Retrospective Analysis of Preseason Run Forecast Models for Warm Springs stock Spring Chinook Salmon in the Deschutes River, Oregon

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Summary

A retrospective analysis of run forecast models for Warm Spring River wild and Warm Springs NFH hatchery spring Chinook salmon was performed based on the methods of Haeseker et al. 2008. The two models that are currently used for run forecasting, the standard linear regression model and cohort model (Lovtang et al. 2011), were re-run on an annual basis starting with return year 1990 using only the data that would have been available to managers at the time. In addition, several alternative forecast models that are used throughout the Pacific Northwest were evaluated for comparison to the traditional forecast models. Performance of each model was evaluated using a variety of metrics that quantify a forecast model's accuracy.

Based on the historical data analyzed, several actions could be taken to improve the forecasting of spring Chinook salmon returns to the Deschutes basin. Recommendations for wild fish forecasts are:

- Use a 10 year rolling dataset for the standard regression model.
- Use the percent-by-age model, with 10 year rolling datasets, to supplement the traditional forecast models. The percent-by-age model could replace the cohort model in the run prediction reports.
- Add a zone (red, yellow, green) descriptor to the point estimates in run prediction reports. Forecasts in the red zone would indicate a high probability of not meeting wild fish escapement goals, in the yellow zone a moderate probability of not meeting wild fish escapement goals, and in the green zone a low probability of not meeting minimum wild fish escapement goals. Statistics, including confidence intervals and evaluation of past model performance should continue to be included in run prediction reports.
- Continue to evaluate forecast model performance on an annual basis.

Recommendations for Warm Springs NFH hatchery fish forecasts are:

- Use natural log transformed data for regression model forecasts.
- Use the percent-by-age model to supplement the traditional run forecast models. The percent-by-age model could replace the cohort model in the run prediction reports.
- Continue to evaluate forecast model performance on an annual basis.

Introduction

Run forecasts for spring Chinook salmon in the Deschutes basin are based on sibling models in which returns of younger aged fish are used to predict returns of older age fish in subsequent years. Forecast accuracy has important implications for management of salmon in the basin, yet the forecast confidence intervals that are generated using sibling models are often quite large, complicating management decisions. Looking back at how the run forecasts models have actually performed in comparison to returns may provide managers with additional perspective regarding run size estimates. In addition, alternative forecast models that are used throughout the Pacific Northwest may improve forecast performance in comparison to the traditional forecast methods used in the Deschutes Basin.

Methods

Run reconstruction data of wild Warm Springs River spring Chinook salmon for brood years (BY) 1975 to 2006, and Warm Springs NFH hatchery spring Chinook salmon for BY 1978 to 2006 were used to estimate the number of age 3, age 4, and age 5 fish that returned to the mouth of the Deschutes River for a given brood year. Run reconstruction methods and data can be found in the annual run forecast reports (Lovtang et al. 2011). Run forecasts for the Deschutes River are made for adult sized fish only, that is age 4 and age 5 spring Chinook salmon returns in a given year. For the retrospective analysis, run forecasts were made for wild adult returns starting with return year 1990, which would be comprised of age 4 returns from BY 1986 and age 5 returns from BY 1985. Return year 1990 was chosen as the starting point so that each wild forecast model would have 10 brood years (BY 1975 to BY 1984) worth of data to start with. For the hatchery forecast models, forecasts were made starting with return year 1993, again so that each forecast model would have 10 brood years (BY 1978 to 1987) of data.

For each model type analyzed, retrospective forecasts were made for total adult (age 4 and age 5) returns for return years 1990 to 2010 for wild fish and return years 1993 to 2010 for hatchery fish. Each forecast was made using only the data that would have been available at the time. For example, the 1990 adult return of wild fish was forecasted using the standard linear regression model of age 3 to age 4, and age 4 to age 5 data through return year 1989. For the 1991 forecast, regressions were run again but this time using data through return year 1990, and so on. A total of 21 forecasts (return years 1990 to 2010) were made for wild fish and 18 forecasts (return years 1993 to 2010) for hatchery fish using each model type.

The performance of each model was then analyzed using methods described in Haeseker et al. 2008. Each retrospective forecast was compared to the observed return in each year. Performance of each model was then evaluated using four performance measures: the mean raw error, mean absolute error, mean percent error, and root mean square error (RMSE) of the forecasts. Raw error is defined as the forecasted return minus the actual return. Negative raw error values indicate over-forecasts, and positive values indicate under-forecasts. The mean raw error, which is the raw error averaged over the number of years forecasted, is a measure of the overall bias of the forecast. Years of over-forecast can be offset by years of under-forecast, which would result in a mean raw error value close to zero. To get an idea of the magnitude of forecast error, regardless of sign, the mean absolute error was also calculated. Mean percent error was calculated as the raw error divided by the actual return. The RMSE was calculated according to methods described in Haeseker et al. 2008, and provides a measure of the forecast error variance. Models with the lowest RMSE would produce the narrowest (best) confidence intervals. Models were then ranked from best to worst for each performance measure.

In the Deschutes River basin, management of spring Chinook salmon is often based on the number of wild fish expected to return to the Warm Springs River. The Confederated Tribes of the Warm Springs Reservation of Oregon's *minimum* escapement goal for wild fish upstream of Warm Springs NFH is 1,000 adults. If less than 1,000 adults are forecasted, no wild fish are incorporated into the Warm Springs NFH broodstock (CTWSRO and USFWS 2007). In addition, if less than 1,000 wild adults are forecasted, harvest restrictions are often imposed on the sport or Tribal fisheries in the Deschutes River. To assess each forecast model's management utility for wild fish management, forecasts and actual returns of less than 1,000 adults were analyzed. The number of times a model correctly and incorrectly forecasted less than 1,000 returning adults was summarized. Plots of forecasted return and actual return were also used to analyze a model's tendency to over-forecast or under-forecast runs above or below the 1,000 fish threshold.

A similar assessment was made for hatchery fish forecast models based on adult return needs for hatchery production at Warm Springs NFH. Current hatchery production goals require a broodstock of 630 adult fish (CTWSRO and USFWS 2007).   The harvest rate of Warm Springs NFH stock adults in the sport and Tribal fishery at Sherars Falls has averaged around 30% (unpublished data). A return of 1,000 Warm Springs NFH hatchery adults was used as the critical management point, with the assumption that a 30% harvest rate would result in 700 adults returning to Warm Springs NFH, sufficient for broodstock needs.

In the Deschutes Basin, several run forecasting models have been utilized over the years. In recent years, run forecasts have been based on a standard regression model and a cohort model (Lovtang et al. 2011). These two "standard" models were analyzed along with a variety of alternative models that have been used either in the Deschutes basin or for other salmon runs in the Pacific Northwest. The forecast models used in this retrospective analysis were:

1) The "standard" linear regression model as described in Lovtang et al. 2011, to predict the age 4 and age 5 returns. The standard regression model assumes a linear relationship between two sibling groups. For the Deschutes River forecasts, linear regression of age 3 (x) to predict age 4 returns (y) and age 4 (x) to predict age 5 returns (y) were

calculated. The forecasted age 4 and age 5 returns were then added to arrive at a total adult return forecast. For example, the formula for predicting age 4 returns in year t is: age $4_{year\ t}$ =a+(b*age $3_{year\ t-1}$), where a and b are estimated parameters from the linear regression.

2) A natural log (LN) transformed regression model as described in Peterman 1982 and Haeseker et al. 2008. This model is similar to the standard regression model, however log_e transformed data is used to construct the regression and then the result is back-transformed into an arithmetic scale. The formula for predicting age 4 returns in year t is: log_e(age $4_{year\ t}$)=a+b*log_e(age $3_{year\ t-1}$)+E, where E is an error term used to account for bias in back-transforming lognormal distributions (see Heaseker et al. 2008 for discussion).

3) The "standard" cohort age at return ratio method as described in Lovtang et al. 2011. This method uses the mean return ratio of age 3 returns to age 4 returns, and age 4 returns to age 5 returns to forecast returns. The formula for predicting age 4 returns in year t using this method is: age $4_{year\ t}$ =age $3_{year\ t-1}$(mean return ratio of age 3 to age 4).

4) A percent-by-age model that uses the mean percent of a brood year that returns as age 3, 4, and 5. The formula for predicting age 4 returns in year t using this method is:
age $4_{year\ t}$ = (age $3_{year\ t-1}$ X mean % age 4)/mean % age 3

5) Modifications to each of the first four models using 10 year rolling datasets instead of all data that would have been available at the time. For example, the standard linear regression model (1) for predicting the age 4 return for brood year 2002 wild fish would use data from brood years 1992-2001, instead of brood years 1975 to 2001. Forecasts using 10 year rolling datasets are often better suited to situations when the sibling relationships are changing over time.

6) A stock-recruit based model using the Ricker stock-recruit relationship to predict a brood year's return.

7) A series of smolt outmigrant models. These models used juvenile outmigrant estimates for the Warm Springs River to predict adult returns (Lindsay et al. 1989). Models were run separately using only fall outmigrant estimates, only spring outmigrant estimates, and total outmigrant estimates.

8) A series of naïve models based on Haeseker et al. 2008. The naïve models used in this analysis were a) using the previous year's return as the forecasted return, b) using the return from 4 years previous as the

forecasted return, and c) using the previous 4 year average as the forecasted return.

Results

Wild Fish

A summary of performance measures for wild fish forecast models is shown in Table 1. Smolt outmigrant models and the return 4 year previous naïve model performed poorly and were not included in any subsequent analysis (data not shown). Ranking of the remaining models by performance measure are shown in Table 2. The percent-by-age models were ranked the highest by most performance measures, with the percent-by-age 10 year model ranking the highest overall. The differences in performance measures between the percent-by-age model using all data and percent-by-age model using the most recent 10 year dataset were small, for example the percent-by-age model had a percent mean error of 39% versus 38% for the % age 10 year model. The stock-recruit model and the standard regression model were ranked the lowest (Table 2).

The difference in performance between the percent-by-age 10 year model and the standard regression model were large. The percent-by-age 10 year model had a 38% mean error and a 374 fish mean absolute error, compared to the standard regression model with a 76% mean error and 518 fish mean absolute error. In general, using 10 year rolling datasets only marginally improved forecast performance measures, with the notable exception being the 10 year rolling dataset for the standard regression model, which reduced the percent mean error from 76% to 62%.

The forecasted and actual returns of age 4 and age 5 wild fish, using the two traditional run prediction models (standard regression and cohort models), are shown in Figure 1. The cohort model performed better, i.e. closer to the line in Figure 1, during years when actual returns were less than 1,000 fish. The standard regression model tended to over-forecast during low return years and under-forecast during high return years.

Table 1. Performance measures for forecast models of **wild** Warm Springs River spring Chinook salmon.

Model Name	Mean Raw Error	Mean Abs Error	Mean % Error	RMSE
Std Reg	280	518	76	639
LN Reg	264	469	56	622
Cohort	251	416	46	633
% Age	125	376	39	533
Std Reg 10yr	250	489	62	645
LN 10yr	238	429	50	586
Cohort 10yr	236	413	45	609
% Age 10yr	72	374	38	509
Stock Recruit	139	806	94	934
Previous Yr	34	749	74	971
4 yr Avg	162	739	103	890

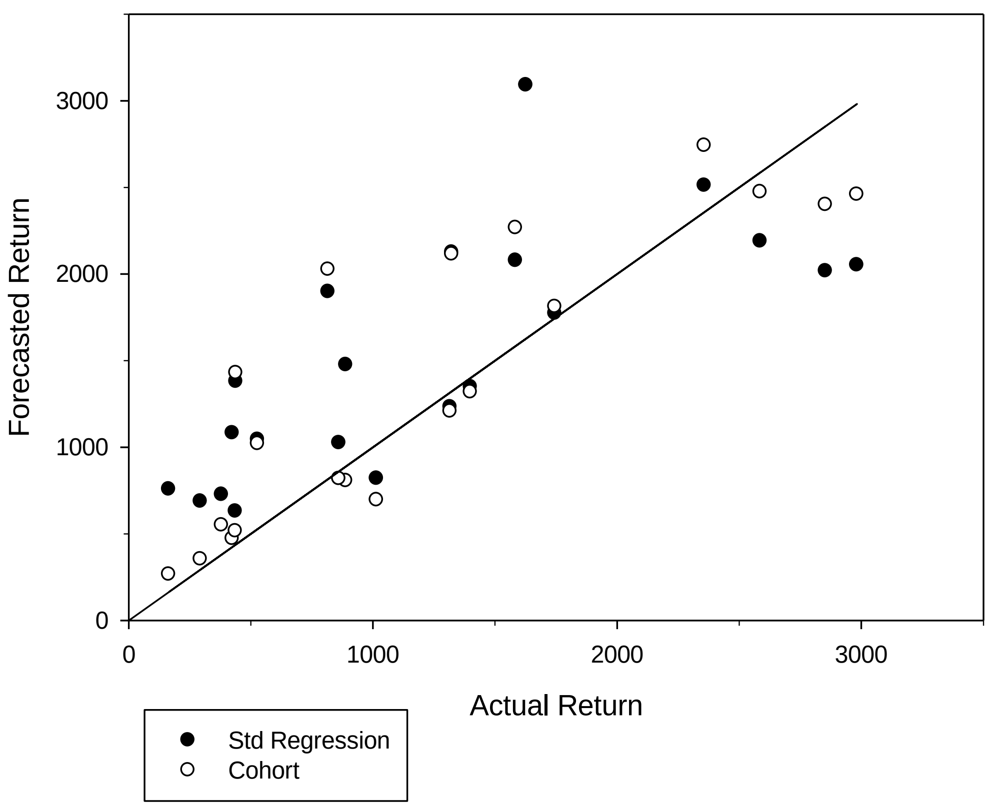

Figure 1. Forecasted and actual return of age 4 and age 5 wild spring Chinook salmon to the mouth of the Deschutes River using the traditional run prediction models (standard regression and cohort models). Return years 1990 to 2010. Line indicates "perfect" forecast, points above the line are over-forecasts, below the line are under-forecasts.

Table 2. Ranking of **wild** fish forecast models by performance measures (rank of 1=best).

Model Name	Mean Raw Error	Mean Abs Error	Mean % Error	RMSE	Average
% Age 10yr	2	1	1	1	1.25
% Age	3	2	2	2	2.25
Cohort 10yr	6	3	3	4	4.00
LN 10yr	7	5	5	3	5.00
Cohort	9	4	4	6	5.75
LN Reg	10	6	6	5	6.75
Std Reg 10yr	8	7	7	8	7.50
Previous yr	1	10	8	11	7.50
4 yr Avg	5	9	11	9	8.50
Std Reg	11	8	9	7	8.75
Stock Recruit	4	11	10	10	8.75

To further assist managers in determining a forecast's utility for making management decision in the Deschutes Basin, graphs of forecasted returns versus actual returns were created for each model, similar to Figure 1. The graphs were then divided up into four regions, based the minimum wild fish escapement goal in the Warm Springs River of 1,000 adults. Regions were defined as:

Region A: Forecasted return of over 1,000 adults and actual return of less than 1,000 adults.

Region B: Forecasted return of greater than 1,000 adults and actual return of greater than 1,000 adults.

Region C: Forecasted return of less than 1,000 adults and actual return of greater than 1,000 adults.

Region D: Forecasted return of less than 1,000 adults and actual return of less than 1,000 adults.

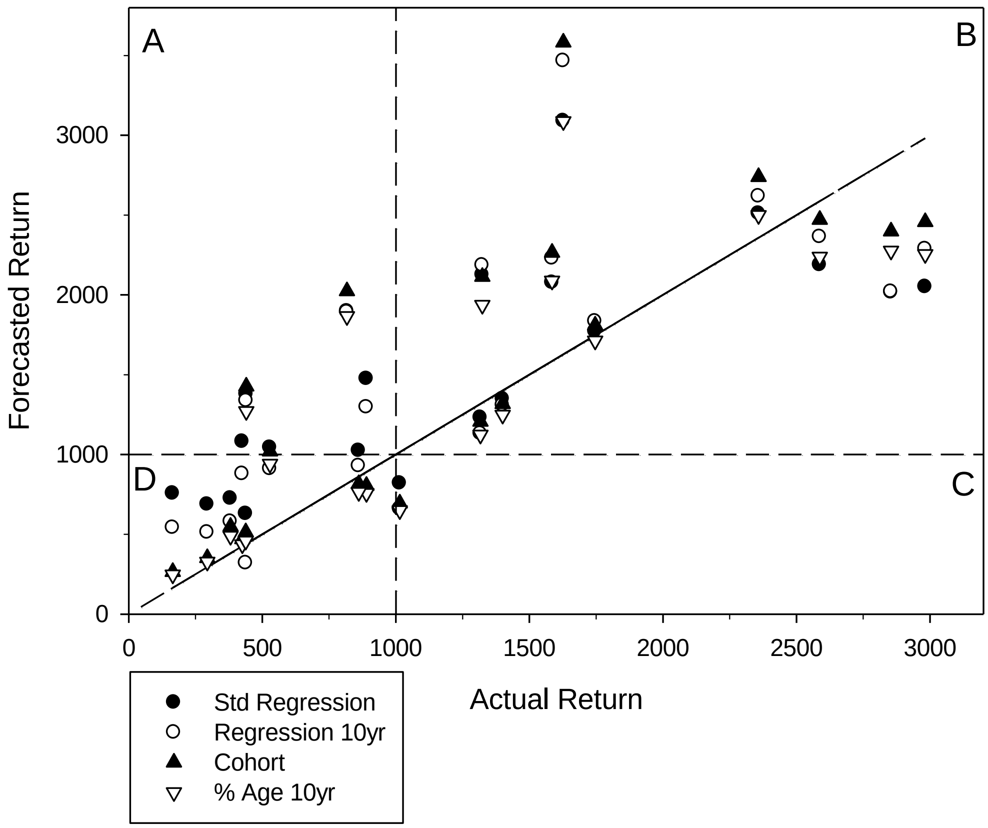

Figure 2. Forecasted and actual return of age 4 and age 5 wild spring Chinook salmon to the mouth of the Deschutes River for a variety of forecast models, return years 1990 to 2010. Regions (A through D) were created relating to minimum wild fish escapement goals in the Warm Springs River (see text). Region A (forecast>1,000 adults and actual return<1,000) represents potential risk to wild population and Region C (forecast<1,000 adults and actual return>1,000) represents potential lost harvest opportunities.

Plots for the standard regression model, regression 10 year model, cohort model, and percent-by-age 10 year model are shown in Figure 3. In cases where forecasts fall into either region B or region D, the models performed reasonably well for management purposes. Forecasts that fall into regions A or C, however, could be problematic. Years when forecasts were in Region C represent potential lost harvest opportunities if fishery regulations were set under the assumption that minimum escapement goals for the Warm Springs River were not going to be met, yet the actual return of wild fish exceeded the minimum escapement level (actual observations indicated that this was a rare event from forecast models). Years when forecasts were in Region A represent the greatest risk to the wild population from a conservation perspective. Region A represents years when the forecasted wild fish returns will meet the minimum escapement goal for the Warm Springs River, however the actual return fell short of the escapement goal (actual observations indicated this may be a problem with many forecast models and will be described in subsequent paragraphs, Table 3). Forecast models that had the fewest occurrences in Region A and C would have the most utility for fishery managers.

The actual return of wild adults to the mouth of the Deschutes River was less than 1,000 adults 10 times between 1990 and 2010. The standard regression model incorrectly forecasted more than 1,000 adults, corresponding to Region A, six times, the cohort model three times, the 10 year regression model three times, and the percent-by-age 10 year model two times (Table 3). All models forecasted in Region C, meaning a forecast of fewer than 1,000 and an actual return greater than 1,000, one time. This occurred in return year 2006, when the actual return was 1,015 adults.

Table 3. Number of years that a model's forecast fell into forecast regions for wild Warm Springs River spring Chinook salmon for return years 1990 to 2010 (see text). Region A (forecast >1,000 and actual return <1,000; risk to wild population) and Region C (forecast <1,000 and actual return >1,000; lost harvest) are critical regions for management purposes.

	Model Name							
	Std Reg	Ln Reg	Cohort	% Age	Std Reg 10yr	LN 10yr	Cohort 10yr	% Age 10yr
Region A	6	4	3	2	3	4	3	2
Region B	10	10	10	10	10	10	10	10
Region C	1	1	1	1	1	1	1	1
Region D	4	6	7	8	7	6	7	8

Hatchery Fish

Performance measures of hatchery fish forecast models are shown in Table 4, and corresponding rankings in Table 5. Similar to wild fish models, the percent-by-age models were ranked the highest by most performance measures, however for hatchery forecasts the percent-by-age model using all data performed better than the percent-by-age 10 year model. A similar pattern was evident for most hatchery models, with the 10 year rolling datasets performing poorer than datasets using all available information. Using natural log transformed data improved the performance of the standard regression model, reducing the mean percent error from 105% to 68% (Table 4). In relation to the traditional run forecasting models, the percent-by-age model using all data had a mean percent error of 45%, compared to 105% for the standard regression model and 60% for the cohort model.

Table 4. Performance measures for forecast models of Warm Spring s NFH **hatchery** spring Chinook salmon.

Model Name	Mean Raw Error	Mean Abs Error	Mean % Error	RMSE
Std Reg	-58	1,224	105	1,812
LN Reg	-12	1,079	68	1,619
Cohort	731	1,230	60	2,101
% Age	-98	998	45	1,441
Std Reg 10yr	415	1,170	91	1,824
LN 10yr	719	1,296	74	2,153
Cohort 10yr	752	1,402	64	2,379
% Age 10 yr	286	1,179	53	1,678
Previous Yr	-112	2,635	103	2,314
4 yr Avg	-178	1,339	259	2,777

Table 5. Ranking of **hatchery** fish forecast models by performance measures (rank of 1=best).

Model Name	Mean Raw Error	Mean Abs Error	Mean % Error	RMSE	Average
% Age	3	1	1	1	1.50
LN Reg	1	2	5	2	2.50
% Age 10yr	6	4	2	3	3.75
Std Reg	2	5	9	4	5.00
Std Reg 10yr	7	3	7	5	5.50
Cohort	9	6	3	6	6.00
LN 10yr	8	7	6	7	7.00
Previous yr	4	10	8	8	7.50
Cohort 10yr	10	9	4	9	8.00
4 yr Avg	5	8	10	10	8.25

The forecasted and actual returns of age 4 and age 5 hatchery fish, using the two traditional run prediction models (standard regression and cohort models), are shown in Figure 3. An analysis of model performance by region, similar to that done for wild fish, was made for hatchery fish forecast models based on adult return needs for hatchery production at Warm Springs NFH. Current hatchery production goals require a broodstock of 630 adult fish (CTWSRO and USFWS 2007). The harvest rate of Warm Springs NFH stock adults in the sport and Tribal fishery at Sherars Falls has averaged around 30% (unpublished data). For this analysis of model performance, a return of 1,000 Warm Springs NFH hatchery adults was used as the critical management point, with the assumption that a 30% harvest rate would result in 700 adults returning to Warm Springs NFH, sufficient for broodstock needs. Plots of model performance by region are shown in Figure 4, and results are reported in Table 6.

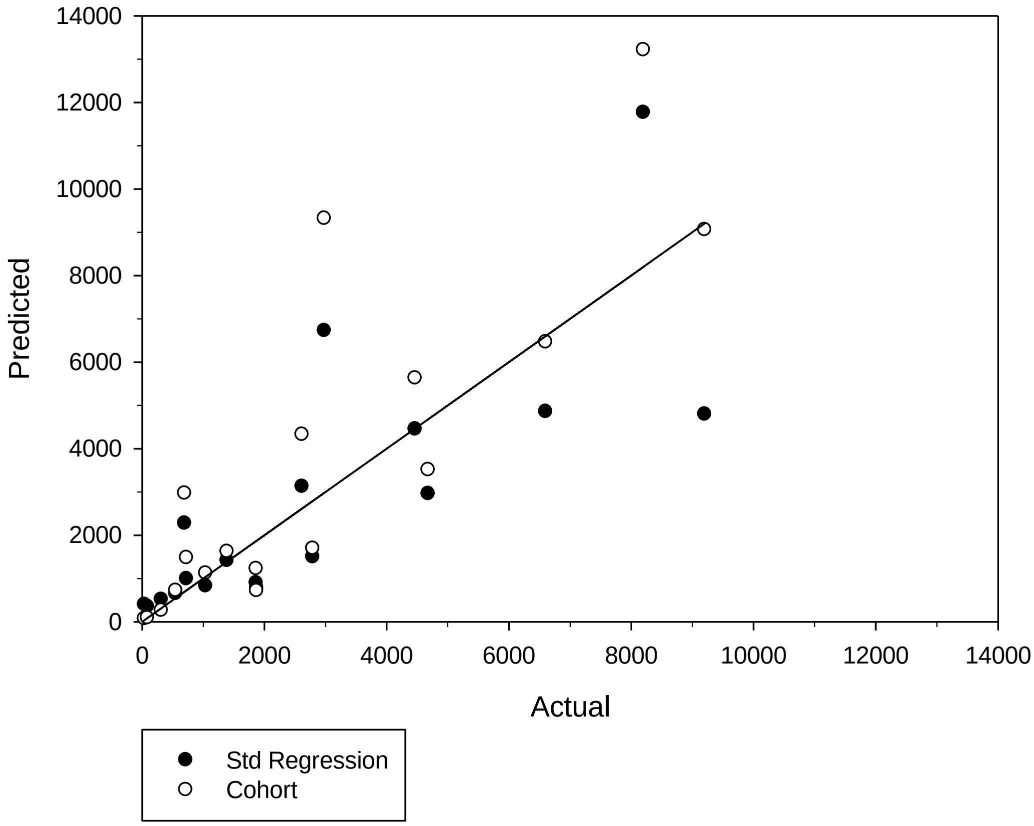

Figure 3. Forecasted and actual return of age 4 and age 5 Warm Springs NFH hatchery spring Chinook salmon to the mouth of the Deschutes River using the traditional run prediction models (standard regression and cohort models). Return years 1993 to 2010. Line indicates "perfect" forecast, points above the line are over-forecasts, below the line are under-forecasts.

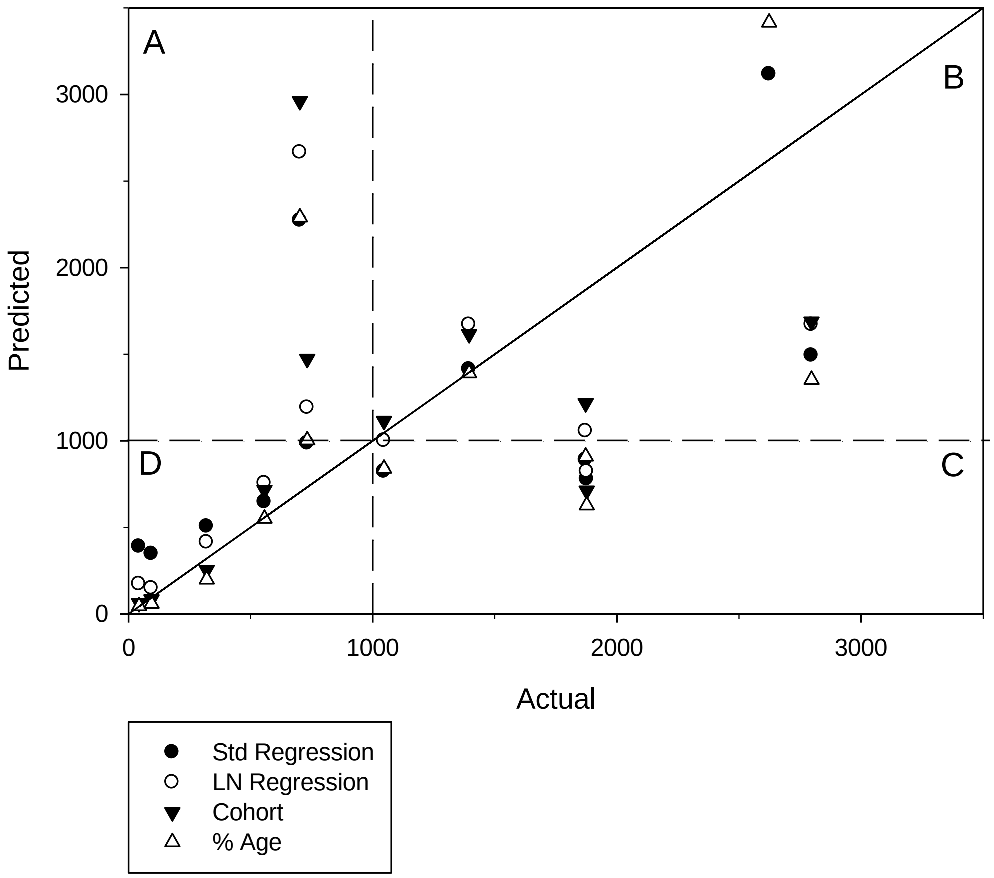

Figure 4. Forecasted and actual return of age 4 and age 5 Warm Springs NFH hatchery spring Chinook salmon to the mouth of the Deschutes River for a variety of forecast models, return years 1993 to 2010. Regions (A through D) based on average harvest rate and broodstock needs (see text). Region A (forecast>1,000 adults and actual return<1,000) represents potential risk to broodstock needs and Region C (forecast<1,000 adults and actual return>1,000) represents potential lost harvest opportunities. Forecasts and actual returns >3,500 not shown in this figure.

Table 6. Number of years that a model's forecast fell into forecast regions for Warm Springs NFH hatchery spring Chinook salmon for return years 1993 to 2010 (see text). Region A (forecast >1,000 and actual return <1,000; risk to broodstock) and Region C (forecast <1,000 and actual return >1,000; lost harvest) are critical regions for management purposes.

	Model Name						
	Std Reg	Ln Reg	Cohort	% Age	Std Reg 10yr	LN 10yr	% Age 10yr
Region A	1	2	2	1	1	1	1
Region B	9	11	11	10	10	10	9
Region C	3	1	1	3	2	2	3
Region D	5	4	4	4	5	5	5

Discussion

Wild Fish

Using a retrospective analysis of run forecasting methods can provide an objective evaluation of a forecast model's utility for management purposes. The traditional run forecasting models used in the Deschutes basin for wild spring Chinook salmon, the standard regression and cohort models, performed moderately well in comparison to the alternative models investigated. In general, the cohort model performed better than the standard regression model, particularly in low return years (Figure 2). Using 10 year rolling datasets marginally improved the performance of the cohort model but greatly improved the performance of the regression model. Use of rolling datasets can often improve forecast ability in situations where the underlying sibling relationships used in the models change over time. Use of the 10 year rolling dataset for the regression model, instead of all data in the regression model, would have reduced the number of times a forecast fell into Region A of Figure 2, a potential risk to the wild fish escapement goal, from six years to three years for return years 1990 to 2010 (Table 3). Based on this retrospective analysis, using a 10 year rolling dataset for the regression model is recommended for wild spring Chinook salmon forecasts in the Deschutes Basin.

Of the alternative forecast models investigated, the percent-by-age model using a ten year rolling dataset performed the best by most measures (Tables 1 and 2). For example, the percent-by-age ten year model had a mean percent error of 38%, compared to 45% for the cohort model and 76% for the standard regression model. The percent-by-age ten year model was also the best performer when looking at management risks pertaining to wild fish escapement goals (Region A in Figure 2, Table 3). The percent-by-age models performed marginally better than the cohort models. The improved performance of the percent-by-age models compared to the cohort models may be due to the fact that the percent-by-age models apportion out the sibling relationship across all three ages at return (age 3, 4, and 5) for a given brood year while the cohort model uses the relationship between just two ages (age 3 to age 4, or age 4 to age 5) in a given brood year.

Forecast models, regardless of the type of model used, provide a point estimate of the number of fish that may return in a given year based on return relationships in previous years. In this analysis, only the point estimates generated by each model were evaluated for performance. In the Deschutes basin, wild spring Chinook returns have varied considerably, ranging from as few as 118 to over 3,000 adult sized fish returning to the mouth of the Deschutes in a given year. In addition to the variability in the magnitude of adult returns, all models investigated in this analysis appeared to have rather large variability in the sibling relationships that underpinned each model's predictive capability. Confidence intervals of a particular year's forecast, if they had been constructed, would have been quite large for all models as evidenced by the RMSE values in Table 1. For example, in return year 2011 the 80% forecast prediction interval using the standard regression model for age 4 and age 5 wild spring Chinook salmon was between 370 and 1,706 fish (Lovtang et al. 2011). If 95% prediction intervals were desired for the forecast, the range would have been even larger.

Prediction intervals can accurately convey the uncertainty around a particular forecast, however the large range of the intervals represent a high degree of uncertainty within which managers in the basin must make decisions. In an effort to assist managers in making decisions, the run prediction reports for the Deschutes basin often include a "best guess" estimate of how many wild fish may return. This estimate is based on forecast model estimates, prediction intervals, the previous year's forecast and actual return, conservation goals, professional judgment, and other non-quantitative approaches. While the quantitative data, including estimators of forecast variability, underpinning the forecast models are provided in the run prediction reports, managers, agencies, and the public often focus on the point estimate "best guess" to set expectations for the spring Chinook salmon return to the Deschutes and Warm Springs rivers.

Looking closer at plots of forecasted and actual returns (Figure 2), a supplemental forecast reporting method can developed that may be a relatively straight-forward way of providing additional information regarding a forecast's accuracy. This supplemental method is based on identifying general zones of forecasts relating to the 1,000 wild fish minimum escapement goal, and then evaluating a model's performance when a given forecast is in a specific zone.

For wild spring Chinook salmon forecasts in the Deschutes basin, the proposed forecast zones are:

> Red Zone: Forecast of less than 1,000 fish; high probability of less than 1,000 fish returning
>
> Yellow Zone: Forecast of between 1,000 and 1,500 fish; moderate probability of less than 1,000 fish returning
>
> Green Zone: Forecast of more than 1,500 fish; low probability of less than 1,000 fish returning

Zone designations were added to the plots of forecasts and actual returns, resulting in Figure 5. Looking at Figure 5, a general idea of the historic probability of fewer than 1,000 fish returning using a given model's forecast can be evaluated. Forecasts in the red zone indicate a high probability of not meeting wild fish escapement goals, forecasts in the yellow zone a moderate probability of not meeting wild fish escapement goals, and forecasts in the green zone a low probability of not meeting minimum wild fish escapement goals. The percent-by-age 10 year model performed the best using the zone method (Figure 5). Using this model, the forecasted return was in the red zone, i.e. less than 1,000 adults forecasted, nine times between 1990 and 2010. The actual return of adults was less than 1,000 (indicated by data points to the left of the dotted line in Figure 5) in eight of those nine years. Fewer than 1,000 wild fish returned in one of three years the forecast was in the yellow zone, and one out of nine years the forecast was in the green zone. A summary of zone forecast performance, by forecast model, is shown in Table 7. Addition of the zone designation to the forecast point estimate in the annual run prediction reports can be particularly helpful to fishery managers in assessing the risk of not meeting the minimum escapement goal for wild fish.

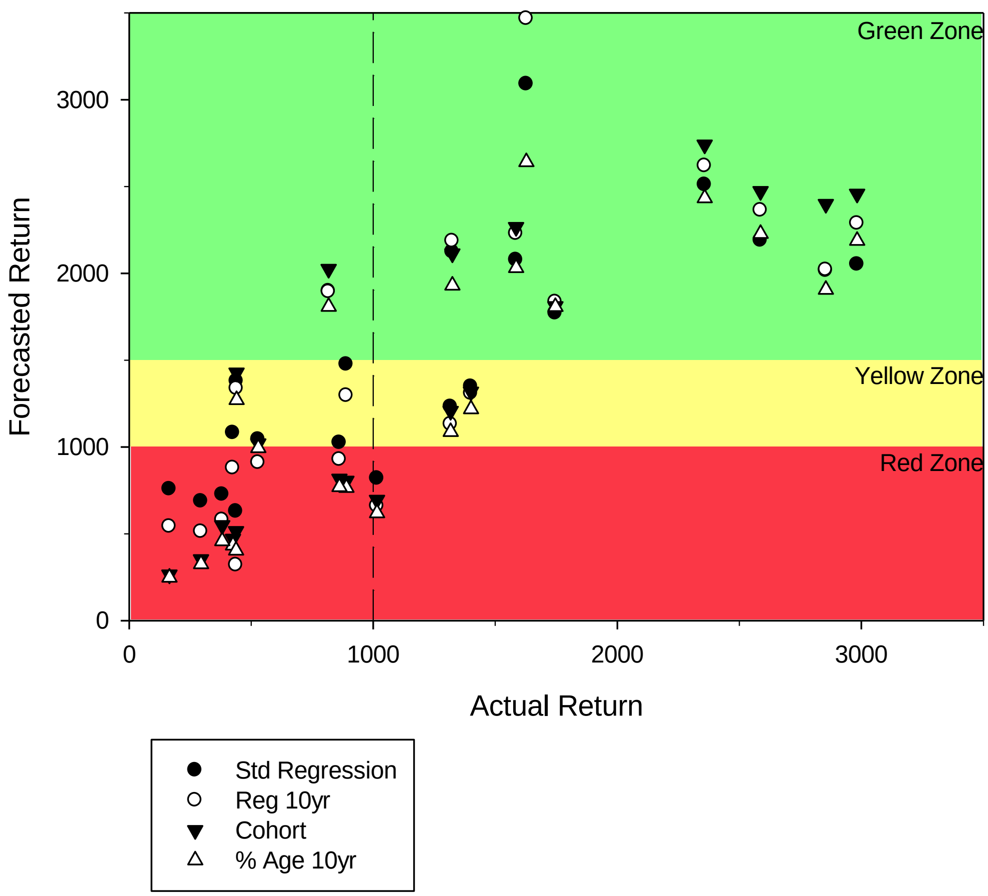

Figure 5. Forecast zones for wild fish models, return years 1990-2010. The dotted line represents the minimum wild fish escapement goal for the Warm Springs River.

Table 7. Percent of times, given a zone forecast, the actual return of wild spring Chinook was below 1,000, between 1,000 and 1,500, and above 1,500 adult fish for return years 1990 to 2010. First column (<1,000 actual return) indicates percent of time wild fish escapement goals were not met when a forecast was in a particular zone. Diagonal values closest to 100% indicate the best predictor models.

		Actual Return		
Model	Zone Forecast	<1,000	1,000 to 1,500	>1,500
Standard Regression	Red	**80%**	20%	0%
	Yellow	71%	**29%**	0%
	Green	11%	11%	**78%**
Regression 10yr	Red	**88%**	13%	0%
	Yellow	50%	**50%**	0%
	Green	11%	11%	**78%**
Cohort	Red	**88%**	13%	0%
	Yellow	50%	**50%**	0%
	Green	11%	11%	**78%**
% Age 10yr	Red	**89%**	11%	0%
	Yellow	33%	**67%**	0%
	Green	11%	11%	**78%**

Hatchery Fish

The percent-by-age model, using all available data, was the best performing model for hatchery forecasts with a decrease in RMSE value of 20% from the standard regression model and 31% from the cohort model. In addition, the natural log transformation decreased the mean percent error from 105% to 68% compared to the standard regression model. Use of the percent-by-age model and natural log transformed regression model for forecasts of Warm Springs NFH hatchery spring Chinook salmon returns would have led to improved forecast accuracy over the years examined in this evaluation. All models, however, were similar in the forecasting of potential shortfalls for broodstock (Region D of Figure 4), with the notable exception of the cohort model in return year 1996, when 732 adults returned. The cohort model forecasted an adult return of almost 1,500 in 1996 while all other models forecasted around 1,000 adults.

Recommendations for Warm Springs stock spring Chinook salmon Forecasting in the Deschutes Basin

Based on the historical data analyzed here, several actions could be taken to improve the forecasting of spring Chinook salmon returns to the Deschutes basin. Recommendations for wild fish forecasts are:

- Use a 10 year rolling dataset for the standard regression model.
- Use the percent-by-age model, with 10 year rolling datasets, to supplement the traditional forecast models. The percent-by-age model could replace the cohort model in the run prediction reports.
- Add a zone (red, yellow, green) descriptor to the point estimates in run prediction reports. Forecasts in the red zone would indicate a high probability of not meeting wild fish escapement goals, in the yellow zone a moderate probability of not meeting wild fish escapement goals, and in the green zone a low probability of not meeting minimum wild fish escapement goals. Statistics, including confidence intervals and evaluation of past model performance should continue to be included in run prediction reports.
- Continue to evaluate forecast model performance on an annual basis.

Recommendations for Warm Springs NFH hatchery fish forecasts are:

- Use natural log transformed data for regression model forecasts.
- Use the percent-by-age model to supplement the traditional run forecast models. The percent-by-age model could replace the cohort model in the run prediction reports.
- Continue to evaluate forecast model performance on an annual basis.

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Appendix 1. Forecast performance measures for wild Warm Springs river spring Chinook salmon forecast models.

Actual Return				Std Model				Ln Model				Cohort				Percent by Age				
Ret. Year	Age 4	Age 5	Total	Pred.	Raw Error	Abs Error	% Error	Pred.	Raw Error	Abs Error	% Error	Pred.	Raw Error	Abs Error	% Error	Pred.	Raw Error	Abs Error	% Error	
1979	1,474																			
1980	1,107	332	1,439																	
1981	1,205	326	1,531																	
1982	1,650	413	2,063																	
1983	1,715	309	2,024																	
1984	937	255	1,192																	
1985	1,503	180	1,683																	
1986	2,160	206	2,366																	
1987	2,064	496	2,560																	
1988	1,772	600	2,372																	
1989	1,641	440	2,081																	
1990	2,366	488	2,854	2,026	-828	828	-29	2,055	-799	799	-28	2,399	-455	455	-16	2,273	-581	581	-20	
1991	864	460	1,324	2,092	768	768	58	2,140	816	816	62	2,114	790	790	60	1,922	598	598	45	
1992	1,323	423	1,746	1,825	79	79	5	1,797	51	51	3	1,810	64	64	4	1,715	-31	31	-2	
1993	474	416	890	1,481	591	591	66	1,341	451	451	51	805	-85	85	-10	735	-155	155	-17	
1994	362	63	425	1,022	597	597	140	782	357	357	84	471	46	46	11	434	9	9	2	
1995	94	71	165	732	567	567	343	367	202	202	123	265	100	100	61	251	86	86	52	
1996	1,376	24	1,400	1,330	-70	70	-5	1,322	-78	78	-6	1,317	-83	83	-6	1,248	-152	152	-11	
1997	826	35	861	1,007	146	146	17	822	-39	39	-5	816	-45	45	-5	762	-99	99	-11	
1998	250	44	294	673	379	379	129	389	95	95	32	352	58	58	20	339	45	45	15	
1999	365	16	381	717	336	336	88	600	219	219	58	549	168	168	44	491	110	110	29	
2000	2,884	98	2,982	2,053	-929	929	-31	2,281	-701	701	-24	2,457	-525	525	-18	2,258	-724	724	-24	
2001	1,854	504	2,358	2,472	114	114	5	2,758	400	400	17	2,740	382	382	16	2,491	133	133	6	
2002	1,386	199	1,585	2,063	478	478	30	2,248	663	663	42	2,265	680	680	43	2,092	507	507	32	
2003	1,249	68	1,317	1,221	-96	96	-7	1,249	-68	68	-5	1,206	-111	111	-8	1,130	-187	187	-14	
2004	2,217	370	2,587	2,193	-394	394	-15	2,371	-216	216	-8	2,472	-115	115	-4	2,247	-340	340	-13	
2005	793	24	817	1,855	1,038	1,038	127	2,036	1,219	1,219	149	2,025	1,208	1,208	148	1,857	1,040	1,040	127	
2006	926	89	1,015	814	-201	201	-20	766	-249	249	-25	694	-321	321	-32	657	-358	358	-35	
2007	378	62	440	1,371	931	931	212	1,446	1,006	1,006	229	1,427	987	987	224	1,273	833	833	189	
2008	486	43	529	1,038	509	509	96	1,063	534	534	101	1,020	491	491	93	943	414	414	78	
2009	399	39	438	623	185	185	42	584	146	146	33	514	76	76	17	460	22	22	5	
2010	1,596	31	1,627	3,085	1,458	1,458	90	3,171	1,544	1,544	95	3,582	1,955	1,955	120	3,089	1,462	1,462	90	
			Mean=		269	509	64		264	469	47		251	416	36		**125**	**375**	**25**	

Appendix 2. Forecast performance measures for Warm Springs NFH hatchery Warm Springs river spring Chinook salmon forecast models

Actual Return				Std Model				Ln Model				Cohort				Percent by Age			
Ret. Year	Age 4	Age 5	Total	Pred.	Raw Error	Abs Error	% Error	Pred.	Raw Error	Abs Error	% Error	Pred.	Raw Error	Abs Error	% Error	Pred.	Raw Error	Abs Error	% Error
1983	326	115	441																
1984	767	20	787																
1985	1,508	73	1,581																
1986	146	71	217																
1987	678	41	719																
1988	520	89	609																
1989	3,254	89	3,343																
1990	1,632	168	1,800																
1991	678	139	817																
1992	1,080	77	1,157																
1993	167	153	320	504	184	184	58	413	93	93	29	254	-66	66	21	199	-121	121	38
1994	27	16	43	388	345	345	802	173	130	130	301	63	20	20	46	45	2	2	5
1995	94	0	94	347	253	253	269	147	53	53	57	84	-10	10	11	58	-36	36	38
1996	731	1	732	986	254	254	35	1,190	458	458	63	1,472	740	740	101	1,003	271	271	37
1997	1,017	29	1046	823	-223	223	21	1,001	-45	45	4	1,114	68	68	7	839	-207	207	20
1998	534	23	557	646	89	89	16	755	198	198	35	715	158	158	28	550	-7	7	1
1999	1,825	47	1872	890	-982	982	52	1,056	-816	816	44	1,216	-656	656	35	909	-963	963	51
2000	9,168	41	9,209	4,788	-4,421	4,421	48	5,126	-4,083	4,083	44	9,052	-157	157	2	6,528	-2,681	2,681	29
2001	4,362	321	4,683	2,956	-1,727	1,727	37	3,347	-1,336	1,336	29	3,507	-1,176	1,176	25	2,926	-1,757	1,757	38
2002	8,074	130	8,204	11,759	3,555	3,555	43	9,068	864	864	11	13,208	5,004	5,004	61	9,813	1,609	1,609	20
2003	6,160	447	6,607	4,851	-1,756	1,756	27	5,252	-1,355	1,355	21	6,456	-151	151	2	5,215	-1,392	1,392	21
2004	4,395	75	4,470	4,446	-24	24	1	4,801	331	331	7	5,624	1,154	1,154	26	4,463	-7	7	0
2005	1,277	118	1395	1,412	17	17	1	1,670	275	275	20	1,615	220	220	16	1,389	-6	6	0
2006	2,697	100	2,797	1,491	-1,306	1,306	47	1,669	-1,128	1,128	40	1,687	-1,110	1,110	40	1,352	-1,445	1,445	52
2007	1,653	223	1876	779	-1,097	1,097	59	821	-1,055	1,055	56	712	-1,164	1,164	62	626	-1,250	1,250	67
2008	2,971	14	2985	6,717	3,732	3,732	125	7,197	4,212	4,212	141	9,313	6,328	6,328	212	6,823	3,838	3,838	129
2009	2,526	97	2623	3,116	493	493	19	3,656	1,033	1,033	39	4,321	1,698	1,698	65	3,415	792	792	30
2010	674	28	702	2,272	1,570	1,570	224	2,664	1,962	1,962	280	2,962	2,260	2,260	322	2,290	1,588	1,588	226
			Mean=		-58	1,224	105		-12	1,079	68		731	1,230	60		-98	998	45