Evaluation of the 2010 Predictions of Run-size and Passage Distributions of Adult Chinook Salmon [*Oncorhynchus tschawytscha*] Returning to the Columbia and Snake Rivers

Technical Report

Postseason Analysis
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Executive Summary

This report is a postseason analysis of the accuracy of the 2010 predictions from Escapement Forecaster / Adult Upstream Model. The effectiveness of these modeling efforts are compared to observations of passage and river conditions at the end of the season. A 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. At the end of the season, for each stock at each observation site, we compute the Mean Absolute Deviation (MAD) for the passage distributions which is a broad measure of the average error in daily passage percentage estiamtes. For spring and fall Chinook in 2010 it was 1.2% and 2.5% respectively. The maximum daily errors were 6.6% and 14.1% respectively.

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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 "RealTime" 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. Each day the predictions are updated on the web.

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 inform decisions about mitigation efforts such as in-river harvest. 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 mainstem Columbia and Snake River dams.

This report is a postseason analysis of the accuracy of the 2010 predictions from EF/AUM. Model results are compared to observations of passage and river conditions at the end of the season. We also compare key results to previous seasons.

Methods

Data

Escapement and travel time 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. For the escapement forecasts, the daily visual counts of returning adult Chinook data come from Bonneville Dam. To assess our upstream run timing predictions, the daily visual counts come from additional detection sites at McNary and Lower Granite Dams. Data is retrieved from a link to the Columbia River DART database and provided as a courtesy by U.S. Army Corps of Engineers, NWD (http://www.nwd.usace.army.mil).

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. On a monthly basis throughout the season, Bonneville Power Administration provides CBR staff with a long-term system operations forecast.

On a daily basis, forecasts for flow, spill, and elevation are replaced with observations with a query to the

Columbia River DART database (CBR 2010a), which includes water quality data from the Army Corps for the majority of monitoring sites in the Columbia Basin. Subsequent fish arrival predictions are therefore based on the forecasted values for flow and spill and the latest available observed data.

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. (2004).

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

Archives of model predictions

The results of EF/AUM runs are stored on the Columbia Basin Research web site (CBR 2010b). Graphs based on the results are available through web-based query tools at http://www.cbr.washington.edu/crisprt/index_adult.html. Runs are made daily and include daily passage distribution forecasts and run-size forecasts.

Models

Initial Run size

The year's initial run-size is determined from the previous year's jack count by using a linear regression of each year's adult return vs. the previous year's jack return for the years 1982-2008. This is useful for the spring run but less so for the fall run. The timeframe for the spring run at Bonneville is March 15 to June 15 and the timeframe for the fall run is August 1 to November 15.

Escapement Forecaster

The Escapement Forecaster predicts the arrival timing and run-size of adult salmon at Bonneville Dam. It consists of an expected distribution based on the previous year's jack counts in the early season, and switches to a pattern matching algorithm in the later season. There is also a blending routine to switch smoothly between the jack-based and pattern match methods.

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 passage (current year) 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 has 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.

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 COMPASS smolt passage model. Fish travel time has been calibrated using PIT-tag data of adult Chinook detected at multiple dams following the method of Salinger and Anderson (2006). 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 (2006) 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 in 2002-2008. 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.

The travel time parameters used for modeling passage in 2010 are shown in Table 2.

Table 2 Calibration parameters used for AUM runs in 2010.

Stock	Years	b0	bTemp	bFlow	vVar	R^2 (Model vs. Obs.)
Snake Spr.	2000-2008	-40.4462	11.9307	-1.7217	110.8212	0.80
Snake Fall	2000-2008	-13.1307	7.0943	-0.7368	171.1739	0.83
UC Spring	2002-2008	27.4733	2.4045	-0.9639	19.5486	0.82
UC Fall	2002-2007	-9.2728	1.7983	1.7368	1894.3038	0.86
Yakima (All)	2002-2008	-26.1674	10.2936	-2.2117	74.2367	0.56

[a]The parameters for Upper Columbia Fall are also applied to Lower Columbia Fall stocks.
[b]The parameters for Snake Spring are also applied to Lower Columbia Spring stocks.

Schematic of data and modeling

The relationship of the data and models is depicted in Figure 1.

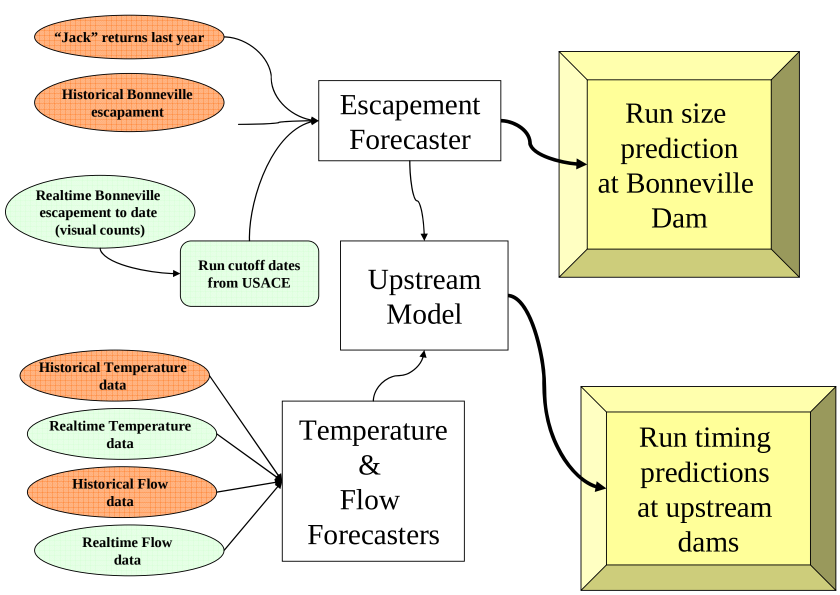

Figure 1 Schematic of data, models and products. Brown is used for historical data, green is real time up-to-date information, white boxes are modeling processes and the yellow frames are final products.

Postseason Assessment of Predictions

Mean Absolute Deviation

To assess the performance of run-size predictions, we compute the first day when the run-size estimate was 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.

To assess the performance of passage timing predictions, we apply the same measure used to assess RealTime/COMPASS predictions (Beer et al. 2008). 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)

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

All estimates of the run passage percentage are as good or better than this estimate.

Results

Initial Run-size

The relationship between jack returns and adult returns has been deteriorating for spring Chinook in recent years and has always been poor for fall Chinook. The preseason estimates were 50% too high and too low for the spring and fall abundances respectively (see Table 6). Current preseason values are available at http://www.cbr.washington.edu/crisprt/adult_preseason.html.

Escapement Forecaster

The escapement forecaster predicted within 20% of the final spring run size on day 109 (April 19), well in advance of the prediction for the previous six years (range: day 126 to 134). The fall prediction was more typical (day 252, Sept. 9, range 243 to 255). The predicted daily passage percentile time series and observed distribution are shown in Figure 3 and Figure 5. Daily predictions for 2010 can be viewed from the Forecast Archive web page, at http://www.cbr.washington.edu/crisprt/archive.html. Alternative targets (10%, 20% and 30%) were each evaluated and are summarized in Table 3.

Run Timing

The EF/AUM model is run daily and upstream passage predictions are archived. Predictions are compared to observations of passage at the end of the migration season. See the figures in the Appendix for passage predictions on several days and the end-of-year observations.

We track the success of these predictions by comparing the estimated percentage passed on each day with the observed passage percentage. For the spring run at Bonneville, the Mean Absolute Deviation (MAD) was 1.2%, the best in eight years. The worst daily prediction, the maximum absolute daily deviation (MADD) was 6.6% on day 107 (April 17). A comparison of the predicted Bonneville Dam passage percentage for each day and final observations is in Figure 3. For the fall run at Bonneville, MAD was 2.5%. MADD was 14.1% on day 266. A comparison of the predicted Bonneville Dam passage percentage for each day and final observations is in Figure 5. These results and others since 2003 are summarized in Table 4.

Discussion

Predictions of passage at Bonneville shape the forecasts of passage at other dams, so all the predictions are sensitive to these important first observations. Any errors end up affecting upstream passage predictions, and run-size predictions interact with the passage percentage predictions. One measure of this error, the Maximum Absolute Daily Deviation (MADD), was a low 6.6% for the spring Chinook and a more typical 14.1% for fall Chinook. The spring fish arrived “smoothly” but in much lower numbers than expected. Once the EF algorithm recognized the low numbers, it quickly adjust the value and was one of the earliest year’s to get within the 20% threshold. The fall fish timing is mosre stable between years, the abundances are are both less predictable and larger in magnitude. The upstream runs, based on stock separation methods at Bonneville are highly variable between years.

In early 2010, Pacific Fishery Management Council (PFMC 2010) issued a preseason forecast of ocean escapement for various stocks. Their predictions are a significant forecast that is used by various agencies for fishery management purposes. Although their predictions are different —ocean escapements not dam arrivals— the overall numbers are an index of the escapement that could be expected in the river. We always 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. Three of them (MCB, URB and SCH) pass Bonneville Dam (and are enumerated as the fall run) and the other two are lower river stocks. Subsequent referrals to the PFMC predictions of fall Chinook will ignore the lower river fish. There is also a Spring Chinook and Summer Chinook prediction. Highlights of their predictions (PFMC 2010) and postseason analysis (PFMC 2011) are shown in Table 6. There are no other estimates of stock run-size for Chinook entering the Columbia.

The fall run is easier to model than the spring run, especially when run size is well predicted, because the timing is much more consistent than the spring run. The jack/adult relationship is shown in Figure 7. For fall Chinook at upstream dams, the final destinations are not certain for any fish arriving on any given day, so a relatively small runs like fall Chinook passing WEL or heading to the Yakima are not a symetrical part of the larger fall run. The stock separation algorithm that routes fish to upstream locations in AUM is dependent on the expected distribution to upstream locations based solely on the previous year’s distributions and the timing of the current run relative to the previous year. The best available stock separation fractions are determined daily according to the methods of Beer (2008).

Preseason estimates for 2011 are based on environmental and cohort variables. For spring Chinook:
Adult.count = 37410 + .2479 * Last.Year.Adult.count + 0.0510 * Jack.count*Last.Year.August.Upwelling

(R^2 = 0.85). For fall Chinook, jacks are a poor predictor so only the previous year adult count is used: Adult.count = 52400 + 0.824 * Last.Year.Adult.count (R^2 = 0.64).

Results and Discussion Figures and Tables

Table 3 Earliest day in 2010, after which the final run-size prediction was within the error specified (10% 20%, or 30%) . In parenthesis, corresponding dates for 2009, 2008, 2007, 2006 and 2005 respectively.

Stock	Within 10%	Within 20%	Within 30%
Spring	118	109	109
	(147, 140, 149, 161, 126)	(129, 126, 128, 134, 126)	(126, 125, 117, 133, 127)
Fall	268	252	243
	(264, 243, 267, 269, 249)	(247, 234, 243, 255, 250)	(218, 215, 243, 247, 251)

Table 4 Summary of Mean Absolute Deviation (MAD) and Maximum Daily Deviation (MADD) results for the last six years (BON).

Measure	Year	Spring Chinook	Fall Chinook
MAD	2010	1.2%	2.5%
	2009	7.0%	2.6%
	2008	5.7%	2.2%
	2007	2.6%	4.7%
	2006	9.5%	5.7%
	2005	3.9%	3.0%
	2004	3.7%	4.8%
	2003	6.7%	3.9%
MADD (day)	2010	6.6% (107)	14.1% (266)
	2009	20.0% (118)	13.8% (246)
	2008	30.4% (118)	10.5% (248)
	2007	11.2 % (114)	17.1 % (261)
	2006	43.8% (121)	20.1% (261)
	2005	25.0% (121)	17.7% (244)
	2004	16.4% (114)	14.2% (254)
	2003	18.4% (103)	19.3% (253)

Table 5 MAD values and MADD values (in parentheses) for other dams in 2010

Site	Spring	Fall
TDA	2.5 (6.1)	3.5 (20.0)
JDA	1.7 (5.4)	3.5 (23.6)
MCN	2.0 (9.1)	4.1 (26.4)
IHR	4.1 (13.0)	2.5 (15.3)
LMN	2.1 (8.4)	2.1 (13.0)
LGS	1.3 (5.8)	1.7 (11.9)
LWG	1.1 (5.6)	2.3 (13.6)
PRD	5.5 (17.8)	8.0 (24.5)
WEL	2.3 (20.0)	6.4 (30.0)

Table 6 Jack-Adult regression and Pacific Fishery Management Council 2010 preseason predictions and postseason results of BON and/or ocean escapement. Numbers in thousands of fish.

Stock	Pre-season	Post-season[b]	Bonneville Passage[d]	Pre/ Postseason	Source
Jack-Adult Regression BON Spring	424.4		277.4	1.5	CBR
Jack-Adult Regression BON Fall	230.4		468.3	.5	CBR
Upriver Spring Chinook[b]		468.4	277.4		PFMC
Upriver Summer Chinook[b]		72.3	64.7		PFMC
Fall Chinook[b,c]		556.2	468.3		PFMC
Fall Chinook (sum of 3 stocks below)	552.4	447.3		1.2	PFMC
Spring Creek Hatchery (SCH)[a]	169.0	123.0		1.4	PFMC
Upriver Brights (URB)[a]	310.8	255.5		1.2	PFMC
Mid-Columbia Brights (MCB)[a]	72.6	68.8		1.05	PFMC

[a] The ocean escapement estimates from a pre-season forecast for 2010 (PFMC 2010a). Not all data available at time of writing.

[b] The in-river escapement estimates from a post-season report for 2010 that provides observations, catches, hatchery returns etc. (PFMC 2011) For regression methods this is the BON count.

[c] Post-season fall Chinook would also include numbers below Bonneville which are significant. There are five stocks in total

[d] Bonneville passage of a stock is determined by date alone. Springs: Mar 15 – June 15. Summers: June 16 – July 31. Falls: Aug. 1 – Nov. 15. The Army Corps reports passage of springs through May 31 and the summers begin on June 1 (CBR 2010b). Beginning in 2005, we adopted the June 15 end date for our spring Chinook run size forecast to best match the Columbia River Fisheries (CRM) spring management period.

Table 7 CBR adult preseason predictions (jack-adult regression) and postseason results for spring Chinook adult run size at Bonneville and fall Chinook run size at Bonneville, 2002-2010. Numbers in thousands of fish.

Stock	Year	Run Dates	Preseason Forecast	Bonneville Passage Observed	Preseason/ Bonneville Passage
Spring Chinook	2010	3/15-6/15	424.4	277.3	1.5
	2009	3/15-6/15	294.3	147.5	2.1
	2008	3/15-6/15	307.0	150.1	2.0
	2007	3/15-6/15	83.1	80.8	1.0
	2006	3/15-6/15	106.7	126.2	0.8
	2005	3/15-6/15	212.4	97.4	2.2
	2004	3/15-5/31	245.4	168.7	1.5
	2003	3/1-5/31	121.4	192.0	0.6
	2002	3/1-5/31	244.0	268.8	0.9
Fall Chin.	2010	3/15-6/15	230.4	467.8	0.49
	2009	8/1-11/15	249.4	283.4	0.88

2008	8/1-11/15	253.8	315.3	0.8
2007	8/1-11/15	231.2	157.8	1.5
2006	8/1-11/15	228.5	299.2	0.8
2005	8/1-11/15	239.0	415.7	0.6
2004	8/1-11/15	237.2	583.7	0.4
2003	8/1-11/15	218.1	610.1	0.4
2002	8/1-11/15	305.4	473.8	0.6

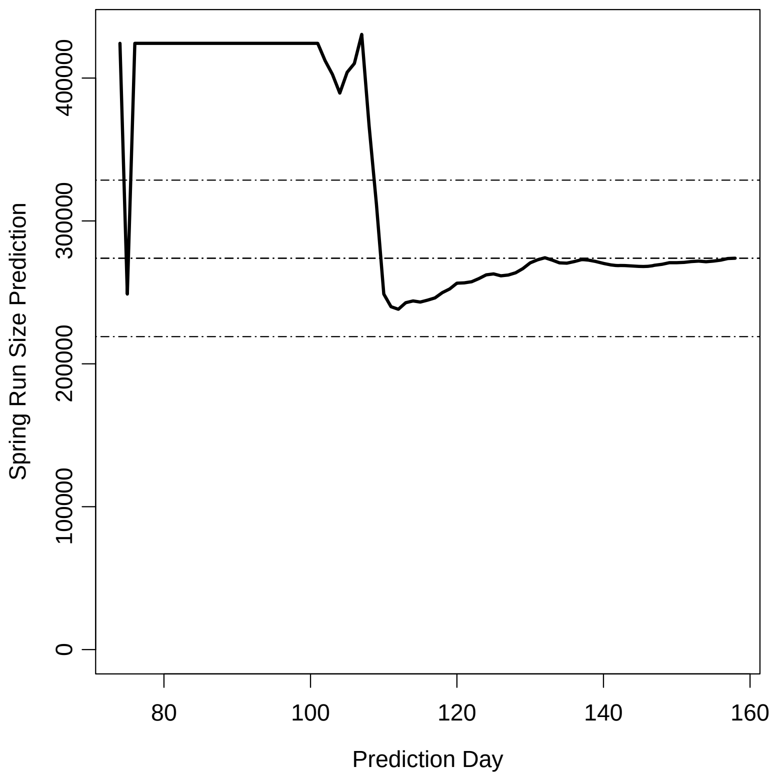

Figure 2 Changes in the daily run size prediction for spring Chinook at Bonneville Dam. Horizontal bands depict 20% margin more or less than the final run size.

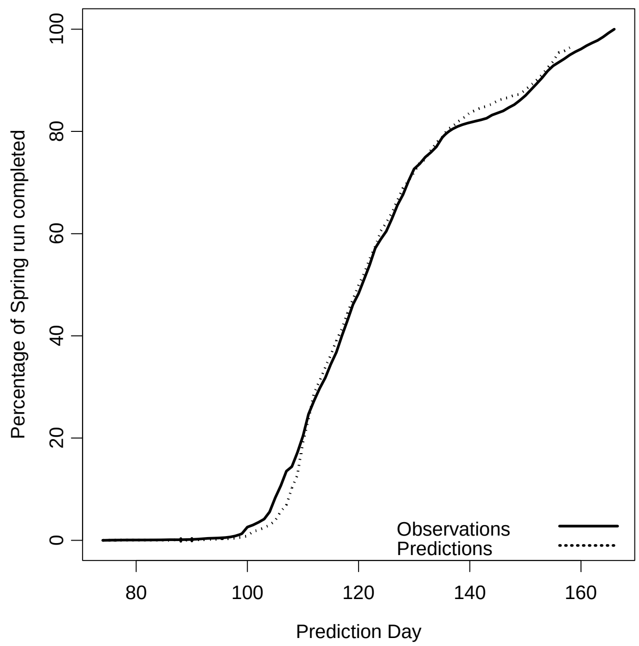

Figure 3 Distribution of spring Chinook arrivals at Bonneville Dam. Note that the "predictions" are the day-to-day declarations of what percentage of the run has passed on this day. That is one reason it has "notches" in it. This is not the same as a comparison of observed passage versus modeled passage. For those, see Appendix.

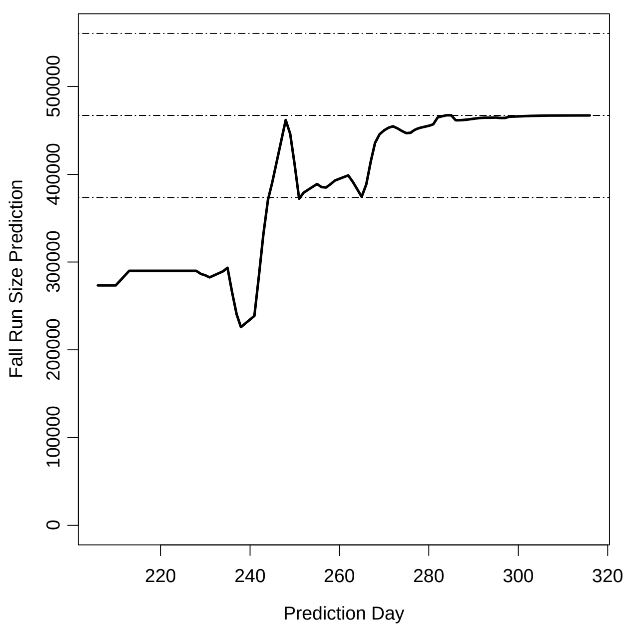

Figure 4 Changes in the daily run size prediction for fall Chinook at Bonneville Dam. Horizontal bands depict 20% margin more or less than the final run size.

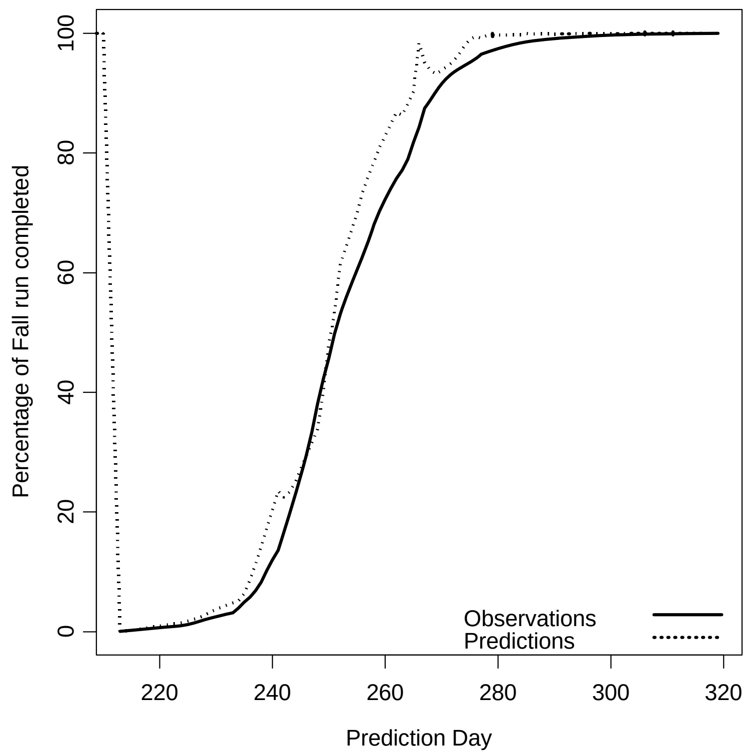

Figure 5 Distribution of fall Chinook arrivals at Bonneville Dam.

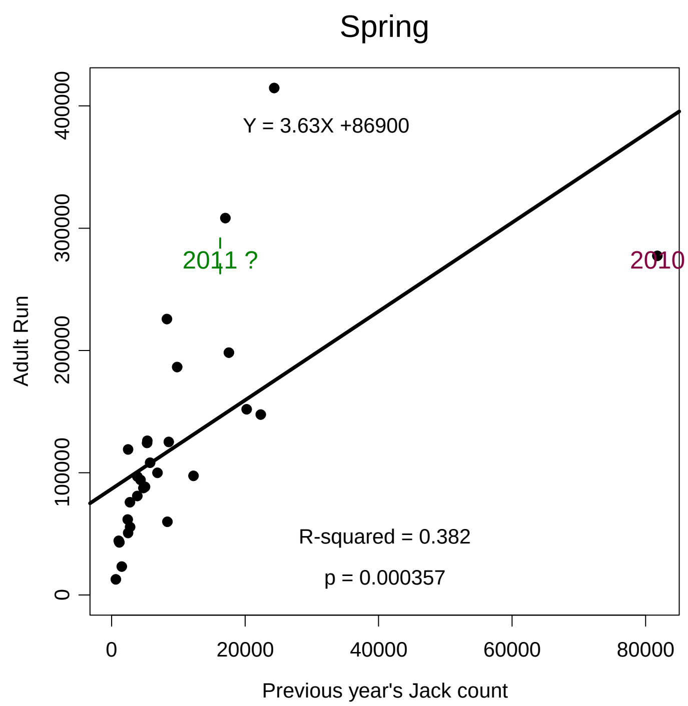

Figure 6 Relationship of previous year Jack counts to current year spring Chinook adult counts. Point 2011 is observed jacks for 2010 and a prediction of adults for next year with a simple linear relationship of adults to jacks. An alternative prediction of abundance includes an environmental covariate as well as cohort relationships.

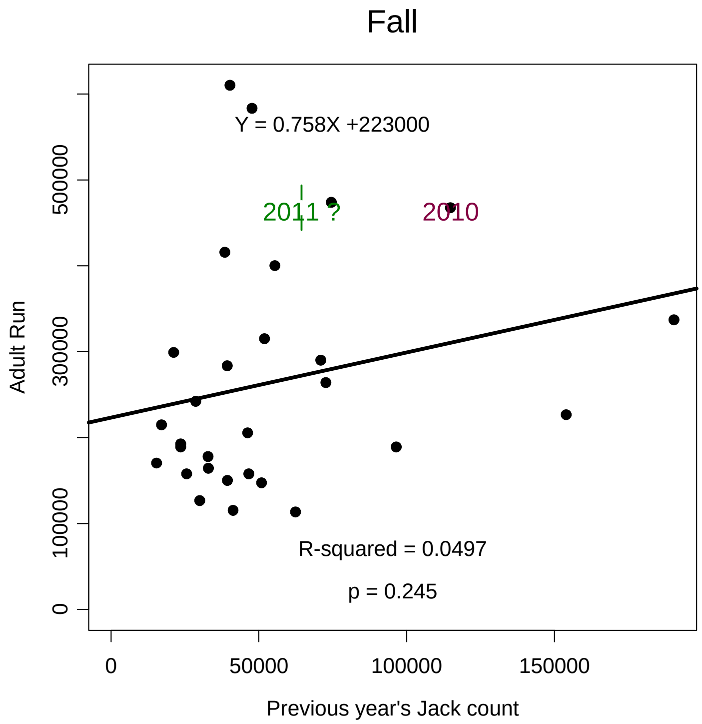

Figure 7 Relationship of previous year Jack counts to current year fall Chinook adult counts. Point 2011 is projected based on 2010 jacks using the linear relationship of jacks to adults. The linear relationship is very weak for fall Chinook.

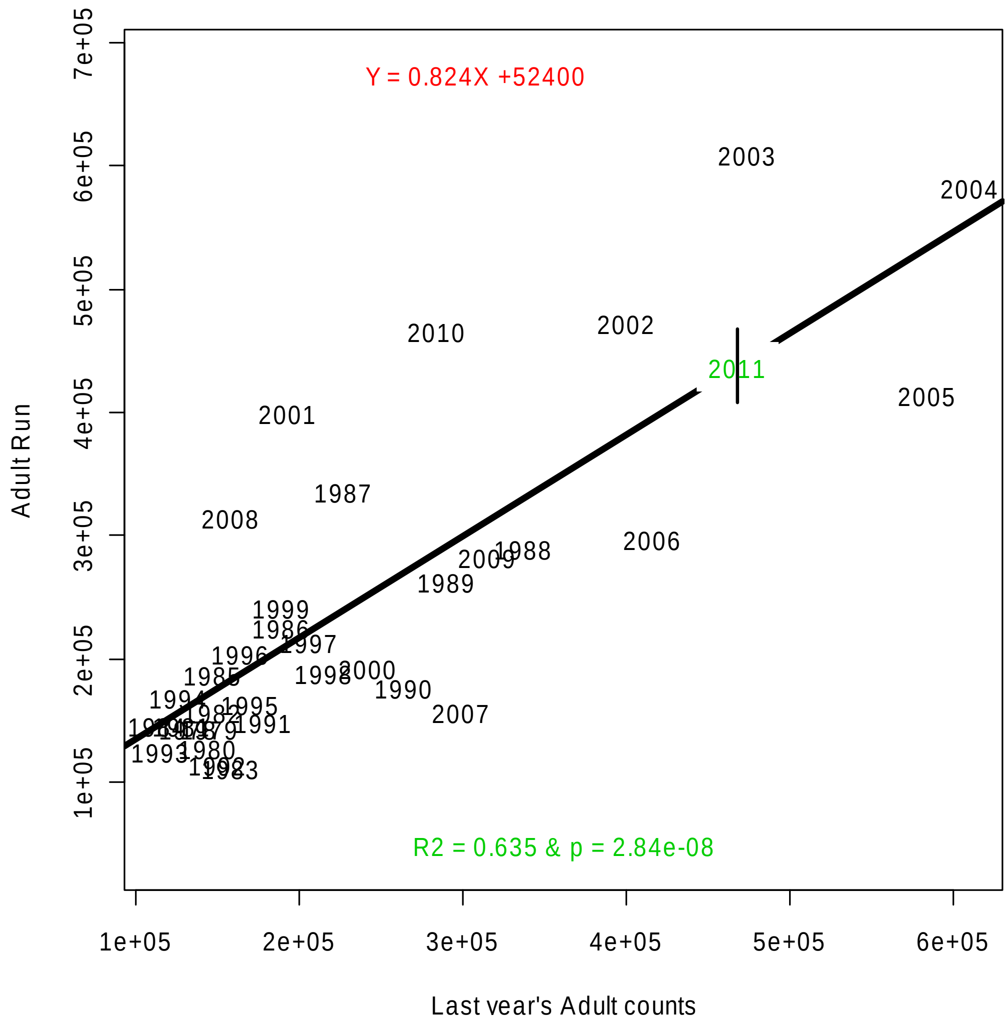

Figure 8 Better than using jack counts for the adult run is to use the previous year's adult run. Fall adult Chinook runs are auto-correlated with signficant one and two year lags.

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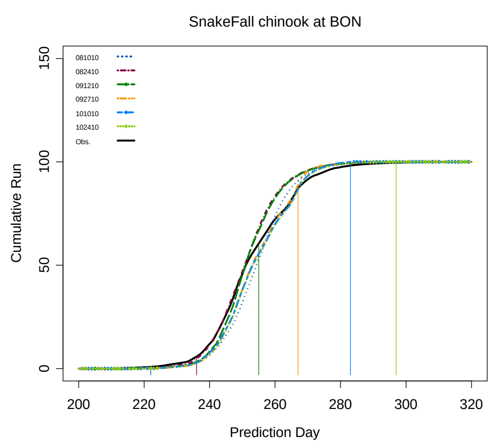
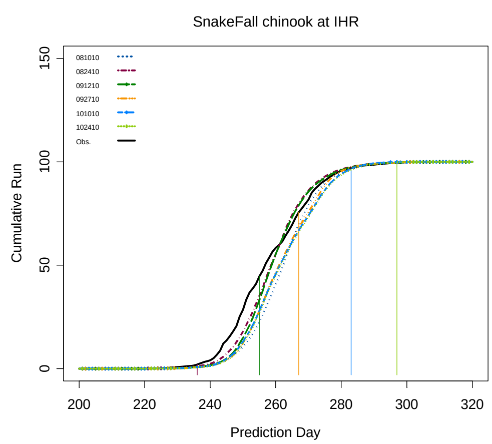
Appendix

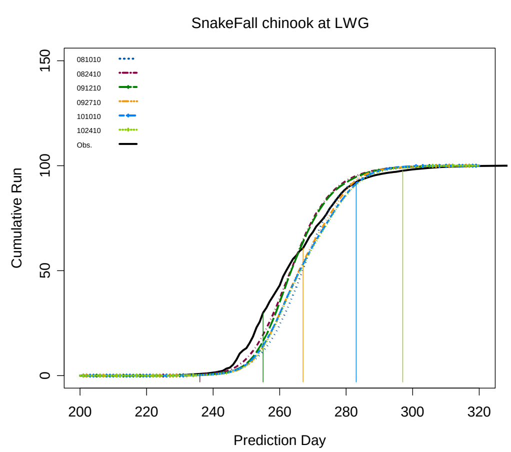
Predictions and observations of cumulative passage at multiple locations. The displays in this appendix depict the distribution of the run and its predictions through the seasons. Interpretation notes: A smooth, “normal-distribution” curve indicates that the stock has a unimodal arrival. When an observation curve is in a cluster of predictions then the stock is represented uniformly across the run at the site.

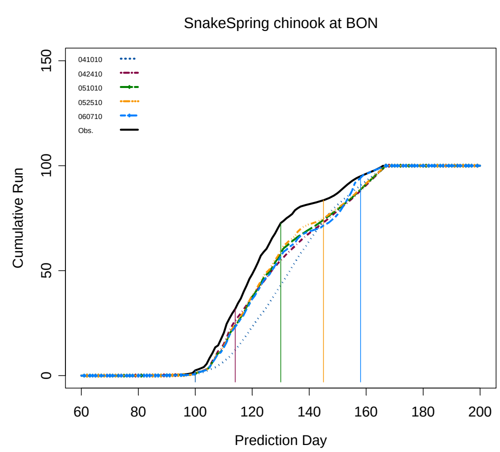
The spring Chinook timing to upper dams was well modeled. UColSpring and UColFall observations at PRD and WEL depict their bi-modal arrivals. There is a distinct early and late group in both runs. This is also possible if the middle of the fall run to the Upper Columbia turns off before Wells dam which may be the case since the passage at PRD shows a bulge in passagein late spring. These fish are likely bound for the many Eastern-Cascade streams that feed the Columbia above PRD.

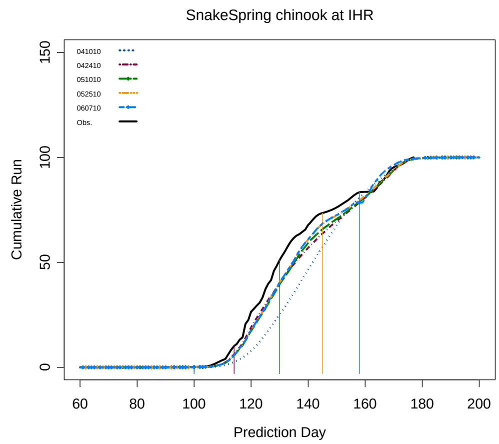
Since the stock separation occurs at BON asn is based on a prior year arrival at the dams, differences in abundance between two coincident groups will appear as one modeled early and the other late. For example, lower and Upper Columbia Spring Chinook are like that.

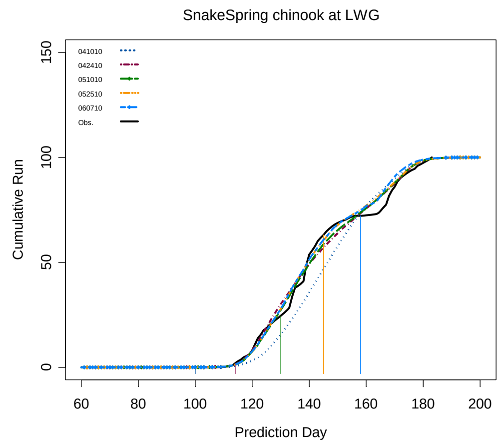









SnakeSpring chinook at IHR
041010
042410
051010
052510
060710
Obs.
Cumulative Run
Prediction Day


SnakeSpring chinook at LWG
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052510
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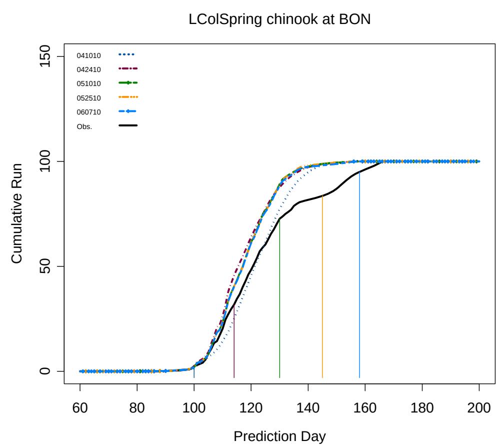
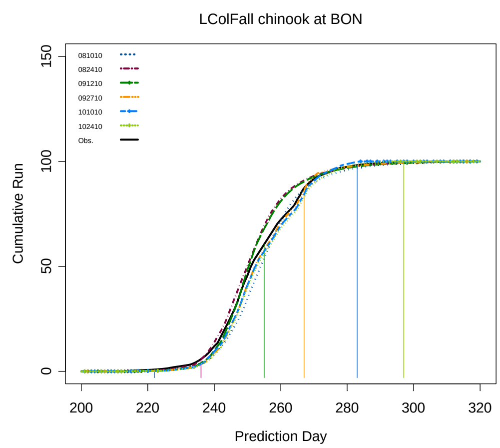
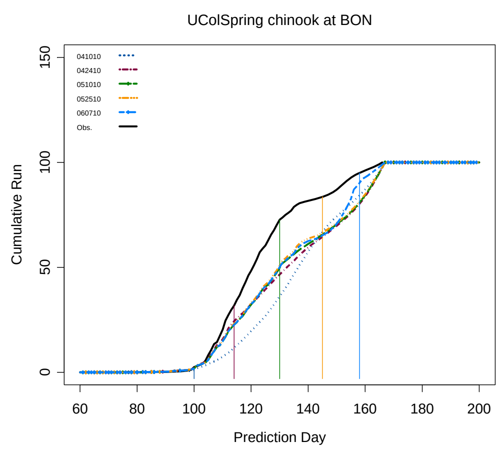
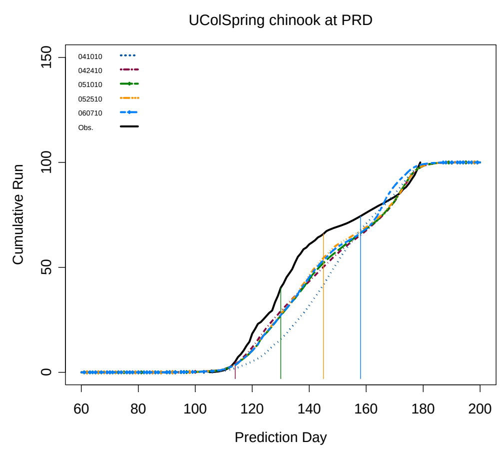
Obs.
Cumulative Run
Prediction Day


LColSpring chinook at BON
041010
042410
051010
052510
060710
Obs.
Cumulative Run
Prediction Day


LColFall chinook at BON
081010
082410
091210
092710
101010
102410
Obs.
Cumulative Run
Prediction Day


UColSpring chinook at BON
041010
042410
051010
052510
060710
Obs.
Cumulative Run
Prediction Day


UColSpring chinook at PRD
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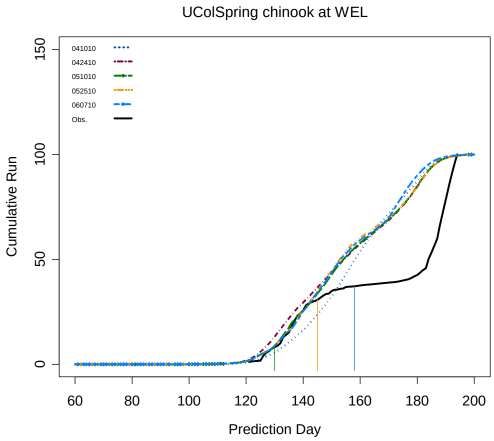
042410
051010
052510
060710
Obs.
Cumulative Run
Prediction Day


UColSpring chinook at WEL
Cumulative Run
Prediction Day
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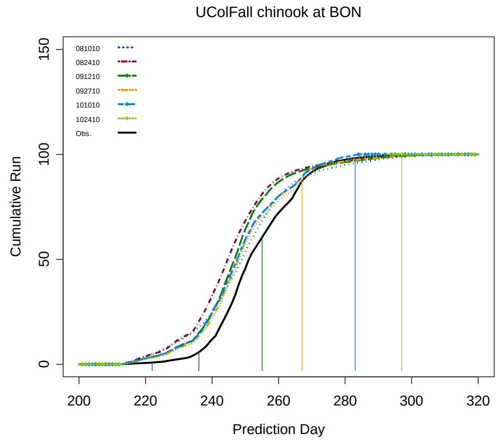
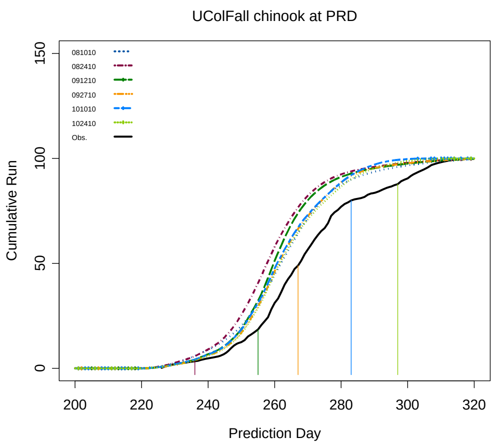
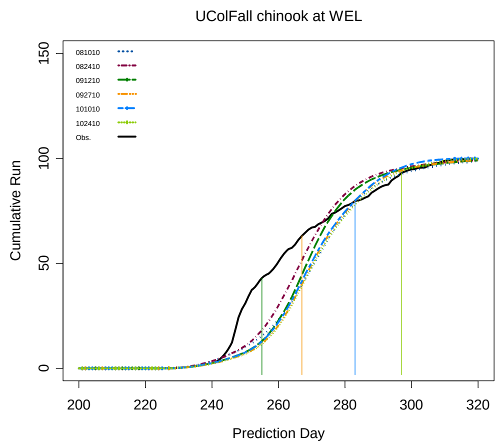
042410
051010
052510
060710
Obs.


UColFall chinook at BON
Cumulative Run
Prediction Day
081010
082410
091210
092710
101010
102410
Obs.


UColFall chinook at PRD
Cumulative Run
Prediction Day
081010
082410
091210
092710
101010
102410
Obs.


UColFall chinook at WEL
Cumulative Run
Prediction Day
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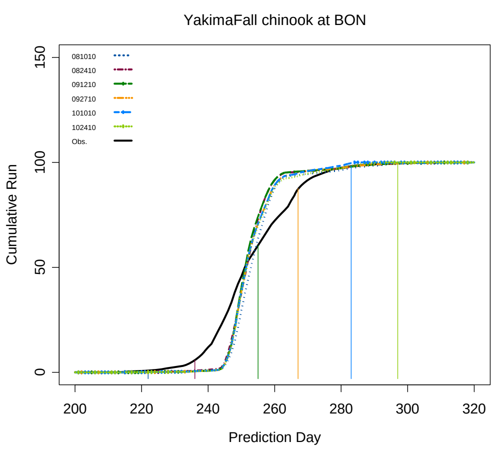
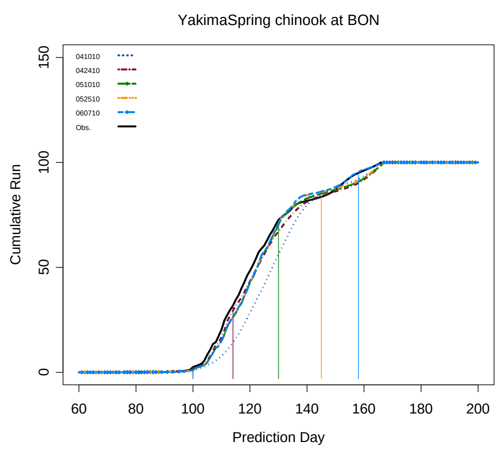
082410
091210
092710
101010
102410
Obs.


YakimaFall chinook at BON
Cumulative Run
Prediction Day
081010
082410
091210
092710
101010
102410
Obs.


YakimaSpring chinook at BON
Cumulative Run
Prediction Day
041010
042410
051010
052510
060710
Obs.