Evaluation of the 2003 Predictions of Run-size and Passage Distributions of Adult Chinook Salmon returning to the Columbia and Snake Rivers

W. Nicholas Beer
David Salinger
Susannah Iltis
James J. Anderson
Columbia Basin Research
School of Aquatic and Fishery Sciences
University of Washington
Box 358218
Seattle, WA 98195

1 Introduction

Visual counts of returning adult chinook have been made at Bonneville Dam each year since 1938. The detection of adult chinook at Bonneville and upstream dams provides a measure of the temporal distribution of the returning adult salmonid populations.

The adult upstream "real-time" forecaster/passage model was developed to predict the current season's adult salmon run-size at Bonneville Dam and run timing from the Bonneville Dam Tailrace to the upstream dams on the Columbia and Snake Rivers. The forecaster consists of an Escapement Forecaster (EF) that predicts the arrival timing and run-size of adult salmon at Bonneville Dam and an Adult Upstream Model (AUM) that predicts the passage timing of the fish at dams above Bonneville Dam.

During the 2001 migration season, Columbia Basin Research launched a prototype run timing system, EF /AUM, to predict run timing with results updated on the World Wide Web. This project was launched in an effort to provide real-time, in-season projections of adult salmon migration to managers of the Columbia-Snake River hydrosystem to assist the managers in decisions about mitigation efforts such as in-river harvest timing. The program EF uses an empirical pattern matching routine to predict the arrival distributions for adult chinook salmon stocks at the first detection point in the migratory route, Bonneville Dam. The AUM model takes the predictions from EF and uses hydrological, fish behavioral and dam geometry information to simulate the movement of the adult salmonid through Columbia and Snake River dams.

This report is a postseason analysis of the accuracy of the 2003 predictions from EF/AUM. The effectiveness of these modeling efforts are compared to observations of passage and river conditions at the end of the season. The analyses and graphic presentations herein demonstrate the accuracy of the models throughout the season.

2 Methods

2.1 Data

2.1.1 Escapement and run timing data

The fish analyzed in this report are adult spring and fall chinook salmon returning to spawn in tributaries or hatcheries of the Columbia and Snake Rivers above Bonneville Dam. We use the daily visual counts of returning adult chinook at Bonneville Dam for the escapement forecasts, and the daily visual counts of adult passage at McNary, Ice Harbor, and Lower Granite dams to assess the upstream run timing predictions. The adult passage visual counts data are from the Columbia River DART database (CBR 2004a); the data are provided as a courtesy by U.S. Army Corps of Engineers, NWD.

2.1.2 Flow and other system operations data

Any forecast of fish movement relies critically on accurate forecasts of flow and other key system operations. The U.S. Army Corps of Engineers generates operational forecasts at all projects on the Columbia and Snake Rivers where there is fish passage. Water supply forecasts are based on a number of factors: the National Weather Service's Northwest River Forecast Center predictions, flood control requirements from the Army Corps, electrical power demand forecasts, and other criteria. The substantial uncertainty associated with springtime conditions often results in frequent and marked changes in these forecasts during April and May. Moreover, attempts to reduce the biological impacts of dissolved gas generated from high spill levels also results in a shifting of spill between projects within as well as outside the basin. Although the forecasts covered as much as 90 days into the future, it must be recognized that their intended use was in deciding operations for the next week. Forecast accuracy beyond even a few days was itself uncertain. Bonneville Power Administration processes the Army Corps forecasts and makes them available to CBR staff throughout the migration season on a biweekly schedule.

Forecasts for flow, spill, and elevation were updated with observed values on a daily basis with a query to the Columbia River DART database (CBR 2004a), which downloads water quality data from the Army Corps. Subsequent fish arrival predictions were therefore based on the forecasted values for flow and spill and the latest available observed data.

2.1.3 Temperature data

The temperature time series is a combination of year-to-date temperature data and forecasted temperatures. The forecasts are based on observed year-to-date temperature and flow data, historical average temperature and flow profiles for 15 locations in the Snake and Columbia rivers, and the flow forecasts. Historic and observed year-to-date data was obtained from the Columbia River DART database. Temperature predictions are made by applying a three-day moving window to fit predicted temperature time series to historical average patterns of temperature change; this method is described in detail in Beer et al. (2003).

Table 1 U.S. Army Corps of Engineers fixed monitoring sites and USGS gaging stations used for temperature forecasts.

Monitoring Locations	AUM Model Input Locations
Chief Joseph Forebay	Columbia Headwater
Wells Forebay	Methow Headwater
Rock Island Forebay	Wenatchee Headwater
The Dalles Forebay	Deschutes Headwater
Anatone, WA USGS	Snake Headwater
Peck, ID USGS	Clearwater Headwater
Peck, ID USGS	North Fork Clearwater Headwater
Peck, ID USGS	Middle Fork Clearwater Headwater
Anatone, WA USGS	Salmon Headwater
Wells Forebay	Wells Pool
Rocky Reach Forebay	Rocky Reach Pool
Rock Island Forebay	Rock Island Pool
Wanapum Forebay	Wanapum Pool
Priest Rapids Forebay	Priest Rapids Pool
Lower Granite Forebay	Lower Granite Pool
Little Goose Forebay	Little Goose Pool
Lower Monumental Forebay	Lower Monumental Pool
Ice Harbor Forebay	Ice Harbor Pool
McNary Forebay	McNary Pool
John Day Forebay	John Day Pool
The Dalles Forebay	The Dalles Pool
Bonneville Forebay	Bonneville Pool

2.1.4 Archives of model predictions

The results EF/AUM runs are stored on the Columbia Basin Research web site (CBR 2004b). Graphs based on the results are available through web-based query tools at http://www.cbr.washington.edu/crisprt/index_adult.html. During the spring migration season (March 1 to May 31) and the fall migration season (August 1 to November 15), runs are made daily and include daily passage distribution forecasts and run-size forecasts.

2.2 Models

2.2.1 Escapement Forecaster

The Escapement Forecaster (EF) predicts the arrival timing and run-size of adult salmon at Bonneville Dam. It consists of a Bayesian-type algorithm with lognormal predictive density (Hyun 2002) and a prior distribution based in the early season on the previous year's jack counts and in the later season on a pattern matching algorithm. There is also a blending routine to switch smoothly between the jack-based and pattern match methods.

The jack-based routine predicts run-size by using a linear regression of each year's total adult return vs. the previous year's total jack return for each of the years 1982-2002. The correlation is strong for spring chinook, but less for fall chinook (r^2 = 0.92 and 0.22 respectively). The arrival distribution is taken as the historic daily mean scaled to produce the correct total run-size.

The pattern matching routine forecasts total run-size and run timing (daily passage) by optimally correlating the shape of the current year's cumulative passage (to date) with truncations of historical cumulative passage data. This returns the fraction of the run complete, f. Total run-size is then predicted by $\tilde{r} = P_c / f$ where P_c is the total current year passage to date.

To compare the current year's passage to that of historic runs, the cumulative current passage data is partitioned into N time intervals. The pattern matching optimization is performed as least-squares minimization; comparing slopes S_i^c over each subinterval i of the current run with slopes $S_i^h(f)$ of subintervals of each historic year run truncated after f fraction of the historic run have passed. The optimization to determine f is then performed as:

$$\underset{f \in (0,1)}{\text{minimize}} \sum_{h \in H} \sum_{i=1}^{N} \left(S_i^c - S_i^h(f) \right)^2$$

where H is the set of historical data years being used.

After the pattern matching method determines the completed fraction f of the current run, the passage forecast for each remaining day of the season is produced by appending the historic daily mean passage for each day of the final $1-f$ fraction of the season – scaled to produce the correct total run-size. In this way, the forecast may be a forward or backward shift in time as compared to the historic average, thereby forecasting not just run-size, but also run timing.

2.2.2 Adult Upstream Model

The Adult Upstream Model (AUM) describes in detail fish movement through reaches and dams and the effects of various river operations on their migration. For in-season forecasts we use the projected escapement at Bonneville as input to AUM and predict the arrival timing at the upstream dams. The model contains a temperature and flow based submodel for reservoir passage and submodels for dam passage, fallback and straying. In addition, it includes a bioenergetic model to predict fish migration energy consumption. River flow and temperature are modeled using portions of the CRiSP smolt passage model. Fish travel time has been calibrated using PIT-tag data of adult chinook detected at both Bonneville and Lower Granite dams. A paper describing the theory and calibration of the model is in preparation (Salinger and Anderson, b). The temperature and flows encountered by upstream migrating salmon are the main factors determining reach migration speed and a submodel controls this process. The flow encountered should subtract directly from the swimming speed in order to compute net up-river velocity. Because oxygen metabolism of chinook is optimal at about 17°C, the sustainable swimming speed is also optimal at about 17°C. To represent this, we use a broken linear model for the net up-river velocity V_M in terms of temperature θ and flow F:

$$V_M = \begin{cases} \beta_0 + \beta_1\theta + \beta_3\mathrm{F}, & \text{where } \theta \le \tilde{\theta} \\ \beta_0 + \beta_1\tilde{\theta} + \beta_2(\theta - \tilde{\theta}) + \beta_3\mathrm{F}, & \text{where } \theta > \tilde{\theta} \end{cases}$$

where β_0, β_1, β_2 and β_3 are the coefficients and $\tilde{\theta}$ is the break point (approximately 17°C). In each reach, the travel time distribution is determined by the migration velocity V_M and by the rate of spreading V_{VAR} (Zabel and Anderson, 1997). Salinger and Anderson (a) more fully develops the net up-river velocity submodel. The migration velocity parameters and the spread parameter (V_{VAR}) are determined from historical data using an optimization routine that compares model predicted passage distributions to observed ones. The arrival distributions were constructed from PIT-tag data of fish detected at both Bonneville and Lower Granite Dams for 1998-2002. These are combined into weekly cohorts with known travel time median and standard deviation. The cohorts create a release distribution at Bonneville Dam, and the model results are compared to the observations using least-squares optimization to pick the best parameterization of the model. Fall-back and dam delay are components contributing to the distribution of travel times for the fish.

2.2.3 Schematic of data and modeling

The relationship of the data and models is depicted in Figure 1. An obstacle to Bonneville escapement prediction for spring is the arbitrary May 31 cut-off date for the spring chinook run, which can make a late run appear smaller, or an early run appear larger, than would be otherwise recorded.

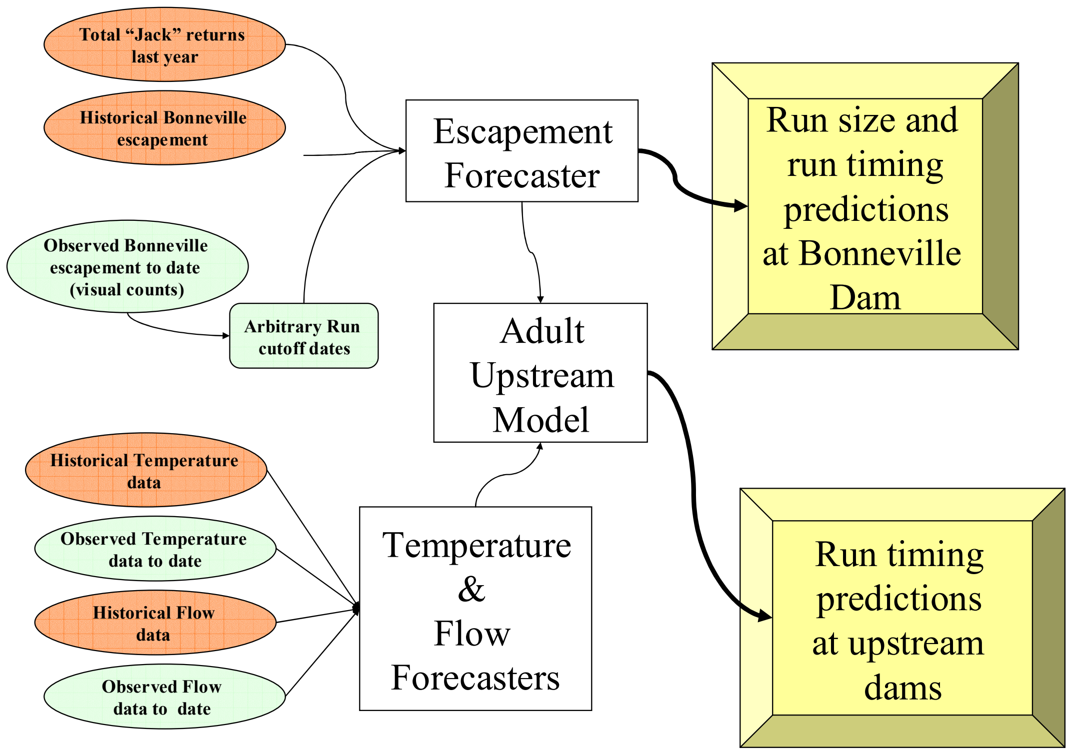

Figure 1 Schematic of data, models and products. Brown is used for historical data, green is observed up-to-date information, white boxes are modeling processes and the yellow frames are final products.

2.2.4 Postseason Assessment of Predictions

To assess the performance of the EF run-size predictions, we compute the earliest day after which we consistently predicted the final run-size to within 10, 20 and 30% of the true run-size, and we determine what percent of the run had been completed on that day. Run size predictions are important for catch allocations and compliance with federal and state regulations on fishery management. There is no established standard by which these predictions are evaluated. In future years (or in a retrospective analysis), these results will be used to compare inter-year performance.

To assess the performance of passage timing predictions, we apply the same measure used to assess RealTime/CRiSP predictions (Beer et al. 2003). For each stock at each observation site, we compute the Mean Absolute Deviation (MAD) for the day (j) on which the prediction was made. This measure is based on the average deviation between predicted and observed cumulative passage on prediction dates during the season. MAD is computed as:

$$MAD_j = \frac{1}{N}\sum_{t=1}^{N}\left|F_{Day_t} - \hat{F}_{Day_{tj}}\right| \times 100$$

where:

- j = forecast day on which MAD_j is calculated;
- t = index of prediction day (from 1 to N);
- N = number of days on which a prediction and observation were made for the stock at the site during the season;
- Day = vector of length N which identifies the days of the year from first observation of the stock at the site until two weeks past last observation (this is fixed for each site and each stock);
- F = observed cumulative passage on Day_t; and
- $\hat{F}$ = predicted cumulative passage on Day_t.

The MAD summation is performed over each of the dates on which model predictions were implemented – approximately every day during the season. This provides a snapshot of how well the model performs as the season progresses based on the final, “true” data. Ideally, there would be general decrease in MAD as t goes from 1 to N because the true distribution of the run should be better known and the true state of the flow and spill profiles should be known.

A second measure for run timing is the Maximum Absolute Daily Deviation (MADD)

$$MADD = \max\left\{\left|F_{Day_t} - \hat{F}_{Day_t}\right| \times 100\right.$$

Each daily estimate of the run passage percentage is as good as or better than this estimate.

3 Results

3.1 Run-size

The EF predicted the total spring chinook run-size within 20% of the final run-size on day 108 when 56% of the run had passed. The fall chinook run-size prediction was first within 20% on day 241 when 49% of the run had passed; although, it subsequently was reduced significantly, as seen in Figure 3, due to a hiatus in adult passage. EF finally predicted within 20% of the final fall chinook run-size on day 256. Daily predictions for 2003 can be seen at http://www.cbr.washington.edu/crisprt/index_adult.html. Targets of 10%, 20% and 30% were each evaluated and are summarized in Table 2.

Table 2 Earliest day after which we consistently predicted the final run-size within the error specified (10% 20%, or 30%).

Stock	Within 10%	Within 20%	Within 30%
Spring chinook	124	108	105
Fall chinook	257	256	255

In both spring and fall of 2003, our early season predictions, which are based on previous year's Jack returns, were low. The in-season predictions based on pattern matching subsequently corrected the prediction. Subsequent variations in the run-size predictions in Figure 2 and Figure 3 may have resulted from delays in the arrivals at Bonneville, since the forecaster becomes more and more sensitive to the data as the season progresses.

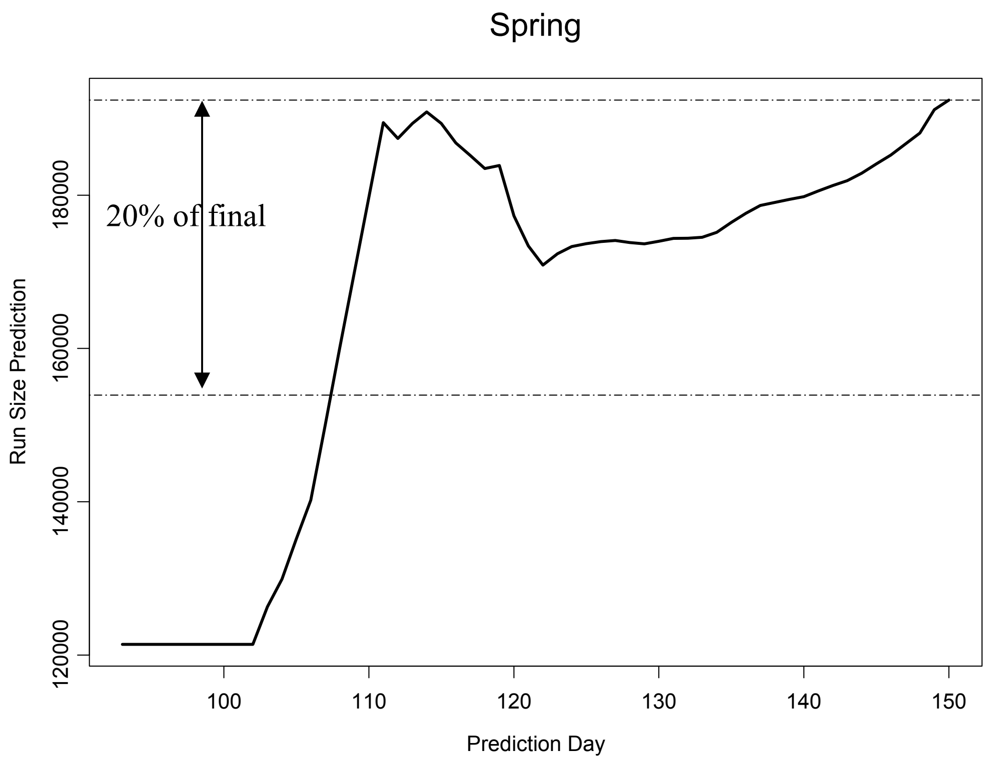

Figure 2 Spring chinook run-size prediction for 2003.

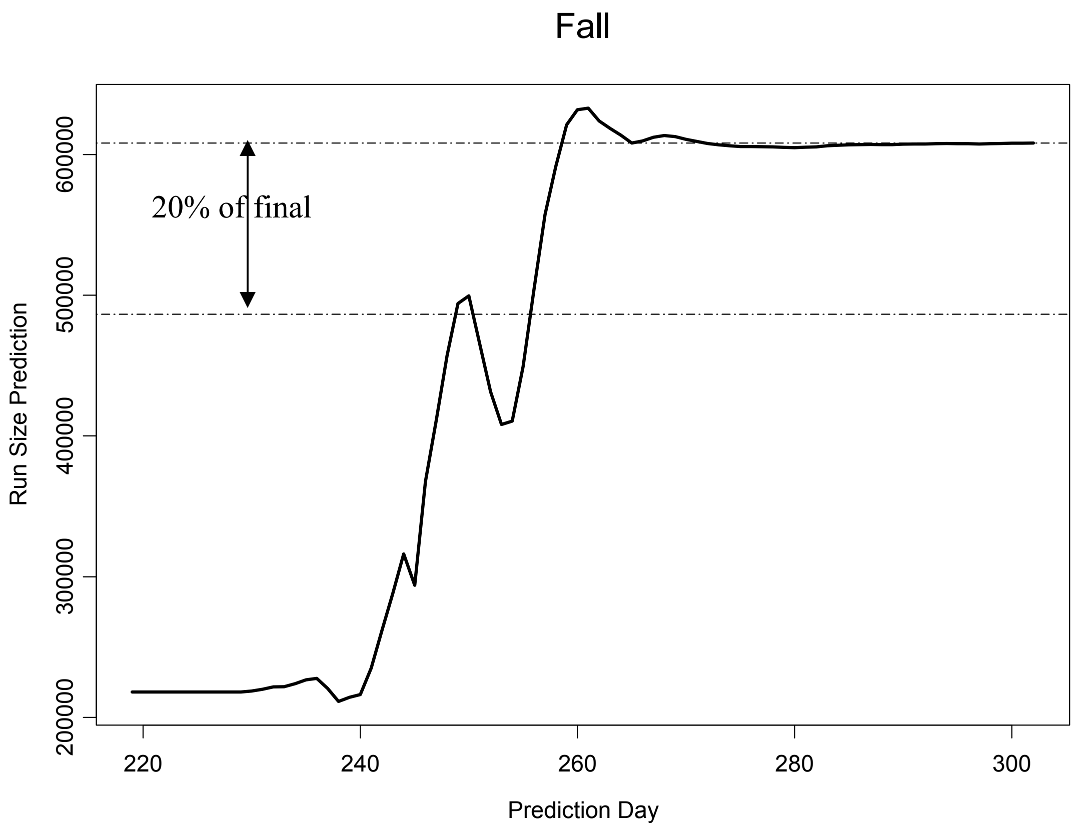

Figure 3 Fall chinook run-size prediction for 2003.

3.2 Run Timing

The EF/AUM model is run daily and upstream passage predictions are archived on the CBR web site. We compare daily forecasts to observations of passage at the end of the migration season. See the figures in Appendix A. Upriver passage forecast performance for passage predictions on several days and the end-of-year observations.

We measured the performance of these predictions by comparing the estimated percentage passed on each day with the observed percentage passed using the Mean Absolute Deviation (MAD). For the spring run at Bonneville, the MAD was 6.7%. We also track the level and day of the worst prediction: the Maximum Absolute Daily Deviation (MADD). The MADD was 18.4% on day 103. A comparison of the predicted and observed Bonneville Dam passage percentage for each day is in Figure 4.

For the fall run at Bonneville, MAD was 3.9%. The MADD was 19.3% made on day 253. A comparison of the predicted and observed Bonneville Dam passage percentage for each day is in Figure 5.

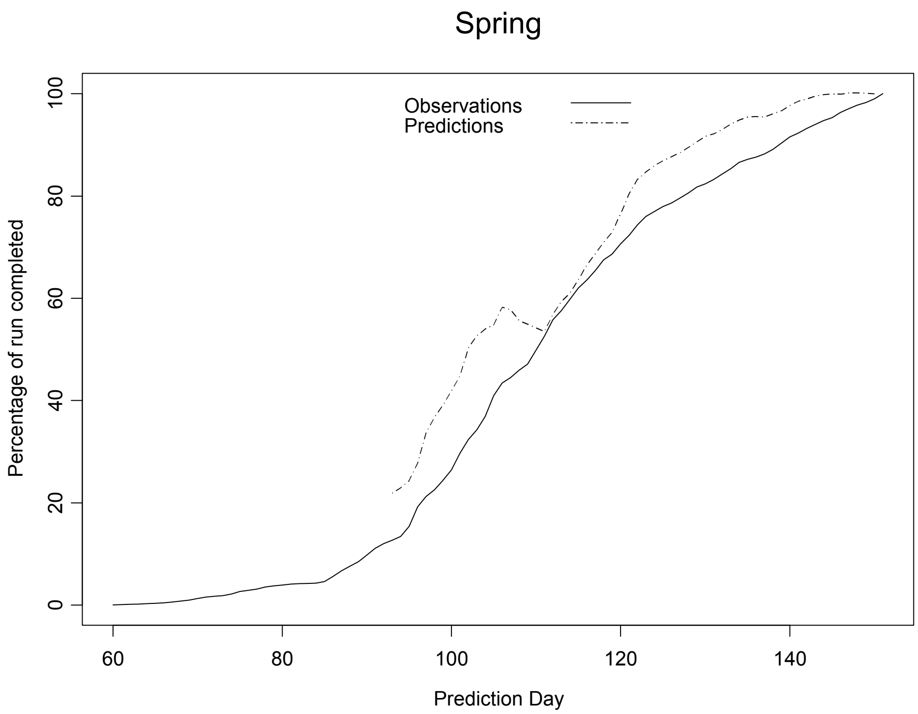

Figure 4 Spring chinook passage prediction at Bonneville for 2003. Note: This is a comparison of the predicted percentage passed and the actual percentage passed on each day of the passage season.

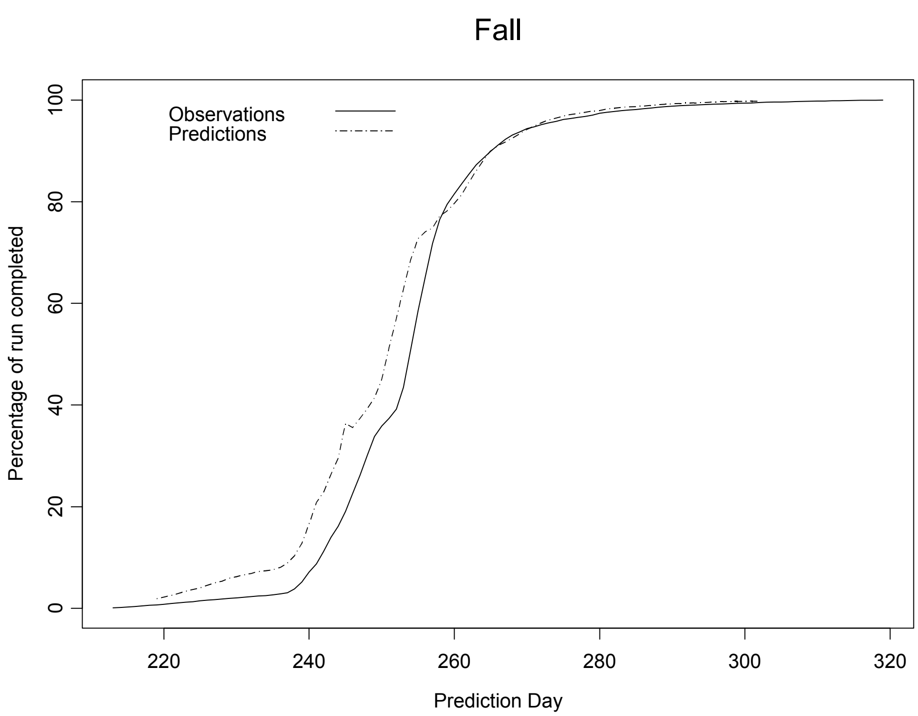

Figure 5 Fall chinook passage prediction at Bonneville for 2003. Note: This is a comparison of the predicted percentage passed and the actual percentage passed on each day of the passage season.

4 Discussion

Predictions of the passage at Bonneville shaped the forecasts of passage at other dams so that all the predictions are sensitive to these important Bonneville Dam escapement forecasts. Any errors in run timing at Bonneville are propagated upstream.

Predictions of the passage at upstream dams for all stocks vary with the prediction day as we would expect; however, the observations of spring chinook at IHR and LWG and other Snake River dams (see Appendix A) obviously show skewed arrivals, as compared to the forecasts, with fish arriving earlier than expected. For example, by April 24, 2003 (042403) nearly 50% of the run had passed IHR. This is probably due to the Columbia River and Snake River fish being disproportionately distributed at Bonneville, with Snake River spring chinook migrating earlier than their Columbia River counterparts.

Distinguishing the passage of individual stocks through the river system could help resolve these predictions more accurately (see Future Work below). Further, this stock separation may also be useful in protecting endangered stocks from over harvest and unfavorable migration conditions.

4.1 Future Work

A summer stock of about 115,000 fish passed Bonneville during 2003, but was not included in this analysis. In subsequent years, we hope to evaluate the efficacy of using the calendar-based method of determining run type. It has certainly been a convenience in the past, but several changes might warrant revisiting this enumeration method because:

- Modern counting and identification procedures (PIT tags) are available that identify individual adult fish and therefore their stock before they arrive at their spawning grounds.
- Possible preferred migration conditions which are correlated to stock type can be identified from river conditions databases such as DART (CBR 2004) and may be related to cueing and therefore provide a mechanism for delineating the differences between the stocks.
- Methods for determining the shape of arrival distributions would allow returning stocks to be partitioned according to those rules as they pass Bonneville. At present, a fish passing Bonneville on July 31 is a summer chinook and one passing on August 1 is fall chinook, and therefore treated distinctly.

During both the spring and fall chinook runs, there were significant periods during the migration season when passage was temporarily depressed. A more detailed understanding of the mechanisms that create this phenomenon will improve the forecasts since the pattern matching algorithm assumes that reductions in passage indicate an end to the run. We are seeking mechanistic explanations for these anomalies in otherwise comparatively smooth return results and tailoring the pattern matching algorithms to be less sensitive to short term noise in the return data while still being responsive to real-time daily conditions.

Identification of specific stocks via PIT-tag detections could provide higher resolution passage data in subsequent years. For example, it could help to distinguish the Snake and Columbia River stocks which are currently in-separable in the visual counts at lower dams. This will be very helpful in predicting the upstream passage movements since the destinations of individuals and therefore proportions of the daily observations will be known.

Daily run-size predictions also include confidence intervals; however, these bounds are not related to other predictions made with our system EF/AUM. Currently, the confidence bounds are based on the Bayesian posterior distribution. In future years, we will be able to compare our in-season run-size forecasts with the predictions made in previous years relative to the final run-size.

As of March 2004, PFMC had projected 360,700 upriver spring chinook and 520,000 upriver fall chinook to return to the Columbia River (see Appendix B). Once again, a very high return compared to the 10-year averages. EF/AUM will run again this year as it did last year.

References

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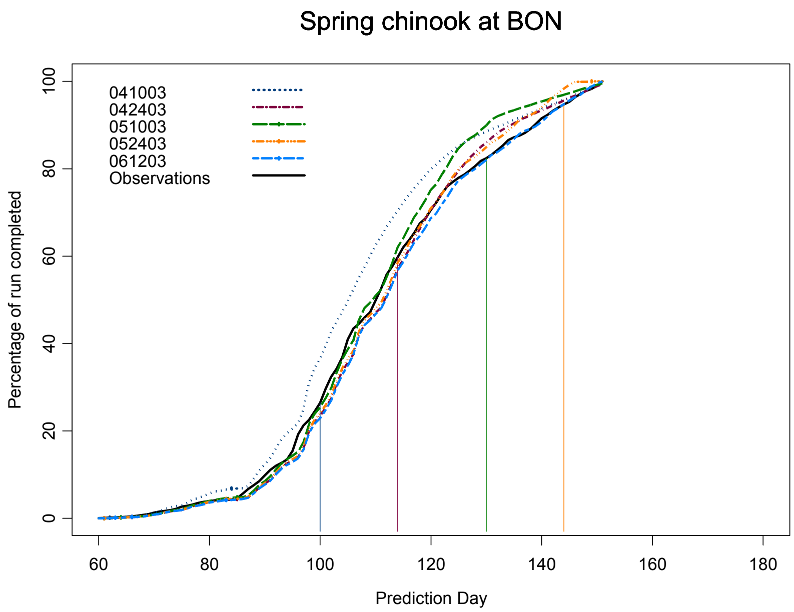
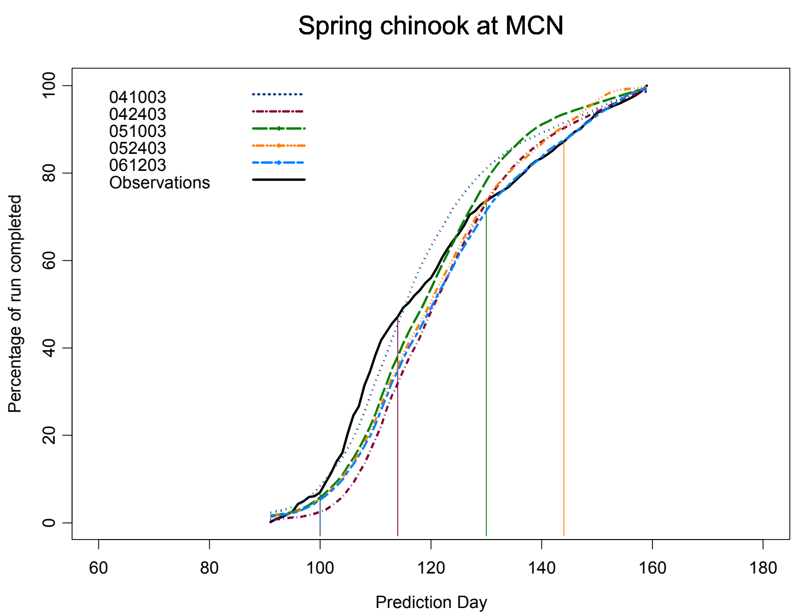
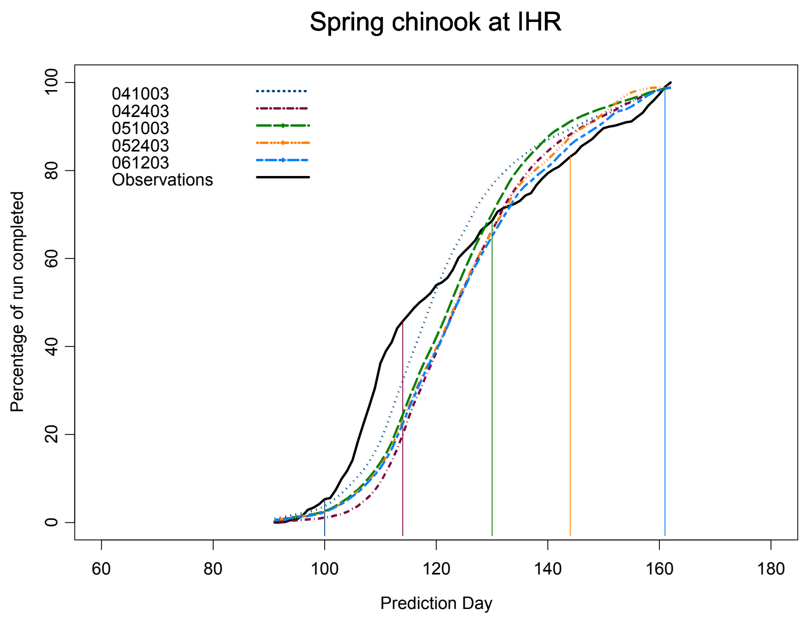
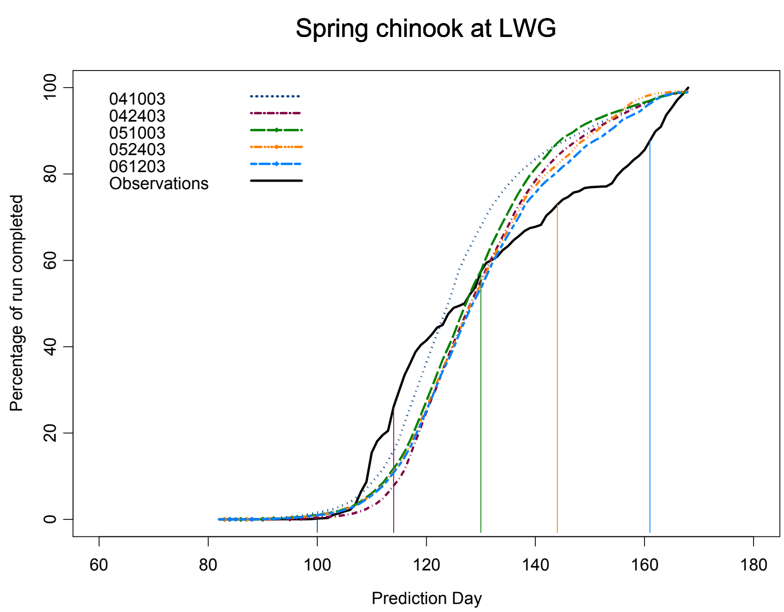
Appendix A. Upriver passage forecast performance

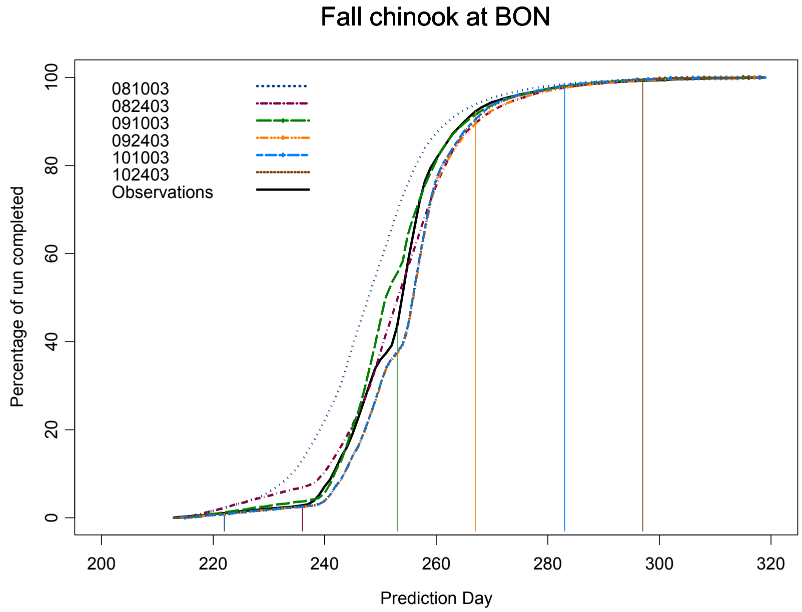
The graphs that follow depict observed passage and selected forecasted passage for spring and fall chinook at various dams (named by the three letter abbreviation). Forecasts made on various dates are drawn in different colors (not available in all distributions) and different line styles.

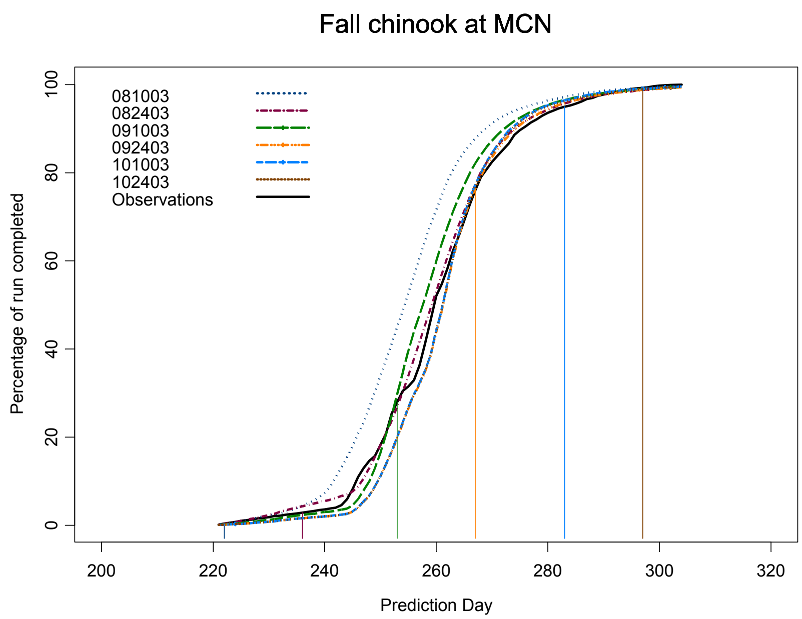




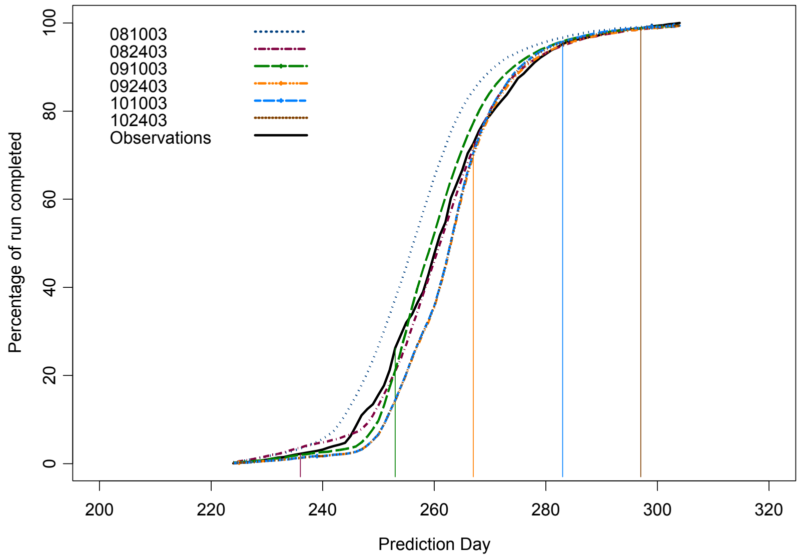

Spring chinook at IHR
041003
042403
051003
052403
061203
Observations
Percentage of run completed
0
20
40
60
80
100
60
80
100
120
140
160
180
Prediction Day


Spring chinook at LWG
041003
042403
051003
052403
061203
Observations
Percentage of run completed
0
20
40
60
80
100
60
80
100
120
140
160
180
Prediction Day

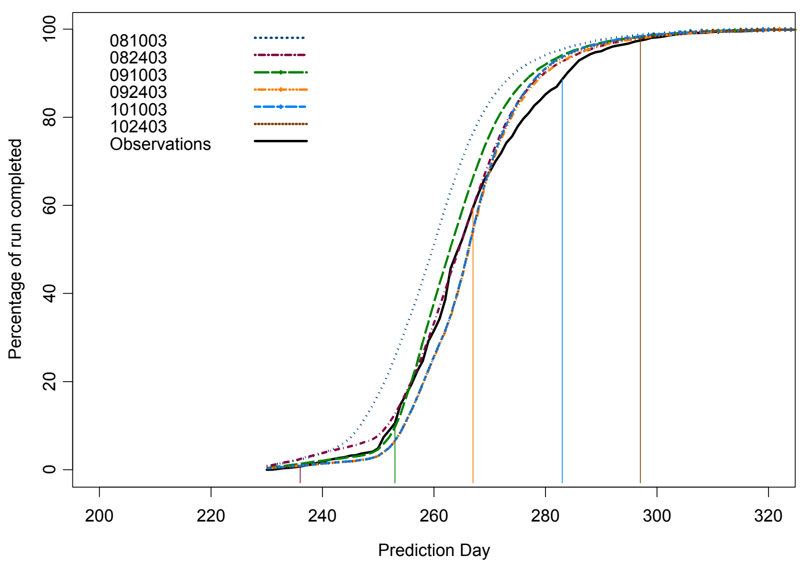

Fall chinook at BON
081003
082403
091003
092403
101003
102403
Observations
Percentage of run completed
0
20
40
60
80
100
200
220
240
260
280
300
320
Prediction Day


Fall chinook at MCN
081003
082403
091003
092403
101003
102403
Observations
Percentage of run completed
0
20
40
60
80
100
200
220
240
260
280
300
320
Prediction Day

Fall chinook at IHR



Fall chinook at LWG



Appendix B. PFMC forecasts

In February of 2003, Pacific Fishery Management Council (PFMC 2004) issued a preseason forecast of ocean escapement. Their prediction is the only other forecast that exists and is intended for fishery management purposes. Although their predictions are different from ours, the overall numbers are an index of the escapement that could be expected in the river. Of course, we expect Bonneville passage to be less than the ocean escapement due to turnoffs and harvest. The PFMC fall chinook are divided into 5 distinct stocks compared to our one stock. Three of them (MCB, URB and SCH) pass Bonneville Dam and the other two are Lower River stocks. Their predictions and postseason analysis is in Table 3. Their estimate of run-size was 68% of the observed fall chinook passage. There are no other estimates of stock run-size for chinook entering the Columbia.

Table 3 Pacific Fishery Management Council 2003 predictions and results of ocean escapement. Numbers in thousands of fish

Stock	Pre-season	Post-season[a]	Bonneville Passage[b]	Pre/ Postseason	Escapement goals
Spring chinook	145.4	NA	192	N/A	43.5
Summer chinook	87.6	NA			80
Spring Creek Hatchery	96.9	180.6		54%	
Upriver Brights (Columbia)	280.4	373.2		75%	
Mid-Columbia Brights	104.8	150.2		70%	
Fall chinook total	482.1	704	608	68%	N/A

[a] The river escapement includes observations of fish passing dams and the estimated catch from all sources.
[b] Bonneville passage of a stock is determined by date alone. Springs: Mar 1 – May 31. Summers: June 1 – July 31. Falls: Aug. 1 – Nov. 15.