Population specific in-season forecasts of Columbia River Chinook salmon (*Oncorhynchus tshawytscha*) returns for allowing selective in-river fisheries

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A. Abstract and statement of innovation

The ultimate objective of this proposed project is to protect and recover weak wild Chinook salmon (*Oncorhynchus tshawytscha*) populations and increase in-river harvest of healthy wild or hatchery Chinook salmon populations. Chinook salmon populations in the Columbia River basin vary in extinction risk status, but they are not distinguished when being targeted by in-river fisheries.

At present, in-season forecasts of fish returns (abundance) are made during the fish run for management purposes, but the current forecast must be reformed or changed because of three reasons. First, the current forecast is made not at the level of populations but only as three seasonally aggregated runs (spring, summer and fall). Furthermore, these seasons are based on fixed calendar dates that do not vary across years. We will make population-specific in-season forecasts to increase the resolution of in-river harvest selection between weak wild and healthy wild or hatchery populations. Second, accuracy is poor in the current in-season forecast during the early run. Early in-season forecast is desired but challenging because of large year-to-year variability in fish return timing. We will investigate a relationship between yearly environmental variables and fish return timing, and will predict the timing in advance. In turn, we will systematically incorporate predicted return timing into population-specific forecasts to increase forecast accuracy. Although a study might have been done about a relationship between environment conditions and return timing, no current work systematically links the relationship with a run forecast. Third, the current in-season forecast methods fail to measure uncertainty in the forecast outcomes. Given the large year-to-year variability in fish return timing, we believe that prediction intervals as well as point forecast values must be presented to managers. We will present forecast outcomes as a probability distribution, quantitatively measuring uncertainty in the outcomes. Finally we will make these new forecasts on a real-time basis during fish run.

Target fish populations used for the demonstration are Chinook salmon populations that can be segregated by genetic stock identification (GSI) techniques or with Passive Integrated Transponder (PIT) tag detection. Data on aggregated escapements to Bonneville dam (visual counts) and PIT tags from adult fish passing dams are available on a daily basis from the US Army Corps of Engineers and the Pacific States Marine Fisheries Commission. Columbia River Inter-Tribal Fish Commission (CRITFC) has collected fish tissue samples at Bonneville dam for GSI, and Hagerman genetics lab of CRITFC has analyzed those samples. We will also need to collect data on in-river catch below Bonneville dam, which have been recorded on a weekly basis by Washington and Oregon Department of Fish and Wildlife. Further we will collect environmental data considered to affect fish return timing.

We will demonstrate these new methods using "actual" data by a hind-casting procedure where, in making runs at a certain time in a past year, we use only data prior to the time, pretending we don't know the run sizes in the year. We have expertise in stochastic modeling and GSI techniques, and will be able to develop and demonstrate this proposed project. We will present final report within the 18-month time frame.

B. Technical and/or scientific background

Several wild Chinook salmon (*Oncorhynchus tshawytscha*) populations in the Columbia River basin are at extinction risk such as spring/summer and fall Chinook salmon from the Snake River and spring Chinook salmon from the Upper Columbia River. Both Snake River spring/summer and fall Chinook salmon evolutionarily significant units (ESUs) are listed as threatened, while Upper Columbia River spring Chinook salmon ESU is listed as endangered. However, Chinook salmon are still most abundant among salmon and steelhead species (*O. sp.*) in the Columbia River, and are highly valued for their flesh quality. Thus, Columbia River Chinook salmon are the main species that commercial and sport fisheries target in the river.

The biggest concern of harvest managers is in-river fisheries' failure to distinguish weak and healthy wild populations when their return timing is similar. Harvest managers have long sought a solution or way that in-river fisheries can selectively catch healthy wild or hatchery populations, protecting weak wild populations. Unfortunately a systematic and rigorous program for the solution is not developed yet.

At present, in-river harvest management decisions are based on in-season forecasts of "aggregated" Chinook salmon runs (i.e., spring, summer, and fall runs) not population specific runs. Further, those runs are defined simply by fixed return dates. Fish that are harvested in Zones 1-6 or that pass Bonneville dam through 15 June are defined as spring run, those from 16 June to 31 July as summer run, and those on 1 Aug and after as fall run (Fig. 1.; U.S. v. Oregon Parties 2005). The definition by fixed return dates is questionable because year-to-year variability in fish return timing is large and run timing is overlapped to some degree between neighboring runs. Especially spring and summer runs are significantly overlapped during June. Also, accuracy in in-season forecasts of even aggregated runs is questionable especially "early" in a return season. Early in-season forecasts are desired but challenging because interannual variability in fish return timing is large. On the basis of data on fish escapements to Bonneville dam from 1980-2005, the coefficient of variation ($CV = \sqrt{var}$ /mean) in yearly run timing at the early stage of fish run was larger than 0.5 up to about 2.0 (i.e., 50% ~ 200%) (Fig. 2b, d). In the last two years the run has been exceptionally late, setting records (since 1983) of latest passage times for every percentile. For example the 25th percentile of the 2006 run passed Bonneville dam on 7 May whereas in 2001, the 25th percentile passed on 12 April, a difference of 25 days, and by 7 May 2001, nearly 82% of the fish had passed indicating the end, not the beginning of the run. This was the latest run timing at Bonneville dam since 1982 and these types of records are held by either the 2005 or 2006 run. The entire first half (up to 54th percentile) of the run has never been later than this year.

In-season forecasts of salmon runs is a matter of prediction of fish return timing. We want to improve early in-season forecasts by investigating environmental variables as a predictor of fish return timing. Environmental variables include not only abiotic but also biotic data. Previous attempts at improving run timing predictions have focused on Columbia River flow, temperature and spill, but have revealed that these variables are not predictors of return timing. In this proposed project, we will explore the 40-year data set of nearshore and oceanic predictors involving upwelling indices, along-shore transport and monthly temperature anomalies. Also we will examine the possibility of using return timing of external populations outside the Columbia River as a predictor of Columbia River Chinook salmon return timing. Finally we will systematically incorporate a predictor of return timing into forecasts of returns. Regardless of

salmon species and setting, such a systematic link between return timing and return size was not conducted.

Further, we need to present forecasts not only as point values but also prediction intervals. The current in-season forecast methods fail to express the considerable variability in run timing. As a run timing index, the current methods use only the mean value of run proportions at a day that were observed at the day from the past years. The use of the mean value may result in serious bias in the forecast when the distribution of run proportions at a day is seriously skewed. Ignoring the large variability in run timing leads to failure to quantify forecast uncertainty, which in turn misleads managers' decisions.

In summary, our proposed project is to change the status quo of in-season forecasts of runs. We will incorporate genetic and Passive Integrated Transponder (PIT) tag data from returning fish collected and detected at Bonneville dam in order to make in-season forecasts at the level of populations, not aggregated runs. The population-specific forecasts will help managers to make harvest decisions at a relatively better resolution between hatchery and wild populations, and between healthy and weak wild populations. Also we will improve accuracy of those forecasts by investigating environmental effects on run timing. Finally, we will systematically synthesize these processes, quantifying uncertainty in forecasts.

Key personnel of this proposed project includes Saang-Yoon Hyun, Shawn Narum, W. Nicholas Beer and James Anderson. Hyun's past research and experience includes (*i*) developing a new statistical model for simultaneously forecasting returns of multiple salmon stocks, (*ii*) estimating multiple parameters in non-linear models, and (*iii*) analyzing coded-wire-tag (CWT) data. Hyun is familiar with advanced statistics, ecological modeling, and salmon management. Also, his expertise includes programming skills especially in ADMB and Splus (or R). His publications in peer-reviewed journals and his education background prove his knowledge, skills, and experience (see "H. Key personnel").

Narum has research experience in genetic stock identification (GSI) methods to estimate composition of mixed fisheries. Narum's research interests include population structure and genetic diversity of natural populations of salmonids to assist with conservation efforts. Much of his research has focused on variation in life history types, interaction of hatchery and wild stocks, mixed stock analyses, and genetic control of smoltification (see "H. Key personnel").

Beer has been a Research Scientist in the School of Aquatic and Fishery Sciences (SAFS) at the University of Washington (UW) for 10 years. His experience includes post-season analysis and reporting on real-time model predictions of upstream and downstream movements of Chinook salmon on the Columbia River, mathematical modeling of ecological processes, data analysis and publication on life-history consequences of thermal regimes on Chinook salmon (see "H. Key personnel").

Anderson is a Research Professor in the SAFS at the UW. He is the Co-Director of Columbia Basin Research (CBR), a group in the School that focuses on salmon issues in the Columbia Basin. His research group has developed models to evaluate the impacts of the Columbia River hydrosystem and fisheries on salmon. He has over 100 publications on a variety of topics including salmon migration, fish passage at hydroelectric dams, toxicology, fisheries oceanography, fisheries ecology, and decision science. He does not need a budget, but will contribute as an advisor and coordinator (see "H. Key personnel").

C. Rationale and significance to the Council's Fish and Wildlife Program

Harvest issues are clearly included as one of so-called "Four Hs" that the 2000 Fish and Wildlife Program addresses (e.g., Four Hs: hydropower, habitat, hatcheries, and harvest). The program promotes increased harvest, consistent with sound biological management practices, recognizing that harvest provides significant cultural and economical benefits to the region. Our proposed project will increase the resolution of a harvest selection that protects weak wild salmon populations and harvests healthy wild or hatchery populations.

D. Relationships to other projects

GSI analyses at the Hagerman lab of CRITFC have been funded by projects of the Pacific Coastal Salmon Recovery Fund (PCSRF) and the National Oceanographic and Atmospheric Administration (NOAA) Biological Opinion. PCSRF project has provided contributions to building the genetic baseline necessary for determining stock composition/proportion of unknown salmon over Bonneville dam. The NOAA Biological Opinion project provided funding for sampling two days per week at Bonneville dam.

To collect data about daily runs and PIT tagged fish from the past years, we will collaborate with the following agencies and parties: the US ACE, the Pacific States Marine Fisheries Commission (PSMFC), WDFW, ODFW, and the US v. Oregon TAC. Also we will collect abiotic data from the NOAA, and Canadian Department of Fisheries and Oceans (CDFO). With fund of Data Access in Real Time (DART) project, the UW CBR posts daily escapements to Bonneville dam, detection of PIT tagged adult fish passing dams, and abiotic data on its website with courtesy of the US ACE, the PSMFC, and the NOAA.

E. Proposal objectives, work elements, methods, and monitoring and evaluation

Objective: Protect and recover weak wild Chinook salmon populations and increase in-river harvest of healthy wild and hatchery populations.

A.
Sub-objective 1: Provide population-specific forecasts of Chinook salmon runs on a real-time basis for helping in-river harvest decisions

Sub-objective 2: Improve accuracy of in-season forecasts

Sub-objective 3: Help managers to make harvest decisions by presenting a forecast outcome with its uncertainty measurement as well as point value.

Work element: Develop a forecast model with data on GSI, PIT tagged fish, daily fish counts during fish run, and historical fish run timing at Bonneville dam.

Work element: Investigate environmental variables that affect fish return timing, and find a predictor of return timing.

Work element: Systematically incorporate a predictor of fish return timing into the forecast model, and present a forecast outcome as a probability distribution that contains information of not only point forecast value but also prediction interval.

METHODS

Data

Once adult Chinook salmon enter the Columbia River, they face in-river fisheries. WDFW, ODFW, and the US ACE monitor and count adult catch in zones 1-5 by in-river fisheries, and escapements to Bonneville dam (Fig. 1). We will collect historical data on catch by in-river fisheries below Bonneville dam from WDFW and ODFW. The in-river fishery catch data have been reported on a weekly basis during fish run, but they are not directly available as a collection format. Historical and in-season data on daily fish escapements to Bonneville dam are directly available from the UW CBR website with courtesy of the US ACE.

Also we will collect abiotic data on upwelling indices, spring/fall transition dates, along-shore transport, and ocean temperature from the NOAA, and Canadian Department of Fisheries and Oceans (CDFO). Those data that belong to the USA are posted in the UW CBR website with courtesy of the NOAA.

Further we will utilize data from real-time GSI analysis and PIT tagged fish that determine population specific proportions throughout the run. Hagerman genetic lab of CRITFC has historical GSI data on spring and fall Chinook salmon populations on a two-week basis from four years of 2003-2006, and it plans to report the data on a weekly basis from 2007. There is a delay from the tissue sample collection to GSI process. PIT tagged fish passing dams are available on a daily basis since 1998 at Bonneville dam, and since 2002 at McNary dam (Fig. 1).

Basic models

Data on fish abundance on a daily basis from the past years are available at the level of aggregated runs (i.e., spring, summer, and fall runs), not at that of populations. Thus, we first make in-season forecasts of aggregated runs, and then those of population-specific runs. Once fish enter the river, fish return size is monitored and reported on a daily basis. The basic idea for calculation of aggregated or total fish return size is simple. If we are given a proportion of total fish return size at a day, we calculate total return size by dividing the cumulative number of observed return abundance to a day by the proportion. The following equation is a starting point for in-season calculation of unknown total return size.

$$R_{t,\bullet} = \frac{c_t}{H_t} \tag{1}$$

where $R_{t,\bullet}$ = unknown aggregated or total return size calculated at day *t*; c_t = cumulative run to day *t*; and H_t = proportion of cumulative return at day *t*. H_t represents fish return timing at time *t*, and is inferred from historical years prior to the year. Information about proportions of total fish return size at days will be available from historical data. The main difficulty in the calculation is from yearly variability in the proportion (i.e., fish return timing) at a day (Fig. 2a, c). The variability is large especially early in the return season. It depends on correctly detecting fish return timing in advance to improve an in-season forecast of total return size.

Finding a significant relationship between an environmental variable and fish return timing will help to predict fish return timing in advance, ultimately leading to improvement in an in-season forecast of abundance. Next, we need to calculate population-specific runs, using genetic and/or PIT tag data from fish tissue samples collected on a real-time basis during fish run. GSI analysis provides population proportions and the variance estimates (Kalinowski 2004). Thus, a population-specific run is the product of aggregated run size and proportion of a population of interest: i.e.,

$$R_{t,i} = R_{t,\bullet} \cdot p_{t,i} \tag{2}$$

where subscript *i* = a population of interest; and $p_{t,i}$ = proportion of population *i* at day *t*.

If populations are identified with GSI techniques, there are two variance sources in the basic models of eq. 1 and 2, which are from H_t and $p_{t,i}$. Variance of H_t represents yearly variability in fish run timing at time *t*, and that of $p_{t,i}$ is from GSI error (Kalinowski 2004). If populations are identified with PIT tag detection, the variance of $p_{t,i}$ is negligible. H_t and $p_{t,i}$ are independently inferred.

Return timing

We need to reconstruct a return timing profile of proportions by day over past years. The current in-season forecasts of aggregated runs are based on historical and in-season data on escapement to Bonneville dam and in-river catch below the dam. Following the practice, the definition of run in this proposed project is escapement to Bonneville dam plus in-river catch below the dam. We will collect the in-river catch data from state agencies (WDFW and ODFW) for the reconstruction of historical run timing profile. The escapement data are directly available from the website of the UW CBR.

We will fit the sigmoid curve of eq. 3 or other form to the reconstructed return timing profile (i.e., data on run proportion against day). For illustration purposes at the proposal stage, we use the sigmoid curve.

$$H_t = \frac{1}{1 + \exp(a + b \cdot T)} \tag{3}$$

where T = time (day), and a and b are parameters that determine the sigmoid shape. Based on historical escapement data that we have at the proposal stage, we find that the sigmoid curve fits the return timing profile well. When we define a yearly run timing index as a day that corresponds to run proportion of 50%, it can easily be shown that the index is the following (Hyun 2002):

$$D_{0.5} = -\frac{a}{b} \tag{4}$$

where $D_{0.5}$ = day that corresponds to 50% run proportion. With historical data, we can measure run timing of the past years (i.e., $D_{0.5}$) as well as other quantiles (e.g., $D_{0.25}$).

Further we will examine effects of yearly abiotic variables on the run timing index by a regression model:

$$D_{0.5} = f(\text{environmental variables}) + error \tag{5}$$

where f = a regression function. Environmental variables include not only abiotic variables but also return timing of Chinook salmon outside the Columbia River basin. We will examine return timing of different populations at latitudes above and below the Columbia River. Generally fish from the lower latitudes return earlier than those from the above latitudes. If we find a correlation in return timing between a few external populations and Columbia River populations, we can use return timing of those external population as a predictor. We will explore the 40-year data set of nearshore and oceanic predictors involving upwelling indices, along-shore transport and monthly temperature anomalies. Because these indicators are available on a latitudinal basis extending from the Gulf of California to the Gulf of Alaska, we will examine the coastal wide patterns.

With the final model of eq. 5 that has only significant environmental variables, we can predict fish run timing in advance given measurements of those variables. We express predicted run timing index as $\hat{D}_{0.5}$. We distinguish a predicted or estimated quantity from a known or observed quantity with tilde (^).

We want to build a new sigmoid curve of eq. 3 to update H_t using the predicted run timing $\hat{D}_{0.5}$ from the regression model of eq. 5. That is, we want to estimate the sigmoid curve's parameters a and b updated with $\hat{D}_{0.5}$, because the H_t is the function of those parameters (eq. 3). Given the predicted run timing $\hat{D}_{0.5}$ and the variance of the predicted run timing, we can generate random variables of $\hat{D}_{0.5}$, with which we can build the likelihood function of a and b:

i.e., $L(a,b \mid \hat{D}_{0.5}) = p(\hat{D}_{0.5} \mid a,b)$. ML estimates of *a* and *b* updated with the predicted run timing $\hat{D}_{0.5}$ are

$$(\hat{a},\hat{b}) = \arg\max_{a,b} L(a,b \mid \hat{D}_{0.5}) \tag{6}$$

Finally we have $\hat{H}_t$ updated with $\hat{a}$ and $\hat{b}$ by eq. 3. In turn, we will be able to estimate $R_{t,\bullet}$ by eq. 1 (i.e., $\hat{R}_{t,\bullet} = c_t \big/ \hat{H}_t$) where predicted run timing is incorporated. We will also carry variances of $\hat{a}$ and $\hat{b}$ from eq. 6 through eqs. 3 and 1 to calculate variance of $\hat{R}_{t,\bullet}$ by a bootstrapping or other method.

Proportion of a population, and population-specific run $p_{t,i}$ is inferred from GSI and PIT tag data at time *t* during fish run. GSI and PIT tag data are independent of and complement each other. GSI analysis compares proportions of fish populations from the baseline and that from fish tissue samples during fish run. We will find the ML estimate of $p_{t,i}$ and the variance of the estimate by the expectation-maximization algorithm and bootstrapping (Millar 1987) or a new method.

This process of population identification is independent of the above forecast of aggregated run. Thus, we incorporate $p_{t,i}$ as another parameter. Once we find the ML estimate of $p_{t,i}$ and the variance of the estimate, $p_{t,i}$ in eq. 2 is replaced by $\hat{p}_{t,i}$: i.e., $\hat{R}_{t,i} = \hat{R}_{t,\bullet} \cdot \hat{p}_{t,i}$. Recalling that the aggregated run and the proportion of a population are independent, the calculation of variance of $R_{t,i}$ will be straightforward with a Delta method (Rao 1973, Benichou and Gail 1989), a bootstrapping, or other approach.

B.
Monitoring & Evaluation sub-objective: Test the forecast model by a hind-casting procedure

Work element: Collect data, and make forecast outcomes by a hind-casting procedure

METHODS

Target populations

In this proposed project, the definition of a population is a fish group that can be segregated by GSI and PIT tag detection. We will test our forecast model by applying it to spring and fall Chinook salmon populations. Hagerman genetic lab of CRITFC identified 13 spring and fall Chinook salmon populations in 2003-2006 with GSI analysis. Those 13 spring populations are Lower Columbia River, Willamette River, Lewis River Hatchery, Klickitat River, Yakima River, Tucannon River, South Fork Salmon River, Mid Fork Salmon River,

Upper Salmon River, Rapid River Hatchery, Mid Columbia River, Upper Columbia River, and Lostine River fish. And those four fall populations are Snake River Upriver Bright (URB), Hanford Reach URB, Deschutes River URB, and Tule fish.

Hind-casting forecasts

We will make in-season forecasts of population-specific runs using a hind-casting procedure where, in forecasting runs at a certain time in a past year, we use only data prior to the time pretending we don't know the run sizes in the year. The hind-casting forecasts are free of concern about autocorrelation in run timing over years that may exist. If the autocorrelation is significant, a method of treating years' runs independently such as retrospective or cross validation method is not appropriate. We can demonstrate our forecast model, making population-specific run predictions at several days in each year of 2003-2007.

Evaluation of forecast performance

We will evaluate the performance of our forecast model in terms of bias and precision. Relative error and frequency that prediction intervals cover true value are good measurements for the purposes (Hyun et al. 2005).

Delivery

We will share our data with the public under the Council's approval, and present our analysis to academic and/or management meetings. We will submit final report to the Council and Bonneville Power Administration whose format is abstract (summary), methods, results, discussion, and conclusions. Also we want to submit a manuscript to a peer-reviewed journal.

F. Facilities and equipment

CRITFC will provide a computer and software (R, Splus, ADMB, MathType, MS Word, etc.) for our development of forecast models and data analyses. Genetic analysis will be completed at the Hagerman Fish Culture Experiment Station operated by University of Idaho and CRITFC staff. The Hagerman site houses multiple laboratories (including genetics, nutrition, and culture) with staff and office space. The genetics laboratory is fully equipped with all major hardware to complete the objectives of this project. This includes robots for DNA extraction, thermal cyclers for PCR, and high throughput ABI capillary sequencers. The UW CBR runs the website where real-time data are posted, and also it will provide a computer and software.

G. Literature cited

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H. Key personnel

- Saang-Yoon Hyun, Quantitative Fisheries Scientist, 1,056 hours (FTE) per year. Hyun will lead this proposed project. Hyun will collect and analyze data, build forecast models, present results, and write reports.

- Shawn Narum, Lead Geneticist, 440 hours (FTE) per year. Narum will run GSI analysis.

- W. Nicholas Beer, Research Scientist, 264 hours (FTE) per year. Beer will collect and analyze environmental data that affect fish return timing, and assist with PIT-tag data timing analysis.

- James Anderson, Research Professor, 0 hour (FTE) per year. Anderson does not request budget for his role for this project. This proposed project is helped by his advice and his research group's project called DART that posts ocean and freshwater data and fish runs on a real-time basis. Also he has extensive experience of research (over 100 publications) in salmon migration, fish passage at hydroelectric dams, toxicology, fisheries oceanography, fisheries ecology, and decision science.

Saang-Yoon Hyun

Degrees

Ph.D., Quantitative Ecology and Resource Management, University of Washington, 2002
M.S., Aquatic and Fishery Sciences, University of Washington, 1996
B.S., Aquaculture and Fisheries Management, Cheju National University (Korea) 1993
- Awarded the prize of Dean at the CNU College of Oceanic Sciences for an honor graduate

Current employment

2003-present: Quantitative Fisheries Scientist, Columbia River Inter-Tribal Fish Commission
Responsibilities are (*i*) to lead quantitative research projects about ecology and management issues for Columbia River salmonids, (*ii*) to develop new research projects and funding, (*iii*) to participate in collaboration projects and to assist other projects for quantitative analyses, and (*iv*) to provide statistical consulting services for biologists in internal and external tribal agencies.

Previous employment

2002-2003: Post-doctoral Research Associate at the University of Washington
1994-2002: Research Assistant and Teaching Assistant at the University of Washington

Expertise

Hyun's past research includes development of a new statistical model for forecasting multiple salmon returns simultaneously, estimation of multiple parameters in non-linear models, population dynamics, and stock assessment. He is familiar to advanced statistics, ecological modeling, and salmon management. Also, his expertise includes programming skills especially in ADMB and Splus (or R).

Selected Publications

Hyun, S., and R. Sharma. 2007. Bayesian decision analysis for status of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*) populations at extinction risk. Fisheries Science. *Accepted*.

Hyun, S., K.W. Myers, and A. Talbot. 2007. Year-to-year variability in productivity of the Columbia River Hanford Reach fall Chinook salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography. *Accepted*.

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Education

Ph.D., Natural Resources, University of Idaho, 2006
M.S., Marine Science, University of San Diego, 2000
B.S., Fishery Biology, Colorado State University, 1996

Appointment

2002-present Lead Geneticist, Columbia River Inter-Tribal Fish Commission

Experience

My research interests include population structure and genetic diversity of natural populations of salmonids to assist with conservation efforts. Much of my research has focused on variation in life history types, interaction of hatchery and wild stocks, mixed stock analyses, and genetic control of smoltification.

Selected Publications

Narum, S. R., and M. R. Campbell. *In press*. Genetic variation and structure of Chinook salmon life history types in the Snake River. Transactions of the American Fisheries Society.

Narum, S. R., W. D. Arnsberg, A. J. Talbot, M. S. Powell. 2007. Reproductive isolation following reintroduction of Chinook salmon with alternative life histories. Conservation Genetics, DOI 10.1007/s10592-006-9268-9.

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Narum, S.R, M. Powell, and A. Talbot. 2004. A distinctive microsatellite locus that differentiates ocean from stream type Chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River Basin. Transactions of the American Fisheries Society 133:1051-1055.

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Education

MS	1996	University of Washington	Seattle, WA	Quantitative Ecology and Resource Management. Developed a mathematical model for temperature-controlled egg growth of Chinook salmon with applications to real stream conditions.
___	1990	Harvard University	Cambridge, MA	Research Fellowship. Graduate School of Education. Fellowship from Outward Bound USA
BA	1983	University of Vermont	Burlington, VT	Environmental Studies

Current Appointment and Experience

Research Consultant, CBR, School of Aquatic and Fishery Sciences, University of Washington. Mathematical modeling and research and support for mechanistic and statistical ecological models of salmon life history in the Columbia and Snake Rivers. Integration of computer models and data using programming and scripting languages: Splus, R, PERL, ARC-AML

Selected Publications

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Education:

Ph.D. 1977. Oceanography, University of Washington, Seattle, WA.
B.S. 1969. Oceanography, University of Washington, Seattle, WA.

Current Employment:

Research Professor, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA. Also Director of the Columbia Basin Research within the School of Aquatic and Fishery Sciences at the University of Washington.

Current Projects:

1989-2009: Hydro Project: various studies on the passage and survival of salmon through the Columbia River hydrosystem. Develop computer for management of Columbia River hydroelectric and fisheries agencies. The work involves building models, maintaining and implementing existing models, and analyzing data on the migration and survival of salmon through the Columbia River system and the harvest of fish in the ocean and rivers. (www/cbr.washington.edu/).

1997-2009: DART project: Provide data integration to the public for more effective access, consideration, and application as well as participating in a regional information review and making recommendations to BPA.

2000-Present: NMFS project: Support for studies of the delayed mortality of fish due to environmental stress and studies of the historical conditions of fish passage through the Columbia River hydrosystem.

Expertise:

Biomathematics, ecology, fisheries, toxicology, biodemography, animal and human behavior, decision processes, fish passage and life cycle modeling.

Selected Publications:

Zabel, R. W. J. Faulkner, S.G. Smith, J. J. Anderson C. Van Holmes, N. Beer, s. Iltis, J. Krinkie, G. Fredicks, B. Bellerud, J. Sweet and A. Girogi. (in press).Comprehensive Passage (COMPASS) Model: a model of downstream migration and survival of juvenile salmonids through a hydropower system. Hydrobiologia.

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Salinger, D. H, and J.J. Anderson (2006) Effects of Water Temperature and Flow on Migration Rate of Adult Salmon. *Transactions of the American Fisheries Society*.135:188-199.

Goodwin, R. A., J. M. Nestler, J. J. Anderson, L. J. Weber, and D. P. Loucks, (2006) Decoding Movement Patterns of Fish for Forecast Simulation Using Individual-based Modeling, *Ecological Modelling*. 192:197-223.

Springman, K. R., G. Kurath, J. J. Anderson, J. Emlen. (2005) Contaminants Viral Cofactors: Assessing Indirect Population Effects with the Vitality Model. Aquatic Toxicology 71, 13-23.

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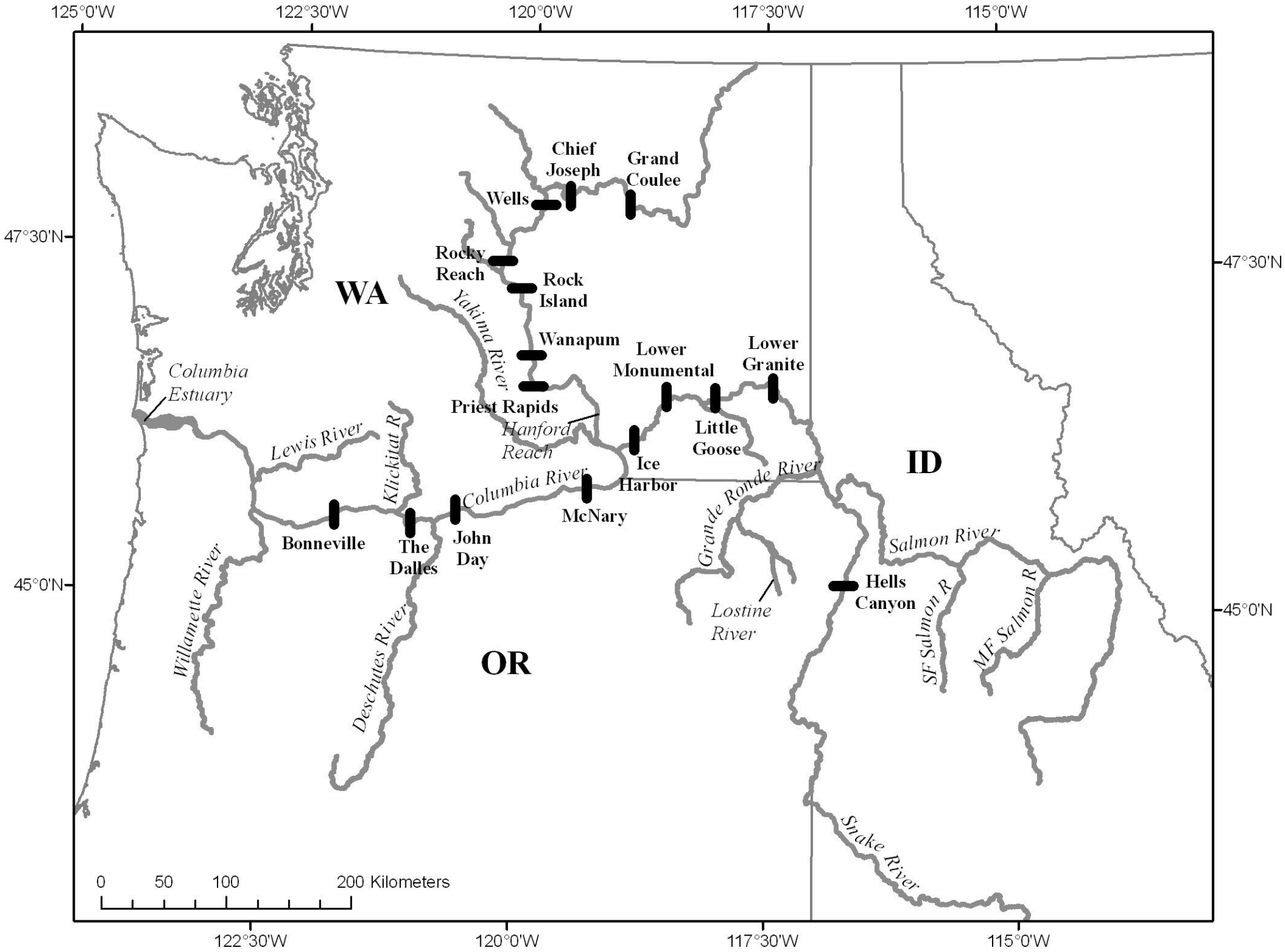
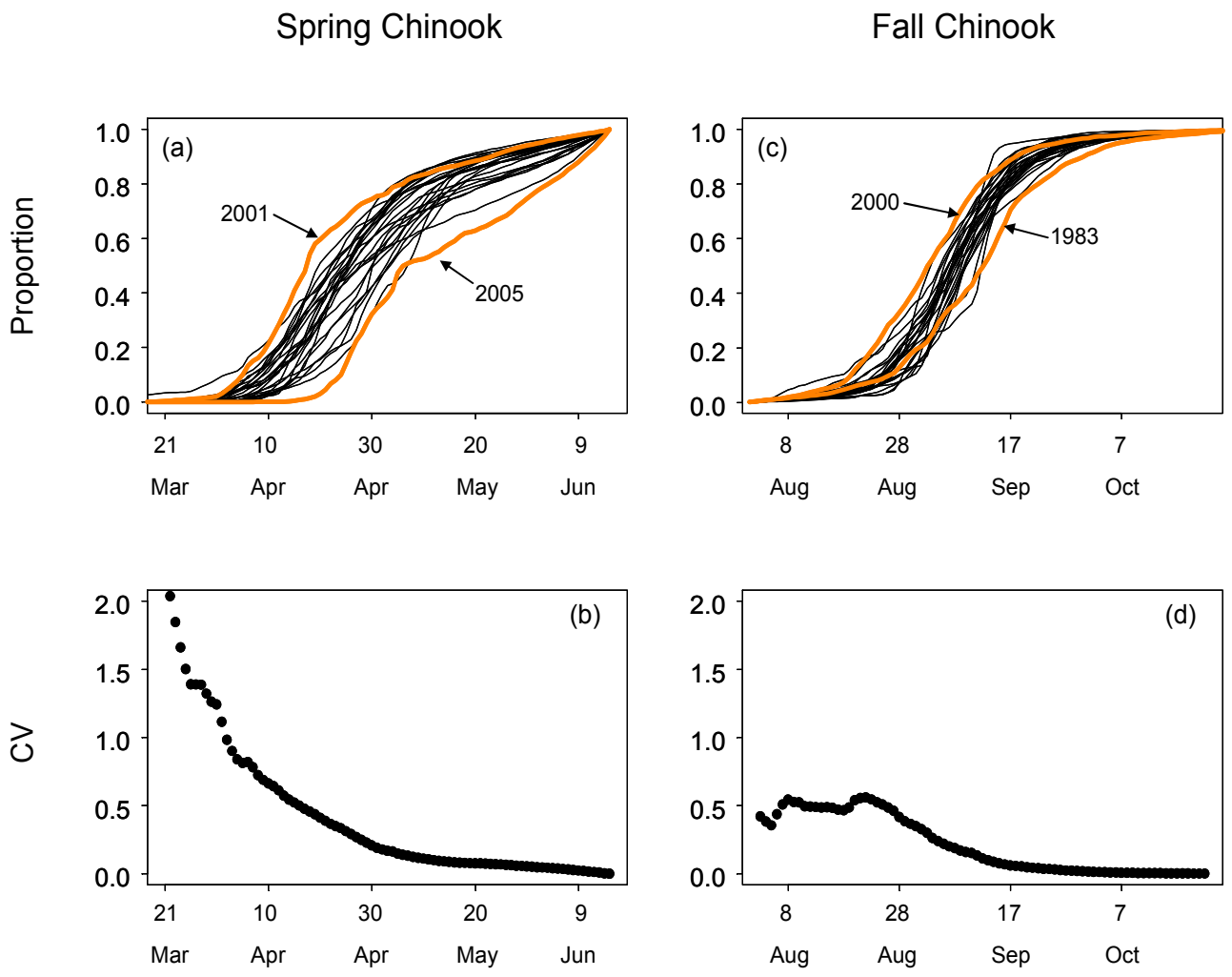
Figure captions

Figure 1. The Columbia River basin in Washington, Oregon and Idaho states. The river main stem from the river estuary to Bonneville dam are designated as zones 1 – 5, and that between Bonneville and McNary dams as zone 6.

Figure 2. Proportions of cumulative escapements at day in 1980-2005 to Bonneville dam, and yearly variability in the proportions. At this proposal stage, in-river catch data are not available, and thus we show our ideas using data on escapements to Bonneville dam. Later when we add in-river catch data, yearly variability in return sizes may be different from that in this figure. Each line in panels (a) and (c) indicates the proportions at day in a year. Panels (b) and (d) shows coefficient of variation (CV) in proportions of cumulative escapements at day in 1980-2005. The left column is for spring Chinook salmon (*Oncorhynchus tshawytscha*), where escapement from 2001 was earliest whereas that from 2005 was latest. The right column is for fall Chinook salmon, where escapement from 2000 was earliest whereas that from 1983 was latest.


125°0'W
122°30'W
120°0'W
117°30'W
115°0'W
47°30'N
45°0'N
WA
OR
ID
Chief Joseph
Grand Coulee
Wells
Rocky Reach
Rock Island
Wanapum
Priest Rapids
Lower Monumental
Lower Granite
Little Goose
Ice Harbor
McNary
John Day
The Dalles
Bonneville
Hells Canyon
Yakima River
Columbia Estuary
Lewis River
Klickitat R
Hanford Reach
Columbia River
Grande Ronde River
Salmon River
Lostine River
SF Salmon R
MF Salmon R
Willamette River
Deschutes River
Snake River
0 50 100 200 Kilometers


Spring Chinook
Fall Chinook
Proportion
CV
(a)
(b)
(c)
(d)
2001
2005
2000
1983
1.0
0.8
0.6
0.4
0.2
0.0
2.0
1.5
1.0
0.5
0.0
21
Mar
10
Apr
30
Apr
20
May
9
Jun
8
Aug
28
Aug
17
Sep
7
Oct