report on “Status of the N. California Current Ecosystem”
- Describe role of climate change on productive marine areas for salmon
- Define role of climate and habitat on health and marine survival

Climate and Freshwater Conditions—

- Maintain long-term monitoring of juvenile salmon survival in tributaries in the Salmon River basin
- Relate juvenile salmon survival to freshwater climate indicators
- Develop growth models based on otolith data to assess how growth varies among populations and in response to climate conditions
- Develop physical models to predict how climate change will alter environmental conditions in salmon spawning/rearing habitats
- Develop models to predict how climate change will impact juvenile salmon survival and growth
- Describe salmon freshwater ecosystems in terms biotic and abiotic factors

Climate and Freshwater/Ocean Interactions—

- Determine how the condition of fish leaving freshwater rearing habitats affects their survival in marine habitats
- Develop a life-cycle model that includes potential synergistic effects between freshwater and marine life stages and model effects
- Describe linkages between marine and freshwater ecosystems via the transport of nutrients by adult and juvenile salmon

These research needs (priorities) are likely to change over time, but we feel they represent our priorities for the next 3 to 5 years given current gaps and information needed by resource managers. These will be refined by meeting on an annual basis to reflect changing needs and funding. Many of the above priorities are already being incorporated into our existing projects. To assist with planning and project tracking, we schedule the start and end of each project and other long-term projects in Table 1. This provides an estimate of when projects will be initiated and completed over the next 10 years. It also provides a schedule that can be modified should funding or priorities change.

Table 1. Timeline for initiation and completion of Climate and Ecosystem major research areas and projects. Base funding represents annual funding from NOAA Fisheries. Other funding represents outside funds or short-term grants received from within NOAA. Bold indicates fully-funded projects and italics indicates partially-funded projects.

		FY05 Funds				**Fiscal Year**						
Research Area/Project		**Base**	**Other**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Climate and Ocean Conditions												
	Long-term coastal observations	**70**	**200**	**270**	**270**	*300*	*300*	*300*	*350*	*350*	*350*	*350*
	Develop Ocean Condition Index	**10**		**10**	**10**	*10*	*10*	*10*				
	Status of N. Calif. Current	**10**		**10**	**10**	*10*	*10*	*10*	*10*	*10*	*10*	*10*
	Assess role of lipid quality				*50*	*50*	*50*	*50*	*50*	*50*		
	Climate impacts on salmon productivity					*150*	*150*	*150*	*150*	*150*	*150*	*150*
	Role of climate and habitat on survival		**200**	**200**	**150**							
Climate and Freshwater Conditions												
	Long-term monitoring in Salmon River basin		*350*	*450*	*450*	*500*	*500*	*550*	*550*	*550*	*600*	*600*
	Relate survival to freshwater indicators				*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*
	Develop growth models				*100*	*100*	*100*	*100*	*100*			
	Develop salmon specific physical models				*100*	*100*	*100*	*100*	*100*			
	Integrate salmon growth and physical model				*100*	*100*	*100*	*100*	*100*	*100*		
	Model development predictive of climate change	**50**			*100*	*100*	*100*	*100*	*100*	*100*	*100*	
	Describe freshwater ecosystem attributes				*75*	*75*	*75*	*75*	*75*	*75*	*75*	*75*
Climate and Freshwater/Ocean Interactions												
	Relate freshwater salmon condition to ocean survival				*75*	*75*	*75*	*75*	*75*			
	Develop integrated life cycle model				*100*	*100*	*100*	*100*	*100*			
	Describe freshwater/marine linkages through nutrient transport				*50*	*50*	*50*	*50*	*50*	*50*	*50*	*50*
TOTAL		**140**	**750**	**940**	*1840*	*1920*	*1920*	*1920*	*1920*	*1920*	*1920*	*1920*