SALMON TECHNICAL TEAM REPORT ON THE SALMON METHODOLOGY REVIEW

The Salmon Technical Team (STT) appreciates the work that the Model Evaluation Workgroup (MEW) has put into documenting the fishery regulation assessment model (FRAM), algorithms and data. The documentation reviewed included a revised overview of the FRAM itself, and descriptions of the base period data and algorithms used for both coho and Chinook. The documentation provides a description of most of the model algorithms, but some of the details of the data and procedures used to in a base period calibration of the model need elaboration. The STT recommends that the documentation be reviewed and organized by a technical editor. This review and organization should help uncover specific areas of the documentation which need clarification. The documentation also lacks a user's manual that would be necessary for anyone wanting to run the model. We understand that the MEW is working toward completion of such a manual.

The STT also reviewed a paper by the MEW describing several methods to generate ocean cohort abundances for Columbia River fall Chinook stocks. While considerable progress has been made, more work needs to be completed before any of these methodologies are ready for use in Council management. We recommend that the MEW work with members of the Columbia River Technical Advisory Committee so that ocean abundance forecasts are available for use in preseason planning for the 2007 season.

PFMC
11/1/05

SALMON METHODOLOGY REVIEW

Each year, the Scientific and Statistical Committee (SSC) completes a methodology review to help assure new or significantly modified methodologies employed to estimate impacts of the Council's salmon management use the best available science. This review is preparatory to the Council's adoption, at the November meeting of all anticipated methodology changes to be implemented in the coming season, or in certain limited cases, of providing directions for handling any unresolved methodology problems prior to the formulation of salmon management options in March. Because there is insufficient time to review new or modified methods at the March meeting, the Council may reject their use if they have not been approved the preceding November.

This year the SSC is expected to report on documentation of the Chinook and Coho Fishery Regulation Assessment Model and Columbia River fall chinook abundance forecasts.

Council Action:

1. **Approve methodology changes as appropriate for implementation in the 2006 salmon season.**
2. **Provide guidance as needed, for any unresolved issues.**

Reference Materials:

Agenda Item G.1.b, Supplemental SSC Report.

Agenda Order:

a.	Agenda Item Overview	Chuck Tracy
b.	Report of the Scientific and Statistical Committee (SSC)	Bob Conrad
c.	Reports and Comments of Advisory Bodies	
d.	Public Comment	
e.	**Council Action**: Adopt Final Salmon Methodology Changes for 2006	

PFMC
10/12/05

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON SALMON METHODOLOGY REVIEW

A joint meeting of the Scientific and Statistical Committee (SSC) Salmon Subcommittee and the Salmon Technical Team (STT) was held on October 12, 2005 in Portland. Presentations were given on the two items identified for review at the Council's September 2005 meeting:

- Documentation of the Coho and Chinook Fishery Regulation Assessment Models (FRAM), and
- Ocean abundance forecasts for Columbia River Fall Chinook salmon.

Coho and Chinook FRAM Documentation

Mr. Andy Rankis, Mr. Jim Packer, and Mr. Larrie LaVoy of the Model Evaluation Workgroup (MEW) gave presentations on the documentation of the Coho and Chinook FRAM models. Currently, the models are described in three documents:

1. Fishery Regulation Assessment Model (FRAM). An Overview for Chinook and Coho (2005 Update).
2. Coho FRAM Base Period Development.
3. Chinook FRAM Base Period Development.

The FRAM models project fishery effects in a given year using stock abundances and fishing efforts "scaled" to stock abundances and fishery exploitation rates (age-specific for Chinook) during a defined base period. The base period development reports were the focus of the meeting discussions.

FRAM Overview for Chinook and Coho - 2005 Update:

The overview document describes the modeling steps used by each FRAM to calculate fishery impacts for 33 Chinook stock groups and 123 coho stock groups. Unless a separate FRAM User's Guide is to be prepared, questions will arise regarding its application. A section describing the process through which FRAM parameter values are established during preseason planning processes would be helpful. The overview documentation also lacks any discussion of the interpretation of FRAM results. This is an extremely important area that should be addressed.

Although the FRAM steps are outlined in flow charts (Figure 1 for coho and Figure 2 for Chinook) and a discussion of some of the algorithms used in the model is included in the report, there is no linkage between these figures and text. If the steps in the figure and the corresponding text were linked a reader could refer to a specific section in the report for details on the methods used at each step.

The FRAM program interacts with two species-specific (Chinook and coho) Terminal Area Management Module (TAMM) spreadsheets that allow users to specify terminal fishery impacts on a finer level of time and area resolution. The Coho TAMM now serves more as a recipient of FRAM output for customized report generation. In contrast, the Chinook TAMM remains a

critical element of pre-season modeling for Puget Sound fisheries, as many populations of management interest need to be "extracted" from the aggregated FRAM stock groupings. The TAMM fishery inputs, in addition to a fixed catch, allow for two fishery control mechanisms that are not used by FRAM: (1) percent of terminal area abundance (TAA) and (2) percent of extreme terminal run size (ETRS). The SSC finds the documentation for the TAMM (section 7 of the overview document) incomplete. The SSC requests that a flow chart and the algorithms used to derive TAA and ETRS, and other TAMM calculations, be included in the overview document.

Coho FRAM Base Period Development:

The Coho FRAM Base Period Development documentation is in draft form. Although Figure 1 provides an overall view of how the data were put together and how the base period was developed, it is difficult to match each step in the figure with the corresponding text that describes the step in the document. The report would benefit if each step in Figure 1 was linked to a section in the document. A reader could then refer to that section in the report for details on the methods used. The text section that is linked to a step in Figure 1 should include all the data input files, data output, the programs used, a brief explanation of what each program does (not the program code), and the algorithms used to manipulate the data. The documentation of the model calibration process provided in the section 3 of the Chinook FRAM Base Period Development report provides an example of this level of documentation. Creating a linkage between the steps in Figures 2 – 9 with text would improve the value of each figure and the report as a whole.

Some of the 123 coho stock groups in the base period do not have coded-wire tag (CWT) data associated with them yet Production Expansion Factors (PEFs) are assigned to them. The report should include a section that describes the methods used to develop PEFs for stock groups without CWT recoveries.

Mr. Packer stated that work on the Coho FRAM is ongoing and the base period will include additional years in the future. The SSC recommends that any changes to the model or the base period be noted in the documentation.

Chinook FRAM Base Period Development:

The documentation for the Chinook FRAM base period was incomplete; consequentially it was difficult to track how the base period calculations were made. It appears that all steps used to develop a base period data set for Chinook are included in Figures 1, 2, 2a, and 3. The SSC suggests that these figures form the basis of the documentation. All steps outlined in these figures should be linked to a section in the report that describes all the data input files, data output, the programs used, a brief explanation of what each program does (not the program code), and the algorithms used to manipulate the data (similarly to the documentation for section 3 of the Chinook report).

A primary point of confusion among the SSC and STT was the derivation of an "all stocks" CWT recovery data set that includes CWT recovery data of stocks tagged during the base period with simulated CWT recoveries of stocks that were not tagged during the base period (Out of Base Stocks or OOB stocks). Because of the importance of stock abundance estimates in the base period for FRAM calculations, this report needs to provide a clearer explanation of the

methods used to bring the OOB stocks into the base period. Providing a simple numerical example of how an OOB stock could be incorporated into the base period would clarify this process.
The documentation for the Chinook FRAM is not yet sufficient to allow SSC review of the model, especially as it applies to mark-selective fisheries. The MEW has indicated that the changes requested could be available for SSC review at the June 2006 Council meeting. If a complete draft document were available in June, the SSC would be able to thoroughly review the documentation and provide additional feedback to the MEW for finalization of the documentation for review during the September/November 2006 PFMC meetings.

To facilitate better understanding of what FRAM does and how it works, the SSC recommends that all programs and data that are used in both the coho and Chinook FRAMs be archived in a single web FTP location and that they be accessible to the public. All changes and modifications to the models, programs, and input data sets should be documented and copies of the documentation should be available from the FTP site.

Ocean Abundance Forecasts for Columbia River Fall Chinook Salmon

Mr. Henry Yuen (U. S. Fish and Wildlife Service) gave a presentation on methods to forecast ocean abundances for four Columbia River Chinook salmon stocks. Currently the Oregon Technical Advisory Committee (TAC) provides forecasts of the return to the mouth of the Columbia River for these stocks. These river-mouth forecasts must then be converted into ocean cohort abundance estimates for use in the Chinook FRAM. The current procedure for making this conversion introduces bias into the preseason planning models and processes. A method which is based on direct forecasts of ocean cohort abundance for these stocks that could be directly entered into Chinook FRAM would address this bias.

A number of the models presented in the report appear promising for forecasting ocean cohort abundance of these four Columbia River Chinook stocks. However, it is unclear how these methods could be utilized in the current management process to establish ocean abundance cohort sizes for Columbia River stocks for use in the Chinook FRAM. Currently, there are no forecast methods that are consistently applied annually to either stocks, age groups, or between years. Each year the TAC evaluates a large number of models and selects a forecast for each stock and age group. The proposed methods will increase the number of forecasts that the TAC evaluates each year and will produce forecasts of ocean cohort abundance estimates rather than Columbia River mouth abundance estimates as is done currently.

Additional work in this area is warranted, and further review is needed, before the SC can endorse the proposed methodologies. Specifically,

- There are several methods that could be used to calculate the ocean abundance of Columbia River Chinook stocks. For this report, a ratio of Columbia River mouth returns (estimated by WDFW) to Columbia River coded wire tag (CWT) recoveries was used to convert the ocean abundance of CWT recoveries to ocean abundance of Columbia River fish. Two other possible methods of estimating ocean abundance use: (1) a run reconstruction algorithm (cohort analysis) or (2) a recursive method which uses estimates of ocean mortality and survival. Before a decision on which forecast models are “best”, an analysis of the differences between the estimates of ocean cohort size provided by the

different methods and an examination of the advantages and disadvantages of each method is needed.

- The TAC should evaluate the advantages of using methods which forecast ocean abundance directly and determine whether the continued use of river-mouth abundance forecasts is warranted.

PFMC
11/01/05

PACIFIC FISHERY MANAGEMENT COUNCIL SCHEDULE AND PROCESS FOR DEVELOPING 2006 OCEAN SALMON FISHERY MANAGEMENT MEASURES

Oct. 31-Nov. 4, 2005	The Council and advisory entities meet at the Hyatt Regency Islandia, San Diego, California to: (1) consider any changes to methodologies used in the development of abundance projections or regulatory options; and (2) adopt the management process and schedule for 2006 ocean salmon fisheries.
Jan. 17-20, 2006	The Salmon Technical Team (STT) and Council staff economist meet in Portland, Oregon to draft *Review of 2005 Ocean Salmon Fisheries*. This report summarizes seasons, quotas, harvest, escapement, socioeconomic statistics, achievement of management goals, and impacts on species listed under the Endangered Species Act. (February 6 print date, mailed to the Council February 23, and available to the public February 28.)
Feb. 7-10	STT meets in Portland, Oregon to complete *Preseason Report I Stock Abundance Analysis for 2006 Ocean Salmon Fisheries*. This report provides key salmon stock abundance estimates and level of precision, harvest and escapement estimates when recent regulatory regimes are projected on 2006 abundance, and other pertinent information to aid development of management options. (February 16 print date, mailed to the Council February 23, and available to the public February 28.)
Feb. 23 through Mar. 5	State and tribal agencies hold constituent meetings to review preseason abundance projections and range of probable fishery options. The Klamath Fishery Management Council completes recommendations for ocean management options affecting Klamath River fall chinook.
Feb. 28	Council reports summarizing the 2005 salmon season and salmon stock abundance projections for 2006 are available to the public from the Council office.
Mar. 5-10	Council and advisory entities meet at the Seattle Marriott Hotel Sea Tac, Seattle, Washington, to adopt 2006 regulatory options for public review. The Council adopts preliminary options on March 7, tentative options for STT analysis on March 8, and final options for public review on March 10.
Mar. 13 though Apr. 2	Management agencies, tribes, and public develop their final recommendations for the regulatory options. North of Cape Falcon Forum meetings are usually scheduled for around March 22-23 (Portland area) and March 28-29 (Seattle area).
Mar. 21	Council staff distributes *Preseason Report II: Analysis of Proposed Regulatory Options for 2006 Ocean Salmon Fisheries* to the public. The report includes the public hearing schedule, comment instructions, option highlights, and tables summarizing the biological and economic impacts of the proposed management options.

Mar. 27 and 28	Sites and dates of public hearings to review the Council's proposed regulatory options are: Westport, Washington (March 27); Coos Bay, Oregon (March 27); and Fort Bragg, California (March 28). Comments on the options will also be taken during the Council meeting on April 4 in Sacramento, California.
Apr. 2-7	Council and advisory entities meet to adopt final regulatory measures at the Doubletree Hotel Sacramento, Sacramento, California. The *Preseason Report II: Analysis of Proposed Regulatory Options for 2006 Ocean Salmon Fisheries* and information developed at the Council meeting is considered during the course of the week. The Council will tentatively adopt final regulatory measures for analysis by the STT on April 4. Final adoption of recommendations to National Marine Fisheries Service (NMFS) are scheduled to be completed on April 6.
Apr. 8-13	The STT completes *Preseason Report III: Analysis of Council-Adopted Regulatory Measures for 2006 Ocean Salmon Fisheries*.
Apr. 14-21	Council and NMFS staff completes required National Environmental Policy Act documents for submission.
Apr. 21	Council staff distributes adopted ocean salmon fishing management recommendations, and *Preseason Report III* is made available to the public.
May 1	NMFS implements federal ocean salmon fishing regulations.

PFMC
10/13/05

TRIBAL COMMENTS
DRAFT

The 2006 schedule will once again present a major challenge for key technical staff who are heavily involved in the PSC process and the Council process.

We certainly do not want, in 2006, to repeat our previous experience with the delayed and erroneous pre-season forecast information received from Canada.

Regarding meeting schedules:

The Pacific Salmon Commission (PSC) will conduct their usual post-season meeting the week of January 9- 13 in Portland and the annual meeting will be the week of February 13 – 17 in Vancouver, BC, Canada.

The North of Falcon meetings have not been scheduled yet. They will likely be scheduled in January 2006 to fit within both the PSC and PFMC processes.

The Salmon Technical Team (STT) proposed meetings will occur between the two PSC meetings. It should be noted that the work load requirements on the Team will be significant, especially for the Team members who are involved with both the Council and PSC processes.

The KFMC meeting will be in late February in Brookings, OR. The tentative dates are Feb. 21 -23. The KFMC will also meet during the March and April Council meetings.

The proposed Council Public Hearing schedule will be March 27 in Westport and Coos Bay and March 28 in Ft. Bragg, CA.

Because of the time compression between the meetings, it seems to me that (1) it is not going to be an easy task for the STT to complete its work in a timely manner and (2) there will likely be another challenge for salmon managers and the Council to establish a range of options at the March Council meeting. The Council needs to be aware of this situation in 2006.

Given the increased scrutiny on harvest these past few months, fishery representatives should plan on giving an extra effort this year to attend and participate in these meetings. Beyond the normal challenges to balance fisheries against weak stock constraints, fishery managers will have the added pressure of threatened legal challenges to their harvest plans. Because of this complication, it will be important to have full participation by all groups in the process for the 2006 season setting cycle.

PRESEASON SALMON MANAGEMENT SCHEDULE FOR 2006

To plan, announce, and meet *Federal Register* deadlines for public hearing sites and the entire preseason salmon management process, staff needs to confirm details of the process prior to the end of November. The proposed 2006 process and schedule is contained in Agenda Item G.2.a, Attachment 1. It follows the same format as in previous years.

For 2006, Council staff recommends one salmon management option hearing per coastal state, the same schedule as in 2005. The hearings would be:

March 27, 2006 Westport, Washington and Coos Bay, Oregon
March 28, 2006 Fort Bragg, California

In 2006, the March Council meeting will occur in Seattle, Washington and the April Council meeting in Sacramento, California. Therefore, the public comment period on Tuesday of the April meeting in Sacramento also serves as a public comment opportunity. If the states desire to have additional hearings, we suggest they organize and staff them as was done in past years. The table below provides the public attendance at the hearing sites since 1995 for Council reference.

	Public Attendance										
Hearing Site Location[1/]	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Westport	49	30	22	4	18	24	30	11	16	16	25
Astoria	28	23	16	-	14	-	-	-	-	-	
Tillamook	-	-	-	28	-	13	16 [2/]	18 [2/]	-	-	
North Bend/Coos Bay	22	30	27	15	31	36	18	40	26	26	105
Eureka	30	45	27	16	18	37	12	25	46	-	
Ft. Bragg	-	-	-	-	-	-	-	-	-	27	38
Sacramento	16	-	-	13	-	-	-	-	-	-	
Santa Rosa	-	-	-	-	-	4	-	-	-	-	
Moss Landing[2/]	-	-	-	100	51	50	33	14	-	-	

1/ Sites in bold are proposed for Council staffing in 2006.
2/ Hearing staffed by state personnel.

Council Action:

1. **Confirm Council-staffed hearing sites and state intentions for additional hearings.**
2. **Approve staff's overall proposed schedule and process for developing 2006 ocean salmon management measures (Agenda Item G.2.a, Attachment 1).**

Reference Materials:

1. Agenda Item G.2.a, Attachment 1: Pacific Fishery Management Council Schedule and Process for Developing 2006 Ocean Salmon Fishery Management Measures.

Agenda Order:

a. Agenda Item Overview — Chuck Tracy
b. Agency and Tribal Reports and Comments
c. Reports and Comments of Advisory Bodies
d. Public Comment
e. **Council Action**: Approve 2006 Preseason Management Schedule and Hearing Sites

PFMC
10/13/05

Klamath River Fall Chinook Stock-Recruitment Analysis

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1 September 2005

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EXECUTIVE SUMMARY

Introduction

At the June, 2005 meeting, the Pacific Fishery Management Council (Council) directed the Salmon Technical Team (STT) to conduct several analyses of Klamath River Basin natural fall Chinook using the best datasets available. The analyses to be performed included:

1) estimate the parameters of a Ricker-type stock-recruitment model, including an estimate of the spawner abundance expected to generate maximum sustainable yield;

2) a correlation analysis of production (survival) and river flow conditions during the juvenile freshwater phase; and

3) a correlation analysis of production and river flow conditions during the parent spawning period.

This report completes the assignment given to the STT. The executive summary provides a very brief review of the methods used in the analyses, and a summary of the results of those analyses. Both the executive summary and the main report present only the results of technical work assigned by the Council to the STT. The results presented here should not be interpreted as a recommendation by the STT to modify the Council's management objectives for Klamath River fall Chinook.

Methods

Stock-Recruitment Model

Three models were used to develop spawner reference point estimates assuming a Ricker-type stock-recruitment relationship. Model 1 used only parent spawner abundance as a predictor of subsequent brood recruitment. Model 2 included both parent spawner abundance and a measure of post-freshwater-rearing survival as predictors of subsequent recruitment. This measure of post-freshwater-rearing survival covered the period from the onset of juvenile outmigration in May-June, through the end of August of that same year. Model 3, under development by the Canadian Department of Fisheries and Oceans, is based on a meta-analysis of Ricker stock-recruitment relationships for Chinook salmon populations from the Oregon coast through Southeast Alaska, and uses accessible watershed area (5^{th} order and higher streams) as a predictor of subsequent recruitment.

Correlation Analyses

While adequate time series of stream flow data in the Klamath Basin were available at a number of locations, wild production estimates were not available. Because of this lack

of direct measure of wild production, we used estimates of hatchery release survival as a surrogate for wild stock survival.

Correlation Analysis – Juvenile phase

Correlation analyses were performed between various river flow measures in the Trinity and Klamath Rivers and cohort-reconstructed release-to-age-2 survival rates of fingerlings released from the hatcheries on these rivers. Correlation analyses were performed on minimum, maximum, and monthly average daily flows during the parental spawning migration as well as the month of release to the release-to-age-2 survival rates.

Correlation Analysis – Adult phase

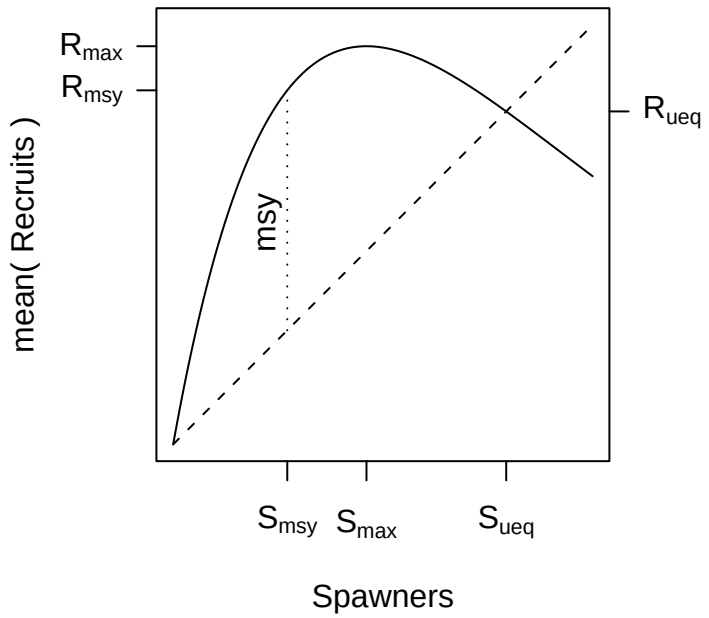
Because the survival of hatchery fish may not necessarily represent that of natural fish, we also performed a cursory examination of correlations between environmental measures and the Model 1 recruitment residuals. The environmental variables used were various measures of flow in the Klamath Basin.

Results

Stock-Recruitment Model

An example of a Ricker spawner-recruit curve and important points on that curve are shown in Figure ES-1.

Figure ES-1. Schematic of a Ricker stock-recruitment curve.



The peak of the curve represents the point of maximum production (R_{max}). The straight (dashed) line represents replacement, where recruitment equals the number of spawners. For any given parental stock size, the harvestable surplus is the difference between the recruitment curve and the replacement line. In the absence of fishing the relationship has an equilibrium spawning escapement at S_{ueq} where recruitment equals escapement. The point labeled S_{msy} represents the number of adult spawners that, on average, will generate maximum sustained yield (msy). Note that the harvestable surplus of the stock at S_{max} is less than the harvestable surplus at S_{msy} even though the number of recruits (R_{max}) is greater. The reference points resulting from the three models used to estimate the stock-recruitment parameters are provided in Table ES-1. Model 1 estimates S_{msy} at 32,700 (90% CI: 25,800 – 42,600). Model 2 estimates S_{msy} to be 40,700 (90% CI: 32,200 – 54,100). Model 3 estimates S_{msy} to be 70,900 (90% CI: 43,700 – 111,000).

Table ES-1. Spawner reference points for Ricker stock-recruitment Models 1,2,3.

Spawner Reference Point	Model 1 (parent spawners)	Model 2 (parent spawners, survival)	Model 3 (watershed area)
S_{ueq}	101,300	112,300	185,000
S_{max}	39,700	56,900	111,200
S_{msy}	32,700	40,700	70,900

Correlation Analyses

Correlation analyses were performed on minimum, maximum, and monthly average daily flows during the parental spawning migrations as well as the month of release, on the survival of hatchery fish to age 2. No significant relationships were found in any of these correlations. The strongest relationships were between survival of releases from Iron Gate Hatchery and flows during the months following release. However, the R^2 values were 0.25 or less, which suggests that only a small portion of the variability in age 2 survival rates can be explained by stream flow conditions.

No significant correlations were found between the Model 1 recruitment residuals and flow variables during the period of juvenile rearing and outmigration. However, significant positive correlations were found between several stream flow measures (e.g., monthly average discharge, minimum discharge, minimum 7-day average discharge, etc.) during the period when adults were migrating and spawning.

We examined the predictive potential of these relationships by incorporating some of these variables with the highest correlations into the spawner-recruit relationship as independent, explanatory variables. While incorporation of flow variables into the spawner-recruit explained more of the variability in recruitment, it decreased the significance of the fit, whether or not the hatchery survival was included.

Introduction

At the June, 2005 meeting, the Pacific Fishery Management Council (Council) directed the Salmon Technical Team (STT) to conduct several analyses of Klamath River Basin natural fall Chinook using the best datasets available. The analyses to be performed included:

1) estimate the parameters of a Ricker-type stock-recruitment model, including an estimate of the spawner abundance expected to generate maximum sustainable yield;

2) a correlation analysis of production (survival) and river flow conditions during the juvenile freshwater phase; and

3) a correlation analysis of production and river flow conditions during the parent spawning period.

This report completes the assignment given to the STT. The executive summary provides a very brief review of the methods used in the analyses, and a summary of the results of those analyses. Both the executive summary and the main report present only the results of technical work assigned by the Council to the STT. The result presented here should not be interpreted as a recommendation by the STT to modify the Council's management objectives for Klamath River fall Chinook.

Data Sources

The spawner and recruitment data used in this report are derived from cohort reconstructions provided by the Klamath River Technical Advisory Team. These data and methods have been recently revised (KRTAT 2002). Changes in data and methodology used in the cohort reconstructions were reviewed and accepted by the STT and SSC during their review of the new KOHM in 2001—2002. We used these data sets, updated through the most recent brood years available, for these analyses.

All streamflow data used in this report were obtained from published United States Geologic Survey (USGS) gauging station records (http://waterdata.usgs.gov/ca/nwis/nwis).

Methods

Three models were used to develop spawner reference point estimates assuming a Ricker-type stock-recruitment relationship. Model 1 used only parent spawner abundance as a predictor of subsequent brood recruitment. Model 2 included both parent spawner abundance and a measure of post-freshwater-rearing survival as predictors of subsequent recruitment. Model 3, under development by the Canadian Department of Fisheries and Oceans, is based on a meta-analysis of Ricker stock-recruitment relationships for a

number of west coast Chinook stocks, and uses accessible watershed area as a predictor of subsequent recruitment.

For the juvenile freshwater phase analysis, correlation analyses were performed on various river flow measures in the Trinity and Klamath Rivers to cohort-reconstructed age 2 survival rates of fingerlings released from their respective hatcheries.

For the adult spawning period analysis, correlation analyses were performed on minimum, maximum, and monthly average daily flows, and the Model 1 recruitment residuals.

Stock-Recruitment Models

Model 1: Ricker model.

A Ricker stock-recruitment model (Ricker 1954) was fit to all available spawner-recruit data for the natural stock of Klamath River fall Chinook salmon.

Assumptions
Several assumptions are made in proceeding with this analysis:

1. *Density dependent mortality.* For some time period prior to recruitment, the brood instantaneous mortality rate is proportional to the number of parent spawners (Ricker 1954).

2. *Stationarity.* The average stock-recruitment relationship is constant over time (Hilborn and Walters 1992), i.e., environmental conditions randomly affect survival, independent of stock size or time.

3. *Lognormal variation.* At any particular spawning stock size the variation in recruitment is lognormally distributed about its average, and acts multiplicatively. This is expected under the Central Limit Theorem of statistics if a combination of normally distributed, random factors affects the instantaneous mortality rate from egg to recruitment (Quinn and Deriso 1999)

4. *Measurement error.* Error in spawning stock size estimates (measurement error) is small relative to the range of spawning stock sizes observed (CTC 1999:section 1.4). Variation in realized recruitment at any particular spawning stock size (process error) dominates recruitment measurement error.

5. *Hatchery/Natural dynamics.* Estimates of spawning stock and recruitment are representative of a natural stock that can be considered independent of hatchery influences.

6. *Aggregate stock.* The contribution of fall Chinook sub-stocks in the Klamath basin is sufficiently stable that parameters for stock-recruit relationships can be adequately estimated by aggregating data.

7. *Reproductive potential.* The appropriate metric for spawning stock is abundance, independent of age, except for fish younger than age 3 which are not considered to be important to recruitment dynamics.

Methods

In general, the methods we used follow those outlined by the PSC Chinook Technical Committee (CTC 1999:section 1).

Data. Parent spawning stock, *S,* was defined as adult spawner abundance in Klamath Basin natural areas (outside hatcheries), and this data was obtained from the California Department of Fish and Game (CDFG 2005). Recruitment, *R*, was defined as the abundance of *S* progeny that survived to ocean age 3 in adult equivalent units (see Appendix A for details), and this data was derived based on the results of cohort reconstructions performed by the Klamath River Technical Advisory Team (as described in Goldwasser et al. (2001)).

Model/Estimation. A stochastic form of the Ricker stock-recruitment model (Quinn and Deriso 1999:equation 3.11, CTC 1999:section 1.6.1) was used to represent the data:

$$R = \alpha S e^{-\beta S + \varepsilon},\ \varepsilon \sim N(0, \sigma_\varepsilon^2), \tag{1.1}$$

with ε being a normally distributed error term. The model was fit to the data by first transforming it into a linear model

$$\log(R/S) = a + bS + \varepsilon, \tag{1.2}$$

and then using ordinary least-squares regression to estimate the parameters *a*, *b*, and σ_ε^2. The Ricker model parameters α and β were then estimated as

$$\hat{\alpha} = e^{\hat{a}},\quad \hat{\beta} = -\hat{b}, \tag{1.3}$$

where a hat, "^", denotes an "estimate". The expected (mean) value, *E*(), of recruitment at a given spawner abundance, *R*|*S*, was estimated as

$$\hat{E}(R \mid S) = (\hat{\alpha} e^{\hat{\sigma}_\varepsilon^2/2}) S e^{-\hat{\beta} S} = \hat{\alpha}' S e^{-\hat{\beta} S}, \tag{1.4}$$

where the term $e^{\hat{\sigma}_\varepsilon^2/2}$ largely corrects for the bias arising from the fact that the expected value of e^{ε} is $e^{\sigma_\varepsilon^2/2}$; not 1 (Hilborn 1985). Given the $\hat{E}(R \mid S)$ function, three spawner abundance reference points were estimated (Ricker 1975:346–347).

S_{msy} : the spawner abundance expected to generate maximum sustained yield

$$1 = (1 - \hat{\beta}\hat{S}_{msy})\hat{\alpha}' e^{-\hat{\beta}\hat{S}_{msy}}. \tag{1.5}$$

S_{max} : the spawner abundance expected to generate maximum recruitment

$$\hat{S}_{max} = 1/\hat{\beta}. \tag{1.6}$$

S_{ueq} : the spawner abundance expected at unfished equilibrium

$$\hat{S}_{ueq} = \log(\hat{\alpha}') / \hat{\beta}. \tag{1.7}$$

Various statistical diagnostics of the model's fit were assessed (see Appendix A for details).

Estimation bias and uncertainty measures for the model parameter and spawner abundance reference point estimates were derived using the bootstrap procedure described by the CTC (1999:18–19), except that regression residuals were re-sampled on the log(*R/S*) scale since it is on this scale that the errors are modeled as additive and of constant variance. The bootstrap number of trials was 100,000.

Results

Data. The {*R, S*} data are presented in Appendix A Table A1. The extent of the current available data is for brood years 1979–2000, which yields 22 (*R, S*) data points. The range of *S* is (11649, 161793), a span equal to about 13 times the minimum observed *S*, which should provide sufficient contrast for estimation of the Ricker model parameters (CTC 1999:5). The range of *R* is (16213, 368159), and recruit-per-spawner ratios, *R/S*, range from (0.22, 22.42), again indicating sufficient contrast should be present in these data to allow for estimation of the Ricker model parameters (CTC 1999:5). All of the above supports analysis assumption 1. Figure 1 is a plot of *R/S* versus *S*, with the dashed line referencing replacement (*R/S* = 1). The two-digit numbers, *xx*, in the plot denote brood years (19*xx* or 20*xx*). Note that the highest *R/S* values have generally occurred at the lower *S* values, and that the lowest *R/S* values have generally occurred at the higher *S* values, which is consistent with the Ricker model presumption of density dependent mortality.

Model/Estimation. Figure 2 is a plot of the transformed data log(*R/S*) versus *S*, with the solid line representing the fitted model on this scale. The corresponding least-squares regression statistics are provided in Appendix A Table A2. The density dependent parameter estimate $\hat{\beta}$ is statistically significant ($p < 0.001$), and the *R*-squared value is 0.5571, which means that the Ricker model accounts for about half of the density independent model residual variation in log(*R*) (see Appendix A for the basis of this interpretation). Figure 3 is a plot of the untransformed (*R, S*) data, with the solid curve representing $\hat{E}(R \mid S)$, and the dashed line referencing 1:1 replacement. Note that there is considerable unexplained variation in *R* about the $\hat{E}(R \mid S)$ curve. The Ricker model parameter and spawner reference point estimates are presented in Table 1, along with associated 90% confidence intervals. All of these results presume the Ricker model is appropriate for these data. A variety of regression diagnostics (Appendix A Figures A1–A4) performed to address this presumption did not indicate a lack of model fit, or violation of analysis assumptions 1–3.

Ricker model

Figure 1. Recruits−per−spawner.

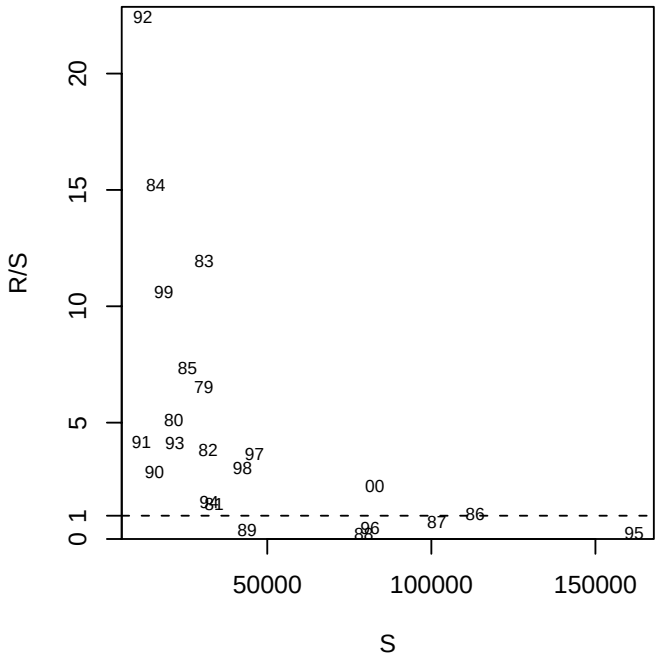


Figure 2. Transformed data and fitted model.

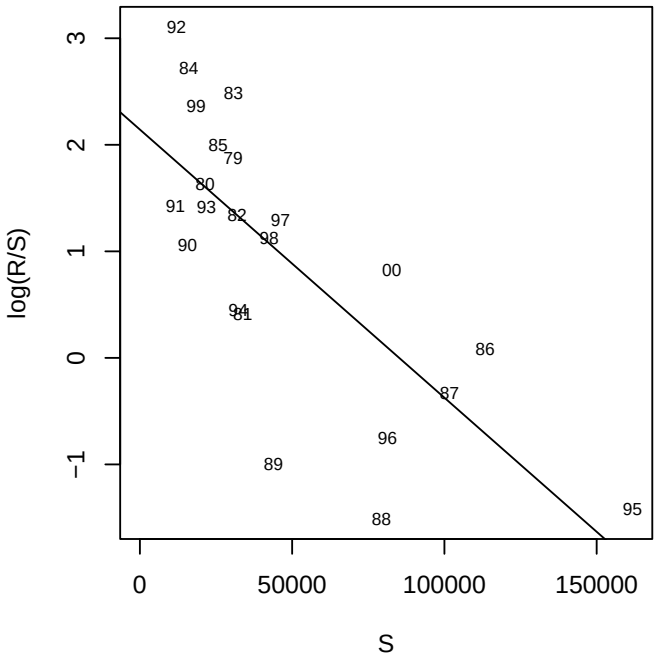


Figure 3. Expected value Ricker model.

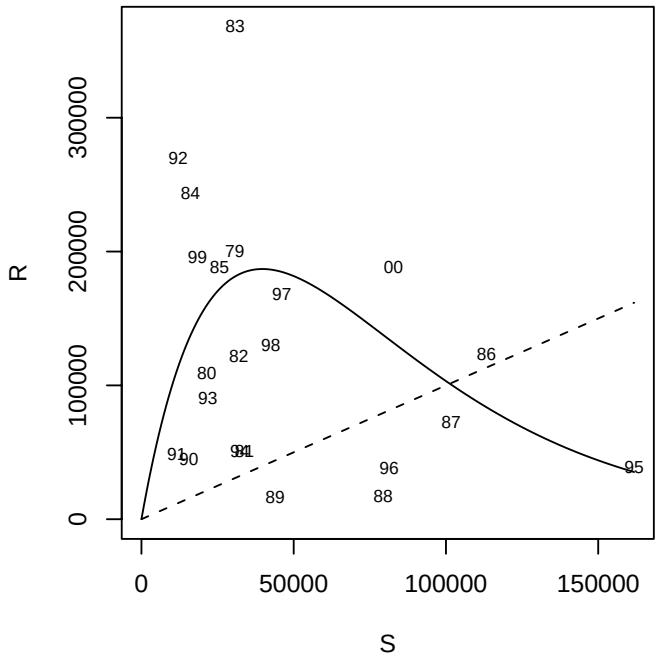


Table 1. Ricker model parameter and spawner reference point estimates.

Quantity	Point Estimate	90% Confidence Interval
α	8.5277	(5.2176–13.673)
β	0.000025171	(0.000017656–0.000033364)
σ_ε^2	0.81089	(0.39482–1.1170)
α'	12.791	(7.7302–19.201)
S_{msy}	32,700	(25,800–42,600)
S_{max}	39,700	(30,000–56,600)
S_{ueq}	101,300	(83,400–124,200)

Model 2: Ricker model w/ survival.

An index of early-life survival was incorporated into the Ricker stock-recruitment model of the previous section, and the model was fit to all available spawner-recruit data for the natural stock of Klamath River fall Chinook salmon.

Assumptions

The previous analysis assumptions (1–7) apply, in addition to the following one:

8. *Survival rate index.* The instantaneous mortality rate for Klamath Basin hatchery fingerlings from release to age 2 (four month period following release) is proportional to that of naturally produced outmigrants over this same period.

Methods

The assessment methods used for Model 2 build on those used for Model 1, and again generally follow the methods outlined by the PSC Chinook Technical Committee (CTC 1999:section 1).

Data. Early-life survival was estimated for hatchery fingerling cwt groups over the four-month period immediately following release (May—Aug) based on the results of cohort reconstructions performed by the Klamath River Technical Advisory Team (as described in Goldwasser et al. (2001)). For each brood year a weighted average, s', of the survival rate estimates for Iron Gate Hatchery (IGH) and Trinity River Hatchery (TRH) fish was derived (see Appendix B for details).

Model/Estimation. Model 1 was extended to include early-life survival as a covariate as follows (CTC 1999:p.9–10):

$$R = \alpha S e^{-\beta S + \theta(s-\bar{s})+\varepsilon},\ \varepsilon \sim N(0,\sigma_\varepsilon^2), \tag{2.1}$$

where $s = \log(s')$ and $\bar{s} = \text{mean}(s)$ over the 22 brood year data set. Notice that the productivity coefficient is now brood-year-specific, $\alpha e^{\theta(s-\bar{s})}$, and depends on the value of s. With the above parameterization, α now represents the productivity under average

conditions $(s = \bar{s})$. The model was fit to the data by first transforming it into a linear model

$$\log(R/S) = a + bS + c(s - \bar{s}) + \varepsilon, \tag{2.2}$$

and then using ordinary least-squares regression to estimate the parameters *a*, *b, c*, and σ_ε^2. The Model 2 parameters α, β, and θ were then estimated as

$$\hat{\alpha} = e^{\hat{a}}, \quad \hat{\beta} = -\hat{b}, \quad \hat{\theta} = \hat{c}. \tag{2.3}$$

The expected value of recruitment at a given spawner abundance was estimated as

$$\hat{E}(R \mid S) = (\hat{\alpha} e^{\hat{\sigma}_\varepsilon^2/2}) S e^{-\hat{\beta}S + \hat{\theta}(s-\bar{s})} = \hat{\alpha}' S e^{-\hat{\beta}S + \theta(s-\bar{s})}; \tag{2.4}$$

also dependent on *s*. Given the $\hat{E}(R \mid S)$ function, the three spawner abundance reference points, S_{msy}, S_{max}, and S_{ueq}, were estimated as:

$$1 = (1 - \hat{\beta}\hat{S}_{msy}) \hat{\alpha}' e^{-\hat{\beta}\hat{S}_{msy} + \hat{\theta}(s-\bar{s})}, \tag{2.5}$$

$$\hat{S}_{max} = 1/\hat{\beta}, \tag{2.6}$$

$$\hat{S}_{ueq} = \left[\log(\hat{\alpha}') + \hat{\theta}(s - \bar{s}) \right] \Big/ \hat{\beta}. \tag{2.7}$$

$\hat{S}_{msy}$ and $\hat{S}_{ueq}$ were computed <u>assuming average early-life survival</u> ($s = \bar{s}$).

To examine the benefit of including *s* in the recruitment model, the observed relationship between the two predictor variables *s* and *S* was explored, as was the relationship between the Model 1 residual variation in log(*R/S*) and that portion of *s* unaccounted for by *S*. The latter provides a direct gauge of the utility of including *s* in the recruitment model, and is complementary to comparison of the Model 2 versus Model 1 regression statistics.

The diagnostics previously described for Model 1 were also used as a check on the aptness of Model 2 (see Appendix B for further details).

Estimation bias and uncertainty measures for the model parameter and spawner abundance reference point estimates were derived using the bootstrap procedure previously described for Model 1.

<u>Results</u>

Data. The $\{s'\}$ data are presented in Appendix B Table B1. The range of s' over the 22 brood year dataset is (0.00043, 0.0625), and the range of *s* is (-7.76, -2.77). Figure 4 is a plot of the s_{IGH} and s_{TRH} time series, and the derived *s*. Typically, $s_{IGH} < s_{TRH}$. The s_{IGH} and s_{TRH} time series display a remarkable coherence (Figure 4) given the two series were independently derived.

Model/Estimation. The covariation between *s* and *S* is displayed in Figure 5. The solid line is the least-squares regression fit, which though marginally significant ($p = 0.0535$), has a low R-squared value of 0.1739 (Appendix B Table B2). The brood years corresponding to the six highest recruit-per-spawner values in the dataset are boxed in

Figure 5; the six lowest are circled. Model 1 assumes that high *R/S* values are entirely a result of low stock size (and random process error). Figure 5 strongly suggests that these high *R/S* values are partially accounted for by a relatively high early-life survival for those brood years. Similarly, Figure 5 suggests that the low *R/S* values associated with high stock-sizes are partially accounted for by a relatively low early-life survival for those brood years.

One measure of the value of incorporating *s* in the Ricker model is to answer the question: What portion of the Model 1 residual variation can be explained by that portion of *s* unaccounted for by *S*? Figure 6 is a plot of the residuals of the Figure 2 model against the residuals of the Figure 5 model. High log(*R/S*) residuals are associated with high *s* residuals, and low log(*R/S*) residuals are associated with low *s* residuals. The solid line is the least-squares regression which is highly significant ($p < 0.0001$), and *s* accounts for 54.5% of the Model 1 residual variation (Appendix B Table B2). Thus, *s* is a significant predictor of recruitment success, above and beyond *S*, and should be incorporated into the stock-recruitment analysis in the form of Model 2.

The least-squares regression statistics for Model 2 are provided in Appendix B Table B2. On the whole, Model 2 is highly significant ($p < 0.0001$) relative to the density independent model, and the R-squared value substantially improves to 0.7986, which means that Model 2 accounts for about 80% of the density independent model residual variation in log(*R*) (see Appendix A for the basis of this interpretation). The coefficient of *s* in Model 2 is significant ($p = 0.00013$) and, in agreement with the Figure 6 analysis results, its inclusion accounts for 54.5% of the Model 1 residual variation (Appendix B Table B2). Figure 7 is a plot of the untransformed (*R, S*) data, with the solid curve representing the estimated Model 2 expected value assuming average early life survival, $\hat{E}(R \mid S, s = \overline{s})$, with the dashed line referencing 1:1 replacement. Recall that for Model 2, the Ricker curve is year-specific in that it depends on the value of *s*. Assuming $s = \overline{s}$, the Model 2 curve is less steep and descends less quickly than the Model 1 curve (compare Figures 3 and 7), which derives from the uneven distribution of *s* values across the range of *S*. The Model 2 parameter and spawner reference point estimates are presented in Table 2, along with their respective 90% confidence intervals. The $\hat{S}_{msy}$ and $\hat{S}_{ueq}$ values are conditional on $s = \overline{s}$. All of these results presume Model 2 is appropriate for these data. A variety of regression diagnostics (Appendix B Figures B2–B5) performed to address this presumption did not indicate a lack of model fit, or violation of analysis assumptions 1–3.

Ricker model w/ survival

Figure 4. log(survival) time series.

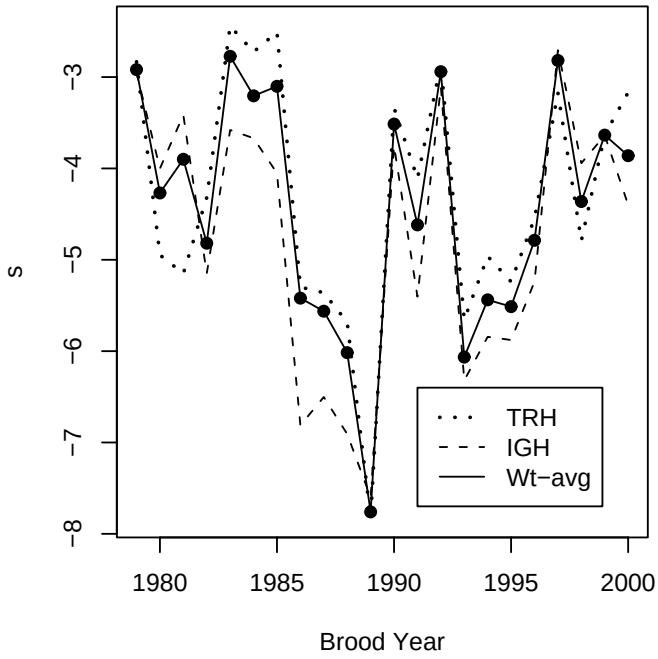


Figure 5. Covariation: log(survival) and S.

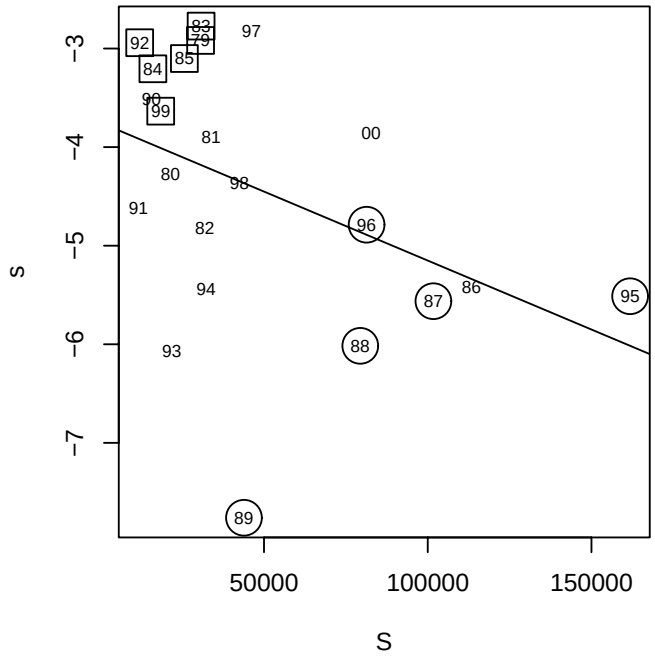


Figure 6. Covariation: log(R/S) and s, unaccounted for by S.

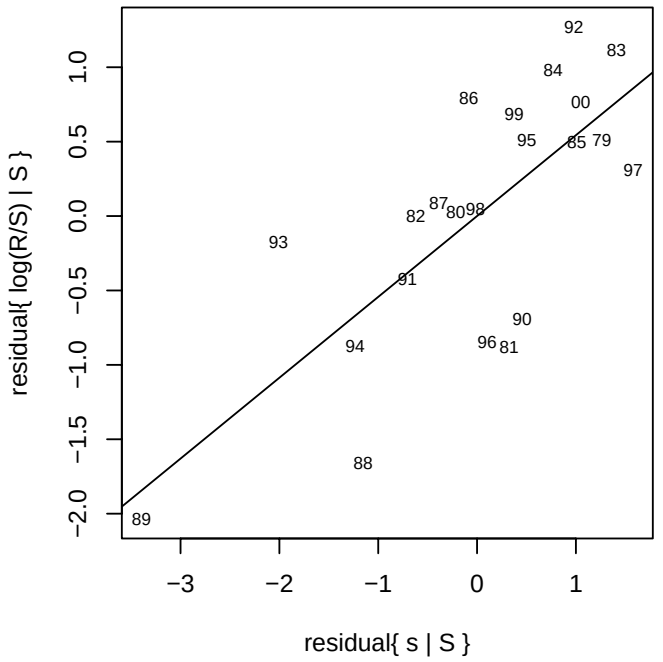


Figure 7. Expected value Ricker model w/ $s=\bar{s}$.

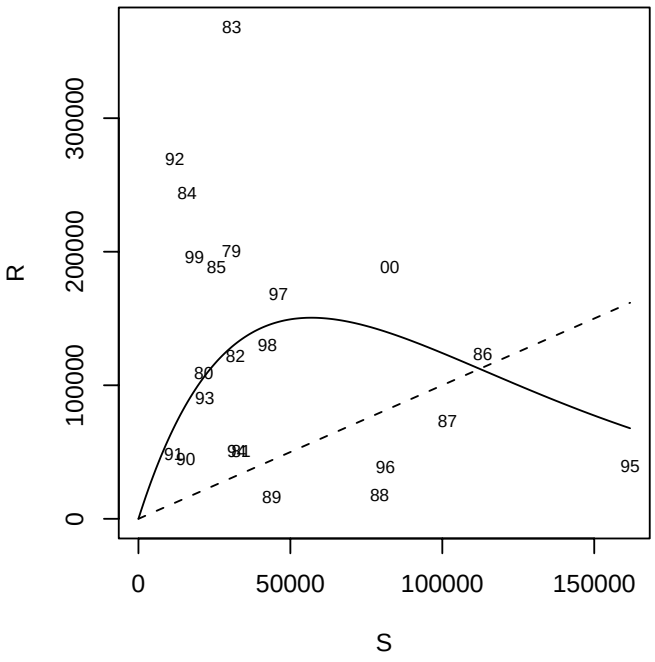


Table 2. Model 2 parameter and spawner reference point estimates. The $\hat{S}_{msy}$ and $\hat{S}_{ueq}$ values are conditional on $s = \overline{s}$.

Quantity	Point Estimate	90% Confidence Interval
α	5.9218	(4.1698–8.3184)
β	0.000017567	(0.000011879–0.000023564)
θ	0.54327	(0.37317–0.72115)
σ_{ε}^2	0.38821	(0.19045–0.48619)
α'	7.1904	(4.9564–9.7130)
S_{msy}	40,700	(32,200–54,100)
S_{max}	56,900	(42,400–84,200)
S_{ueq}	112,300	(91,500–142,400)

Discussion: Model 1, Model 2.

Assumptions

We first briefly discuss analysis assumptions 1–8 in light of the observed data and analysis results.

1. *Density dependent mortality.* The highest *S/R* ratios have occurred at lower levels of spawner abundance, and vice-versa, which is consistent with, though not necessarily proof of, density dependent mortality. As a result, the {*S, R*} data are clearly more consistent with the density dependent recruitment models (Models 1 and 2) than a density independent recruitment model.

2. *Stationarity.* Background processes whose effects on mortality have not occurred randomly with respect to stock size during the period when the {*S, R*} data was collected may seriously bias the estimated spawner-recruit relationship in terms of future predictions. Our analysis strongly suggests that the magnitude of density independent early-life survival over the four-month period following the onset of juvenile outmigration may not have been randomly distributed across the range of observed stock sizes (relatively higher *s* values were associated with lower *S* values, and vice-versa), and this is the rationale for including *s* as a covariate in the Ricker model. Other, currently unrecognized, factors may have influenced the observed {*S, R*} relationship as well.

3. *Lognormal variation.* The Model 1 and 2 residual variation in log(*R*) is largely consistent with this distributional assumption.

4. *Measurement error.* There are currently 22 (*S, R*) data points, and the contrast within these data appear to be sufficient for identifying/estimating the parameters of a Ricker stock-recruitment relationship in the presence of measurement error. The actual contributions of process and measurement errors to the overall variation in *R* at any particular value of *S* are not presently known. Process error

was assumed to dominate recruitment measurement error. This assumption is precautionary, i.e., estimates of spawner reference points would be lower as the relative contribution of measurement error increases.

5. *Hatchery/Natural dynamics.* The adequacy of this assumption (independence) is contingent on the stray rate of hatchery fish into natural areas, particularly in the proximity of the Klamath Basin's two production hatcheries. If the stray rate were to increase in the future, and the offspring of these spawners are not as fit as their natural-origin counterparts, the currently estimated spawner-recruit curve would be overly-optimistic of the productivity of the "natural" stock.

6. *Aggregate stock.* Differing maturation schedules and river conditions for the Klamath and Trinity River stocks argue for conducting separate spawner-recruit analyses for the two systems. However, the available data are insufficient to reliably conduct such an analysis. Even so, if one of these two sub-basin stocks has a lower productivity than the other (or if this is true of any other stock sub-units), then managing according to the composite $\hat{S}_{msy}$ may seriously deplete, and even extirpate, these less productive stock sub-units over time (Walters and Cahoon 1985).

7. *Reproductive potential.* Failing to account for age 2 fish on the spawning grounds is unlikely to have significantly affected the analysis conclusions. Data are insufficient to determine if the recruit-per-spawner ratio is a function of the age-sex composition of the adult (age 3 and older) spawning stock.

8. *Survival rate index.* The proportionality assumption cannot be directly confirmed, but if this rate primarily reflects early-life marine environmental conditions, then it is entirely plausible (discussed further below). The explanatory power of *s* as a predictor of natural-stock recruitment variability was clearly significant, and consistent with this assumption.

Model 1 versus Model 2.

The Model 1 (Ricker without survival) estimated recruitment curve is rather steep near the origin ($\hat{\alpha}_1 = 8.5$) which, in and of itself, is indicative of a rather productive stock, especially considering that the age of recruitment in our analysis was defined as ocean age 3 (September 1). However, the Model 1 estimated spawning stock size resulting in maximum recruitment, $\hat{S}_{max,1} = 39{,}700$, seems rather low for a basin of this size, and is no where near the value predicted under the habitat-based meta-analysis recruitment model for West Coast Chinook presented in this report. The Model 1 estimate $\hat{S}_{msy,1} = 32{,}700$ is 2,300 fish less than the current minimum spawner floor value of 35,000. This is consistent with the findings of the KRTAT (1999) which suggested, based on a Model 1 spawner-recruit curve fit to the 1979–1993 brood year data, that S_{msy} was between

30,000 and 35,000 fish, depending primarily on the level of imprecision in preseason ocean abundance forecasts.

In contrast, the Model 2 (Ricker with survival) estimated recruitment curve corresponding to the average value of *s* is less steep and descends less quickly than the Model 1 curve. This derives from the apparent non-random distribution of *s* with respect to *S* for the years examined in this analysis. Generally, *s* was relatively high for those brood years produced at low stock abundances, and thus under the average *s* observed for the entire dataset, the expected productivity will be reduced when compared to that of Model 1. The Model 2 productivity estimate ($\hat{\alpha}_2 = 5.9$) is 30% less, and $\hat{S}_{max,2} = 56{,}900$ is 40% greater, than the Model 1 estimates as a result. The unexploited equilibrium spawner stock size under the two models is similar. The Model 2 estimate under average survival conditions is $\hat{S}_{ueq,2} = 112{,}300$, which is 11,000 fish higher than $\hat{S}_{ueq,1}$. For Model 2, again assuming average survival conditions, $\hat{S}_{msy,2} = 40{,}700$, which is 5,700 fish more than the current minimum spawner floor value of 35,000. Other $\hat{S}_{msy,2}$ values would result under alternative assumptions about the magnitude of *s*. For example, a more risk-averse value of *s* might be considered during periods of poor early-life survival conditions.

The statistical support for both density dependent models was strong relative to a density independent recruitment model. Recruits-per-spawner declined with increasing spawning stock size consistent with the Model 1 and 2 assumption of density dependent mortality. The estimated density dependent parameters for Model 1 and 2, $\hat{\beta}_1$ and $\hat{\beta}_2$, respectively, were statistically significant, as was the Model 2 survival coefficient, $\hat{\theta}$. Fifty-six percent of the density independent model residual variation in log(*R*) was accounted for by Model 1; 80% was accounted for by Model 2. The incorporation of the covariate *s* into the Ricker model accounted for 55% of the Model 1 residual variation in log(*R*), with $\hat{\theta}$ being statistically significant at the $p = 0.00013$ level. This one additional parameter in the model provided an as good or better fit than Model 1 to 20 of the 22 (*R, S*) data points (exceptions were brood years 1979 and 1997). The significance of *s* implies that the stationarity assumption may have been violated for Model 1 (time-dependent α a function of *s*). The statistical support for including *s* as a covariate in the Ricker model is compelling.

Early-life survival

As discussed by the CTC (1999:10), the fitted stock-recruitment relationship can be strengthened by including marine survival as a covariate. This also holds true for measures of survival during density independent freshwater life-stages. The relationship will be strengthened when the variation in the survival measure unaccounted for by *S* correlates well with the log(*R/S*) Ricker model residuals, as was demonstrated for the survival index *s* proposed here (r = 0.74).

The hatchery fingerling release-to-age-2 survival rate was selected as a surrogate index for the survival rate of progeny from natural spawning escapement. No comparable time series of survival estimates is available for the natural stock. The use of the *s* time series in our analysis does not require that the hatchery and natural stocks have equivalent survival rates, but only depends on the assumption that the survival of both stocks varies proportionately and synchronously.

The independently derived $\{s_{IGH}\}$ and $\{s_{TRH}\}$ time series were strongly coherent, and clearly suggestive of an annual effect. There are three plausible sources for this effect: (a) hatchery effect; (b) downstream migration effect; or (c) early-life marine effect. A hatchery effect seems unlikely for an annual signal in that the hatcheries are independently operated, but would have to have the same relative annual effect on *s* each and every year. A downstream migration effect also seems questionable for an annual signal in that the majority of the downstream migration route for the two hatchery stocks is in different river systems (although annual climatic events may shape the environment in both systems similarly). An early-life marine signal seems the most plausible. This is the environment shared by both hatchery stocks, and when coupled with the fact that IGH and TRH hatchery fingerlings take only about three weeks to outmigrate, this suggests that *s* may primarily reflect early-life marine survival (first three months), and explain why *s* correlated so well with recruitment success for the natural stock.

Model 3: Habitat-based methods for estimating stock-recruit reference points

The potential of the Klamath watershed to produce Chinook can be evaluated through an assessment of suitable habitat. In 1985, the California Department of Fish & Game estimated a range for the optimum spawning escapement for the Klamath basin of between 40,100 to 105,900, based on expert opinion of field biologists (Hubbel and Boydstun 1985). More recently, in June 2005, the Pacific Salmon Commission's Chinook Technical Committee accepted a habitat-based method for estimating maximum sustained yield (MSY) escapement levels. The method, under development by the Canadian Department of Fisheries and Oceans (CDFO), is based on a meta analysis involving stock-recruit models for several stocks along the coast (Chuck Parken, CDFO, personal communication August, 2005). In its present form, the CDFO model estimates the spawning escapements associated with MSY, maximum production, and unfished equilibrium (S_{msy}, S_{max}, and S_{ueq}, respectively) using a single variable, accessible watershed area (square kilometers for 5th order and higher streams for stocks with ocean-type life histories). The current watershed area for 5th order and higher streams in the Klamath Basin below impassable barriers is estimated as 16,561 square kilometers.

Methods:

CDFO's approach is derived from a meta analysis of Chinook salmon populations from the Oregon coast through Southeast Alaska using Ricker stock-recruitment relationships, assuming multiplicative, lognormal error:

$$R = \alpha * S * e^{-\beta * S} \exp(\varepsilon)$$

where R = recruitment
S = spawners
α = slope at origin
β = the capacity parameter
ε = lognormal process error with mean 0 and variance σ^2

For each Ricker stock-recruitment relationship the biological reference points of S_{msy}, S_{max}, and S_{ueq} were calculated and the relationship between the reference points and habitat was estimated assuming an allometric relationship with a single habitat parameter, accessible watershed area (WA):

$$y = a * WA^{b} * \exp(\varepsilon) \tag{3.1}$$

The relationship was estimated by linear regression using the log-transform of the model:

$$\log(y) = \log(a) + b\log(WA) + \varepsilon \tag{3.2}$$

Parameters were estimated separately for ocean and stream-type Chinook. Twelve stocks[1] were employed to estimate parameters for ocean-type Chinook in the CDFO Habitat Model.

Reference points $(y = S_{msy}, S_{max}, S_{ueq})$ are calculated using the following equation:

$$\hat{y} = WA^{\hat{b}} * e^{\log(\hat{a}) + (\frac{\hat{\sigma}^2}{2})} \tag{3.3}$$

Table 3. Parameter values for the CDFO Habitat Model reference points for ocean-type Chinook are presented in the following table:

Parameter	$y = S_{msy}$	$y = S_{max}$	$y = S_{ueq}$
log(a)	2.240	2.170	3.560
B	0.911	0.962	0.875
σ^2	0.158	0.206	0.138

[1] The ocean-type stocks included in the meta analysis included the Chehalis (WA), Cowichan (BC), Harrison (BC), Humptulips (WA), Lewis River (CR), Nehalem (OR), Queets (WA), Quillayute (WA), Siletz (OR), Situk (AK), Siuslaw (OR), Skagit (WA).

Results:

Substituting the estimated watershed area for the Klamath (16561 square kilometers) and the parameters from Table 3 into equation (3.3), yields estimates for the reference points of: $S_{msy} = 70,900$, $S_{max} = 111,200$, and $S_{ueq} = 185,000$.

Table 4. Point estimates and confidence intervals for S_{msy} and S_{ueq} based on the Habitat Model provided by CDFO staff[2]:

	S_{msy}	S_{ueq}
Point estimate	70,900	185,000
Coefficient of Variation	0.29	0.27
Percentiles	5th = 43,700 10th = 48,100 25th = 57,600 50th = 69,900 75th = 85,100 90th = 101,000 95th = 111,000	5th = 118,000 10th = 130,000 25th = 153,000 50th = 184,000 75th = 219,000 90th = 259,000 95th = 283,000

Discussion:

The Klamath River system encompasses a watershed area of nearly 13,000 square miles (~ 33,500 square kilometers) and continues to be a major producer of Chinook salmon (USFWS 1979). Since 1981, the combined natural and hatchery production of fall chinook has ranged from a low of 67,700 in 1992 to 1,448,900 in 1986 (September abundance of age 3 and 4 fish) while natural spawning escapements of adults has ranged from 11,600 in 1996 to 161,800 in 1995 (KRTAT 2005, STT 2005). Production has been highly variable; data employed in the STT's stock-recruitment analysis indicate that production of natural-origin Klamath fall Chinook has ranged from a low of 16,200 for the 1989 brood to a high of 368,200 for the 1983 brood.

Hubbel and Boydstun (1985) reported that CDFG established a spawning escapement goal of Klamath fall chinook of 115,000 adults (97,500 natural spawners plus 17,500 hatchery spawners) in 1978. The goal, which represented the average number of spawners observed during the 1960s, was subsequently adopted by the PFMC to guide the development of its fishery management plans. Until the mid 1980s, escapements averaged less than 35% of the goal and some groups began to express concerns that the goal was not appropriate for current conditions within the watershed. This controversy led to the creation of the Klamath Fishery Management Council in 1986 and the availability of resources to increase the information basis for management of this stock. In response to concerns for adverse impacts to the fishing industry that would result from

[2] Estimates provided by CDFO staff, Chuck Parken, pers.com. Confidence intervals were generated using bootstrap methods involving resampling of regression residuals.

strict adherence to the 97,000 escapement goal, the PFMC reduced the goal to 86,000 and adopted a plan to rebuild escapements to attain the 115,000 goal over a period of years (Amendment 9 to the Council's Salmon Fishery Management Plan). In 1986 and 1987, natural escapements exceeded 100,000 adults, but then remained well below the original goal of 97,000 except in 1995 (Figure 8).

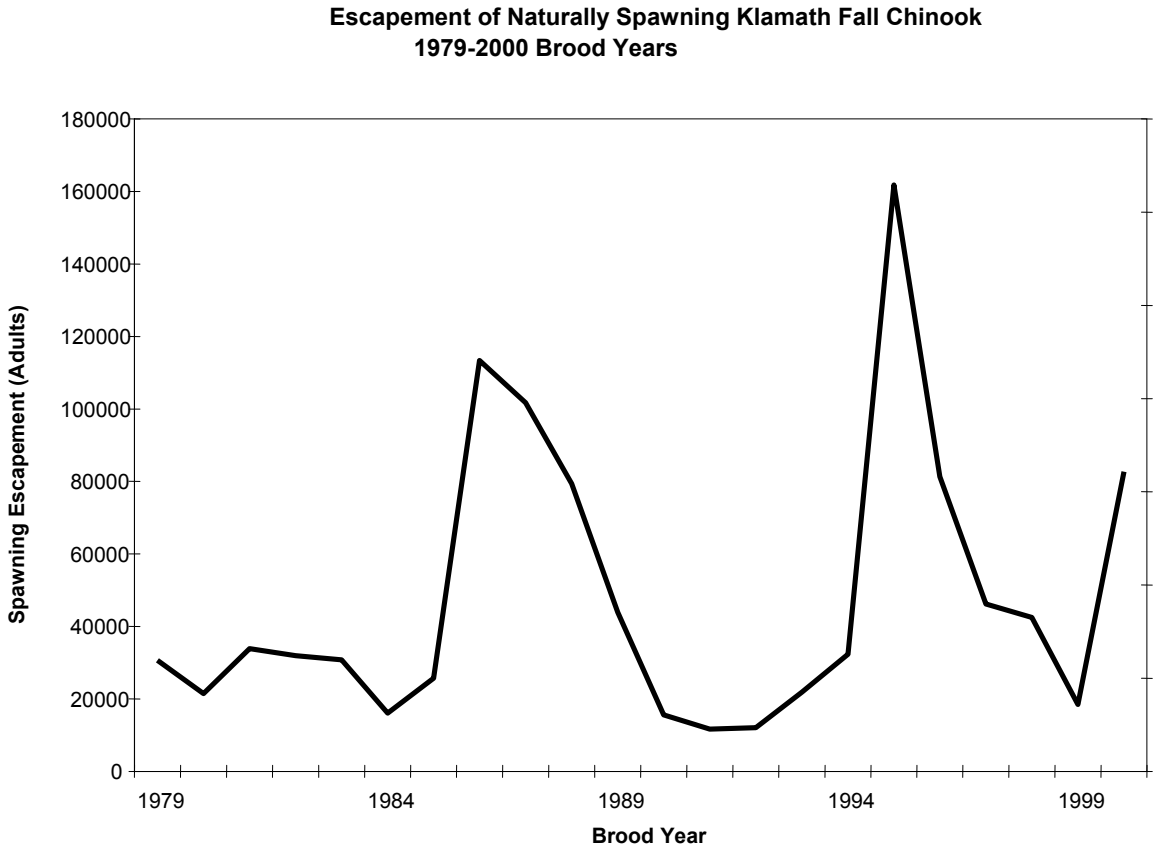


Figure 8. Natural spawning escapements for Klamath fall chinook for the 1979 to 2000 brood years

Production from these three years, when the escapement exceeded the original goal of 97,000 spawners, was poor; only the 1986 brood had production that exceeded spawning escapement. It is unclear, however, if the cause of this poor production is due to depensatory effects of spawning escapement or the coincidence of adverse environmental conditions resulting in poor survival of progeny. A survival index, based on estimated survivals of fall chinook fingerling releases from Iron Gate and Trinity hatcheries indicates that very low survival of brood year progeny coincided with high spawning escapement levels (Figure 9). Both escapement and the survival index were highly variable during the time period for which data are available to perform stock-recruitment analyses. Production from any given level of spawning escapement can vary

substantially from average expectations. Considerable uncertainty remains over whether the results from stock-recruitment analysis can reliably predict future production from spawning escapement levels over the long term.

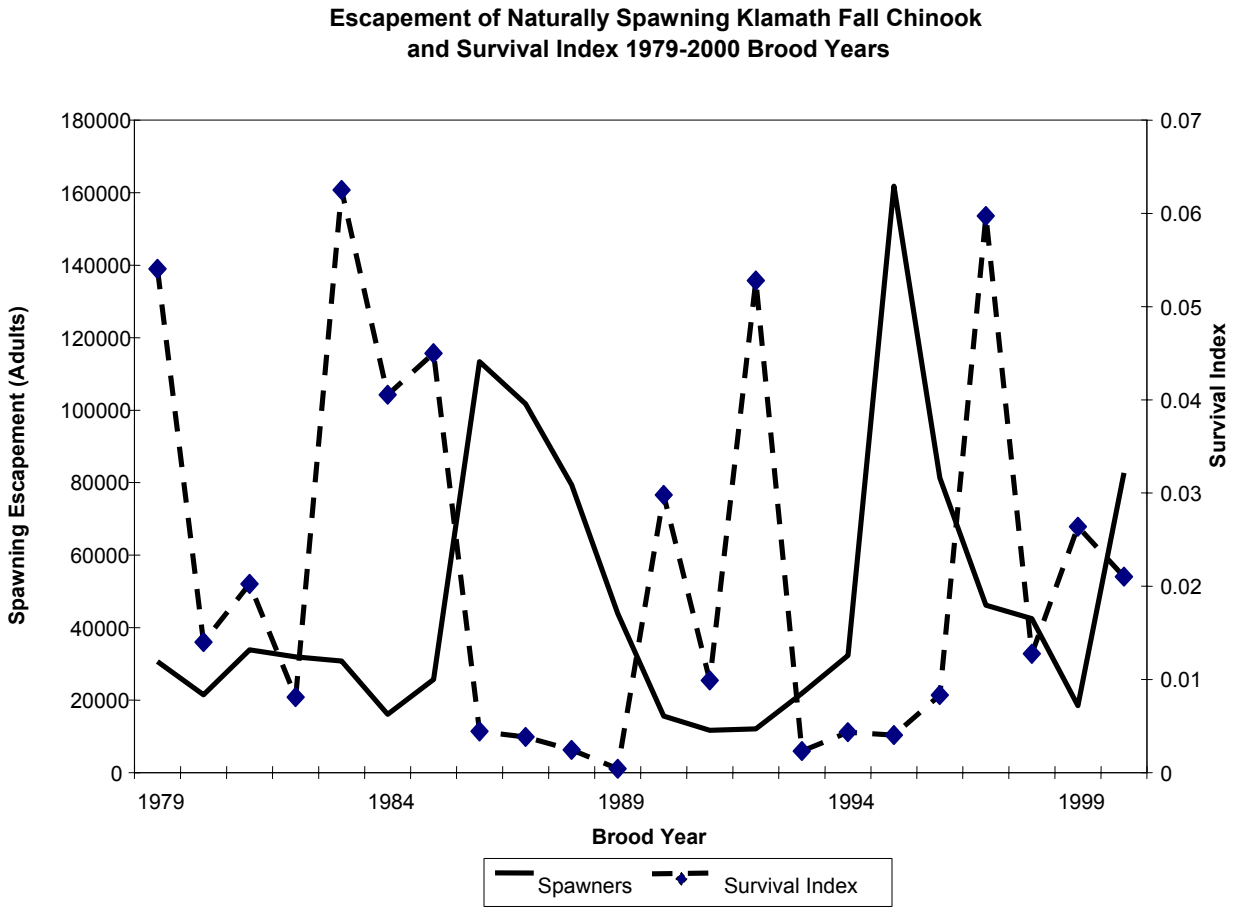


Figure 9. Natural spawning escapements for Klamath fall chinook and survival index for the 1979 to 2000 brood years

Available information about the productivity and capacity of Klamath fall Chinook is conflicting. The stock-recruitment analyses suggest that data for the 1979-2000 broods indicate that S_{msy} is likely to lie within the range of 25,800 to 54,100. On the other hand, historical information indicates that the Klamath basis was capable of supporting large runs of Chinook salmon and that spawning escapements averaged 97,000 during the 1960s. The CDFO habitat model indicates that an S_{msy} of 70,900 adults would be expected, and that estimates of S_{msy} and S_{ueq} derived from stock-recruitment analysis using the data for the 1979-2000 broods lie well outside computed confidence intervals.

It is nearly certain that other factors influence the production of fall Chinook from the Klamath River Basin. Water quality studies indicate that dissolved oxygen and water temperatures in the Klamath River reach conditions that are stressful and even lethal to salmon. A massive fish kill observed in 2002 spurred numerous investigations into the cause. Concerns have been raised as to the effects of water management and diversion on ecosystem functions in the Klamath basis. There are indications that water flow conditions may affect survival of fingerling fall Chinook releases from Iron Gate Hatchery. There are also indications that environmental conditions have changed in the Klamath basin since the 1960 and that they will continue to change in the future.

Bartholow (2005) found evidence that water temperatures in the Klamath River has been increasing at about 0.6 C per decade since the 1960s, that the season of high temperatures stressful to salmon has lengthened over a month during the same period, and that the average length of the Klamath mainstem with cool summer temperatures has declined by about 8.2 km/decade. Bartholow concluded that if the trends continue, recovery of salmonids in the Klamath will become increasingly problematic.

Correlation Analyses – Juvenile Survival and Freshwater Flows

A review of potential sources of data and prior analyses of flow and temperature conditions on the Klamath and Trinity rivers was conducted. Long time series of flow data are readily available at a number of locations within the Klamath and Trinity basins on the USGS web site (http://waterdata.usgs.gov/ca/nwis/nwis). However there were no comparable time series of temperature data available. Flow data was used from the gauging station at Hoopa on the Trinity River and at Orleans on the Klamath River. These were the lowest gauging stations where the two rivers were separate. Flow data were also available on the mainstem Klamath River near Klamath, but the time series of discharge data from this station has missing data. In addition attempts were made to locate a time series of juvenile production estimates from natural areas in the Klamath and Trinity River basins. Juvenile sampling in the basin has been conducted sporadically and only in recent years has this sampling been done in such a way that production estimates could be made. However these recent production estimates were not yet available from the investigators for our analysis. Because of this lack of direct measure of wild production we decided to explore the use of hatchery survival as our only available surrogate for the wild stock survival.

Correlation analyses were performed on various river flow measures in the Trinity River and Klamath Rivers to cohort reconstructed age 2 survival rates of fingerlings released from their respective hatcheries. Correlation analyses were performed on minimum, maximum, and the monthly average daily flows during the parental spawning migrations as well as the month of release to age 2 survivals. The strongest relationship was the Klamath River minimum flows during and immediately after the month of release. However the R^2 value was just over 0.20 which suggests that only a small portion of the variability in age 2 survival rates could be explained by river flow conditions. It is likely that hatchery operations have more effect on survival than does flow alone. A more

through analysis of fish health and handling conditions at time of release for individual batches of fish may better isolate the effect of flow on survival. Hatchery reports contain more information about fish disease and success of release than does the RMIS data. In some cases the RMIS data contain errors such as the date of release and fail to detail conditions that would affect juvenile survival. Considerable detective work would be necessary to verify the accuracy of the release data. Even if this was done there would still be the problem of determining if survival of the hatchery stock represents survival of the wild stock.

Correlation Analysis – Ricker Model Residuals and River Flow

Because the survival of hatchery fish may not reflect survival of natural fish, another approach taken by the STT was to examine correlations between environmental variables and the residuals of recruitment from that predicted by the Ricker spawner-recruit relationship without incorporation of the hatchery survival index (Table 5).

Table 5. Correlations between residuals from predicted recruitment and monthly average daily discharge during adult spawning migration and juvenile rearing and outmigration.

Month	Brood year	Year of outmigration
March		-0.007
April		0.019
May		0.054
June		0.087
August	0.298	
September	0.408*	
October	0.400*	
November	0.375*	
December	0.066	
Sept-Oct	0.439*	

* $p<0.05$ (one-tailed test)

No significant correlations with discharge were observed during the period of juvenile rearing and outmigration, but significant correlations were observed during the period of adult migration and spawning. These correlations, though significant, are weak, and are similar in magnitude to those between discharge and the hatchery survival index. Because the strongest correlations were observed with average daily discharge in September and October, we also computed the correlation between recruitment residuals and daily flow averaged over both months, and found that it had a higher correlation than daily discharge averaged over each month individually (Table 5).

In an attempt to see if there was some other aspect of flow that may have better predictive ability, we also examined correlations between the recruitment residuals and the maximum and minimum daily and weekly discharge for the basin as a whole and for each river (Klamath and Trinity) individually monthly mean flow for each River separately. These variables are highly correlated with each other, and showed similar patterns of

correlation with recruitment residuals. The highest correlation observed (0.625) was with the minimum daily flow in the month of November.

To investigate the predictive capability of these relationships, we included them as independent variables in the spawner-recruit regression.

$$log(R/S) = \alpha + \beta X + \varepsilon ,$$

Where β is a vector of coefficients and X is a vector of predictor variables (spawners, survival index, and flow variables). While inclusion of flow variables marginally improved the fit of the spawner-recruit relationship (Table 6), the improvement was less than that of including the survival index. In every case examined, when flow variables were included in the regression, the loss of degrees of freedom resulted in lower overall significance of the fit, than the same model without the flow variables included.

Table 6. Results of including hatchery survival index and flow variables in the spawner-recruit regression.

Model (predictor variables)	**Adjusted R^2**	**d.f.**	**F**
Spawners (S)	0.535	20	25.16
S + log(survival)	0.777	19	37.66
S + Sept-Oct flow	0.616	19	22.57
S +log(survival) + Sep-Oct flow	0.814	18	26.24
S + Nov minimum flow	0.622	19	18.28
S + log(survival) + Nov min flow	0.782	18	26.14

Because including flow variables in the spawner-recruit relationship resulted in lower significance of the overall regression, we did not pursue further investigations with flow relationships.

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Appendix A: Model 1

Data. The {*R, S*} data are presented in Table A1. *BY* denotes brood year; $N_{3,Sept1}$ denotes the abundance of progeny spawned by *S* in calendar year *BY* that survive to become ocean age 3 on September 1 in calendar year $BY+3$; $R = R_3 + R_4 + R_5$ denotes recruitment and is equal to $N_{3,Sept1}$ in adult equivalent units. That is, R_a is the number of $N_{3,Sept1}$ that would have been expected to spawn at age $\{a = 3,4,5\}$ if no fishing would have occurred:

$$R_a = N_{3,Sept1}\left[\prod_{j=3}^{a-1}(1-v_j)(1-m_j)\right](1-v_a)m_a(1-r_a), \tag{A1}$$

where $v_a = 1-\prod_{t=Sept}^{Aug}(1-v_{at})$ is the annual natural mortality rate at age *a* absent fishing; v_{at} is the age *a* natural mortality rate in month *t*; m_a is the age *a* maturation rate (taken to occur on August 31); and r_a is the age *a* out-of-basin stray rate. The $\{m_a, a = 3,4,5\}$ are also year-specific. Values of $N_{3,Sept1}$, $\{v_{at}\}$, $\{m_a\}$, and $\{r_a\}$ were provided by the Klamath River Technical Advisory Team.

Table A1. Klamath River fall Chinook stock-recruitment data set.

BY	$N_{3,Sept1}$	R_3	R_4	R_5	*R*	*S*	*R/S*
1979	423701	42235	137103	21360	200698	30637	6.6
1980	236144	28082	56102	25246	109430	21484	5.1
1981	106338	16737	26354	7877	50968	33857	1.5
1982	277850	17331	61442	43414	122187	31951	3.8
1983	776743	73352	259838	34969	368159	30784	12.0
1984	512171	46576	181026	16450	244052	16064	15.2
1985	391378	52017	119909	16796	188722	25676	7.4
1986	256532	29759	84135	9353	123247	113359	1.1
1987	148910	20399	50415	2167	72981	101717	0.7
1988	37029	2871	13010	1569	17450	79385	0.2
1989	33368	4921	9962	1330	16213	43869	0.4
1990	85146	29185	13186	2539	44910	15596	2.9
1991	91590	29578	18478	457	48513	11649	4.2
1992	526545	129836	132474	7368	269678	12029	22.4
1993	177305	40102	48124	1984	90210	21858	4.1
1994	99535	24195	24978	1667	50840	32333	1.6
1995	72062	28271	10703	229	39203	161793	0.2
1996	74965	17305	21052	51	38408	81326	0.5
1997	327575	84784	76782	6523	168089	46144	3.6
1998	253386	62628	66021	1634	130283	42488	3.1
1999	406036	74558	89368	32271	196197	18456	10.6
2000	386121	60997	112628	14912	188537	82729	2.3

Model/Estimation. Basic regression statistics for the fitted model are presented in Table A2.

Table A2. Model 1 regression statistics.

Model	Coef.	Estimate	Std. Err.	t-value	Pr(>|t|)
$\log(R/S) = a + bS + \varepsilon$	a	2.143e+00	3.079e-01	6.962	9.31e-07
	b	-2.517e-05	5.018e-06	-5.016	6.62e-05
Residual standard error: 0.9005 on 20 degrees of freedom.					
F-statistic: 25.16 on 1 and 20 degrees of freedom, p-value: 6.625e-05.					
R-squared: 0.5571.					

We note that the Ricker model could be alternatively fit using least-squares regression as $\log(R) = a + \log(S) + bS + \varepsilon$, with an implicit coefficient of 1 for the log(*S*) term (in other words, by treating log(*S*) as an "offset"). Note that the hypothesis to be tested $H_0 : b = 0,\ H_1 : b \neq 0$, has an equivalent interpretation under both transformations. The base model under H_0 is $R = \alpha S e^{\varepsilon}$; density-independent recruitment. The model under H_1 is the Ricker model; density-dependent recruitment. The base model under consideration therefore is not a constant recruitment model, $R = \alpha e^{\varepsilon}$; which isn't a submodel of either formulation. While the log(*R/S*) transformation is convenient, it is often noted that with *S* appearing on both sides of the equation correlation will be induced between log(*R/S*) and *S*, even if covariance(*R, S*) = 0. Though true, both transformations lead to the same point estimates and residual sums-of-squares terms, and thus both transformations lead to equivalent regression R-squared and F-statistic values as these are functions of the residual sums-of-squares terms (M. S. Mohr[3], unpublished). To emphasize, R-squared is the fraction of the density-independent model residual variation, in log(*R/S*) or log(*R*), that is accounted for by introduction of the density-dependent term, bS. It is not the fraction of variation in *R* accounted for by the Ricker model.

Regression model graphical diagnostics are presented in Figures A1–A4 that examine the appropriateness of analysis assumptions 1–3. Numbers that appear within Figures A1–A4 denote brood year order within the time series (i.e. "1" represents *BY* 1979, "2" represents *BY* 1980, … , "22" represents *BY* 2000). Figure A1 is a plot of the normalized residuals versus fitted values; a horizontal band of points symmetric about the value 0 is expected under the Ricker model (assumption 1). Figure A2 is a quantile-quantile (Q-Q) plot of the observed versus residuals expected for a normally distributed error term; a straight line is expected under the model (assumption 3). Figure A3 is a plot of Cook's distance which is a measure of the relative influence of each data point on the regression parameter estimates. Figure A4 is a plot of the autocorrelation function (ACF) versus lag, which examines the dependence of the model residuals on time; correlations contained within the two dashed lines are statistically insignificant; for lag 0 the correlation is 1 by definition (assumption 2).

[3] National Marine Fisheries Service, Southwest Fisheries Science Center, Fisheries Ecology Division, Santa Cruz, CA.

Diagnostics: Ricker model

Figure A1. Residuals vs fitted.

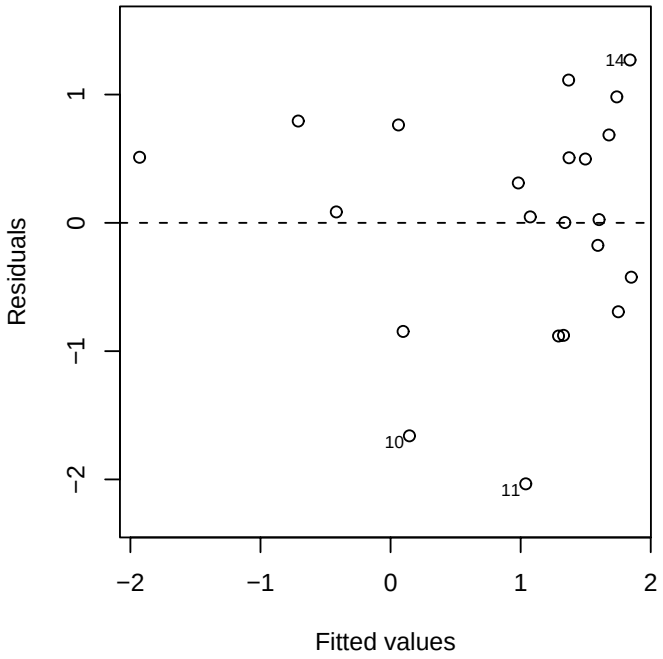


Figure A2. Normal Q−Q plot.

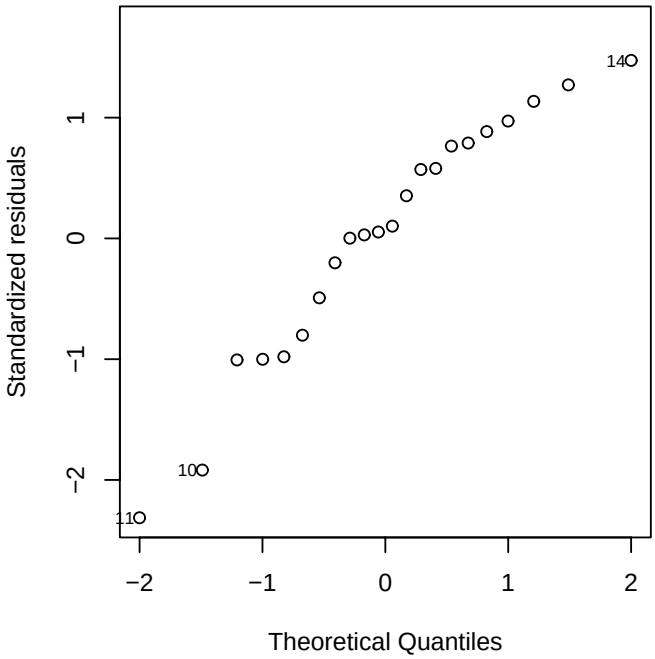


Figure A3. Cook's distance.

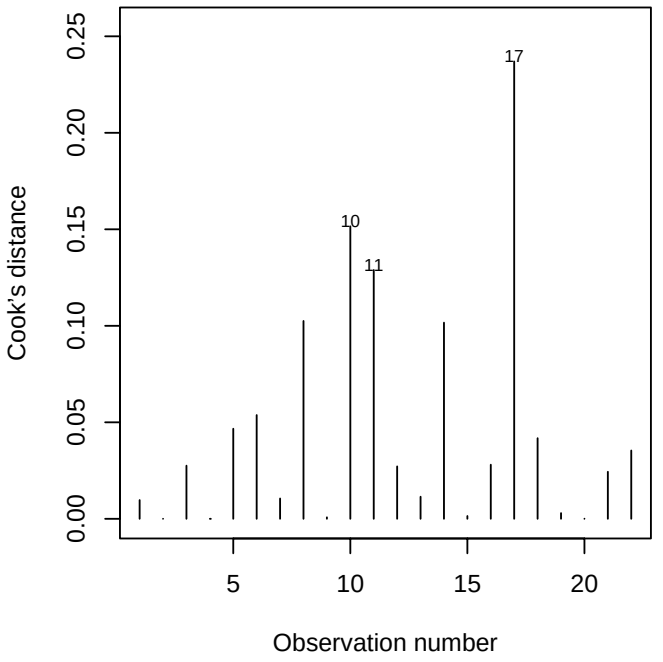
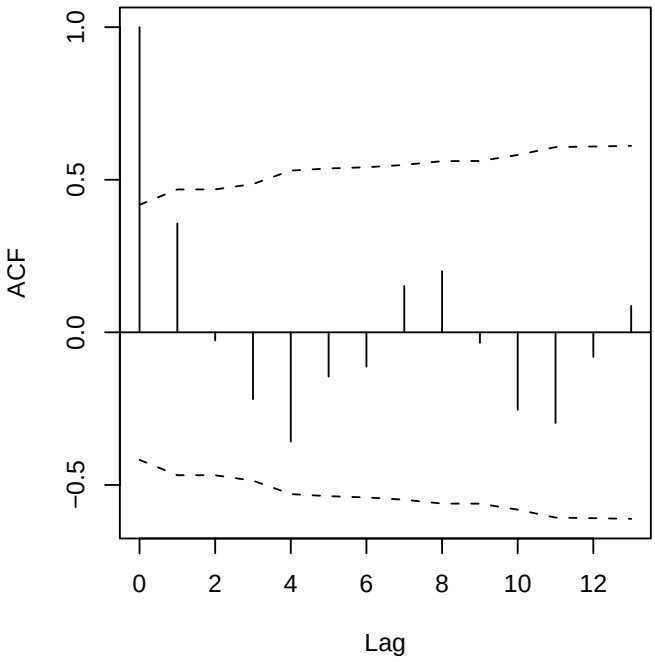


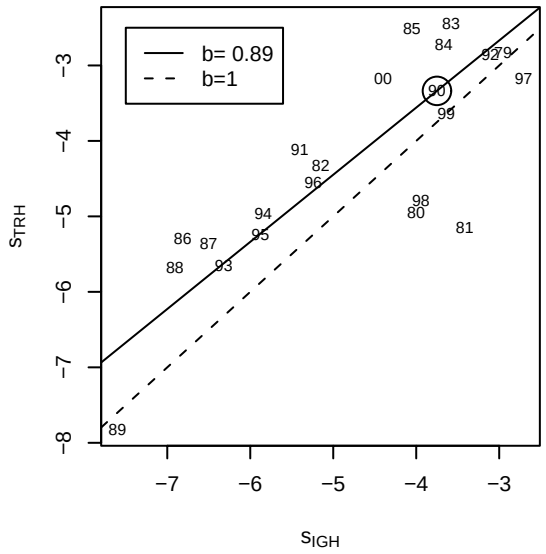
Figure A4. Residual autocorrelation.



Appendix B: Model 2

Data. The $\{s'_{IGH}\}$ and $\{s'_{TRH}\}$ sets of survival rate estimates were independently derived based on the results of cohort analyses performed separately on fingerling cwt groups released from the two hatcheries. For a given brood year and hatchery, s' was computed as the estimated abundance of fingerling releases that survived to the onset of age 2 (approximately four months after release, on September 1) divided by the initial number released. Brood-year-specific estimates of s' for each hatchery are available for all of the {*R, S*} dataset brood years, except for $s'_{TRH,1990}$. The log of the estimates, s_{IGH} and s_{TRH}, for each brood year are plotted against each other in Figure B1. The two time

Figure B1. log(survival): TRH vs IGH.



series of estimates are well correlated (r = 0.80). The solid line in Figure B1 depicts a least squares regression fit through the origin:

$$\hat{s}_{TRH} = 0.89 s_{IGH}; \qquad \text{(B1)}$$

the dashed line is a 1:1 reference line. The regression was used to impute the missing value of $s_{TRH,1990}$ based on the value of $s_{IGH,1990}$. The imputed data point is circled in Figure B1. The full $\{s'_{IGH}, s'_{TRH}\}$ dataset, including the imputed value, is presented in Table B1.

Because the stock-recruitment analysis is not sub-basin-specific, the two estimates for each brood year must be combined in a way thought to be most representative of the composite natural stock. The most appropriate weighting would be natural stock sub-basin-specific age-two recruitment of each brood, but that data is unavailable. A proxy measure for this would be natural stock sub-basin-specific spawning escapement of each brood (across ages), but sub-basin-specific natural area spawner age composition data

Table B1. Klamath River fall Chinook early-life survival data set.

BY	s'_{IGH}	s'_{TRH}	S_{KR}	S_{TR}	S_{UN}	w_{KR}	w_{TR}	s'
1979	0.0522	0.0589	21141	8028	1468	0.725	0.275	0.0540
1980	0.0183	0.0071	12383	7700	1400	0.617	0.383	0.0140
1981	0.0329	0.0058	17517	15340	1000	0.533	0.467	0.0202
1982	0.0058	0.0133	21177	9274	1500	0.695	0.305	0.0081
1983	0.0279	0.0870	12230	17284	1270	0.414	0.586	0.0625
1984	0.0255	0.0656	9420	5654	990	0.625	0.375	0.0405
1985	0.0174	0.0814	12166	9217	4294	0.569	0.431	0.0450
1986	0.0011	0.0050	15893	92548	4919	0.147	0.853	0.0044
1987	0.0015	0.0047	26511	71920	3286	0.269	0.731	0.0038
1988	0.0010	0.0034	29783	44616	4987	0.400	0.600	0.0024
1989	0.0005	0.0004	10584	29445	3839	0.264	0.736	0.0004
1990	0.0235	*0.0356	7102	7682	812	0.480	0.520	0.0298
1991	0.0045	0.0164	5905	4867	877	0.548	0.452	0.0099
1992	0.0447	0.0575	4135	7139	754	0.367	0.633	0.0528
1993	0.0018	0.0035	13385	5905	2568	0.694	0.306	0.0023
1994	0.0029	0.0070	20003	10906	1424	0.647	0.353	0.0043
1995	0.0028	0.0053	79851	77876	4067	0.506	0.494	0.0040
1996	0.0053	0.0106	31755	42646	6925	0.427	0.573	0.0083
1997	0.0668	0.0419	29015	11507	5622	0.716	0.284	0.0597
1998	0.0194	0.0083	16407	24460	1621	0.401	0.599	0.0128
1999	0.0263	0.0265	10883	6797	777	0.616	0.384	0.0264
2000	0.0123	0.0421	58388	24340	0	0.706	0.294	0.0211

* imputed value: $\hat{s}'_{TRH,1990} = \exp(0.89 s_{IGH,1990})$.

isn't available prior to 1991, and also differing maturation schedules for Klamath River and Trinity River fall Chinook (and thus exposure to fisheries) would confound the relation between sub-basin-specific age-two recruitment and brood spawning escapement. Instead, the hatchery-specific survival rate estimates were weighted proportional to the sub-basin-specific natural area parent spawner abundance (age 3 and older) of that brood year (i.e., proportional to sub-basin initial production). These spawner abundances are listed in Table B1, with S_{KR} and S_{TR} denoting Klamath and Trinity Basin natural area spawner abundance (age 3 and older), respectively. Prior to 2000, there is a small number (typically < 10%) of natural area spawning fish that were accounted for, but for which the spawning sub-basin was unspecified, and these fish are listed in Table B1 as S_{UN}. Together: $S_{KR} + S_{TR} + S_{UN} = S$. Given these data, the weights were calculated as

$$w_{KR} = \frac{S_{KR}}{S_{KR} + S_{TR}} \quad \text{and} \quad w_{TR} = \frac{S_{TR}}{S_{KR} + S_{TR}}, \tag{B2}$$

from which the brood-year-specific survival rate weighted average was computed as

$$s' = w_{KR} s'_{KR} + w_{TR} s'_{TR} \tag{B3}$$

(Table B1). Finally, we note that the interannual variation in s' substantially exceeds the intrannual variation in s'_{KR} and s'_{TR}, and thus the Model 2 overall results should be fairly insensitive to the choice of weights.

Model/Estimation. To evaluate the significance of the Model 2 parameter θ, and thus the significance of Model 2 versus Model 1, an F-statistic for the nested submodel was used:

$$F = \frac{(RSS_1 - RSS_2)/(df_1 - df_2)}{RSS_2 / df_2}, \tag{B4}$$

which is distributed as $\mathcal{F}_{(df_1 - df_2, df_2)}$ under the basic model structure if $\theta = 0$, where RSS_i is the residual sum-of-squares under Model *i* (i = 1, 2), and df_i is the associated degrees of freedom. The analogous R-squared value

$$\text{R-squared} = 1 - \frac{RSS_2}{RSS_1} \tag{B5}$$

measures the fraction of Model 1 residual variation accounted for by the introduction of *s* into the model. Basic regression statistics for the fitted models are presented in Table B2.

Table B2. Model 2 regression statistics.

Model	Coef.	Estimate	Std. Err.	t-value	Pr(>|t|)
$s = a + bS + \varepsilon$	a	-3.751e+00	4.184e-01	-8.965	1.92e-08
	b	-1.400e-05	6.820e-06	-2.052	5.35e-02
Residual standard error: 1.224 on 20 degrees of freedom. F-statistic: 4.211 on 1 and 20 degrees of freedom, p-value: 5.349e-02. R-squared: 0.1739.					
$\text{resids}\{(R/S) \mid S\} = a + b * \text{resids}\{s \mid S\} + \varepsilon$	a	0	-	-	-
	b	5.433e-01	1.110e-01	4.896	8.72e-05
Residual standard error: 0.6073 on 20 degrees of freedom. F-statistic: 23.98 on 1 and 20 degrees of freedom, p-value: 8.724e-05. R-squared: 0.5452.					
$\log(R/S) = a + bS + c(s - \overline{s}) + \varepsilon$	a	1.779e+00	2.263e-01	7.859	2.18e-07
	b	-1.757e-05	3.820e-06	-4.599	1.96e-03
	c	5.433e-01	1.138e-01	4.772	1.32e-04
Residual standard error: 0.6231 on 19 degrees of freedom. $H_0 : b = c = 0 \mid a.$ F-statistic: 37.67 on 2 and 19 degrees of freedom, p-value: 2.449e-07. R-squared: 0.7986. $H_0 : c = 0 \mid a, b.$ F-statistic: 22.78 on 1 and 19 degrees of freedom, p-value: 1.324e-04. R-squared: 0.5452.					

Model 2 regression diagnostics are presented in Figures B2–B5 that examine the appropriateness of analysis assumptions 1–3. These are the same diagnostics that were used for Model 1. The interpretation of Figures B2–B5 are described in Appendix A.

In Figure B6, the Model 1 fit (dashed curve) is contrasted with the brood-year-specific Model 2 fit (solid curves). There is one plot for each brood year, with the brood year label marking the respective (*R, S*) data point. For all brood years except 1979 and 1997, Model 2 provides an as good or better fit to the observed (*R, S*) data than does Model 1 without the *s* covariate. The highest *R/S* values (brood years 1983, 1984, 1992) at low *S* values are now partially accounted for by the relatively high early-life survival following outmigration for those brood years. The lowest *R/S* values (brood years 1988, 1989) are now partially accounted for by the relatively low early-life survival following outmigration for those brood years.

Diagnostics: Ricker model w/ survival

Figure B2. Residuals vs fitted.

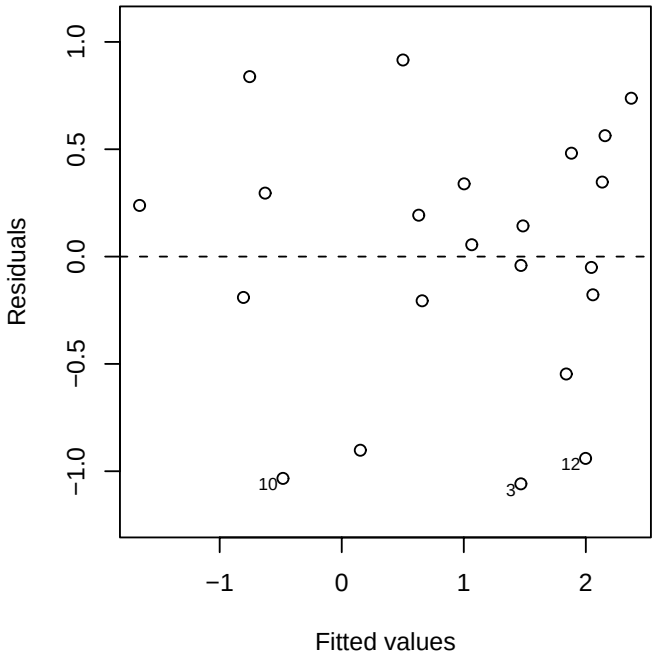


Figure B3. Normal Q−Q plot.

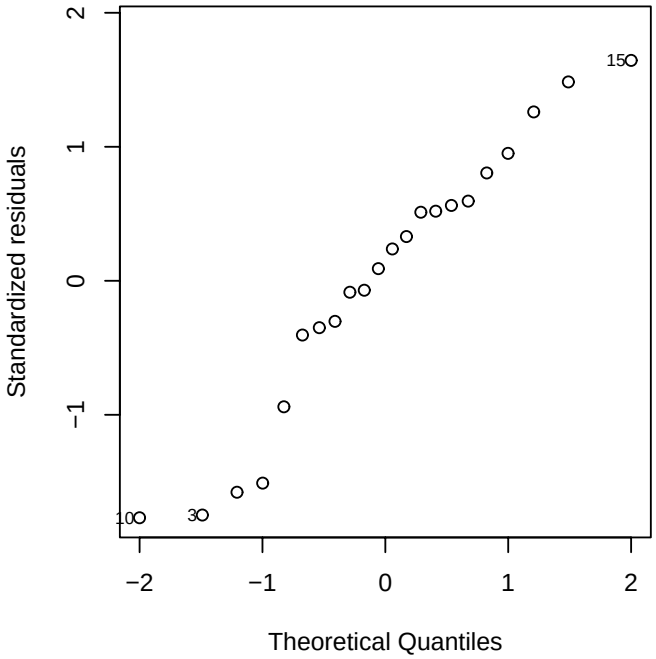


Figure B4. Cook's distance.

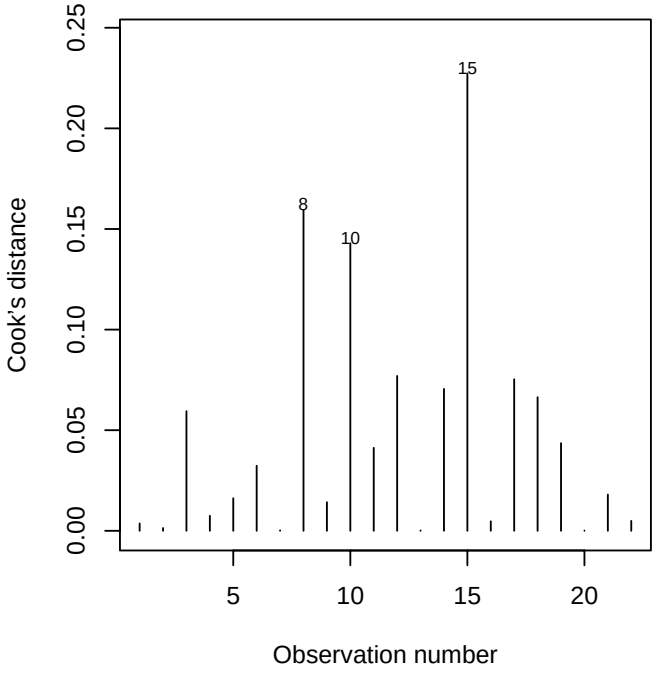


Figure B5. Residual autocorrelation.

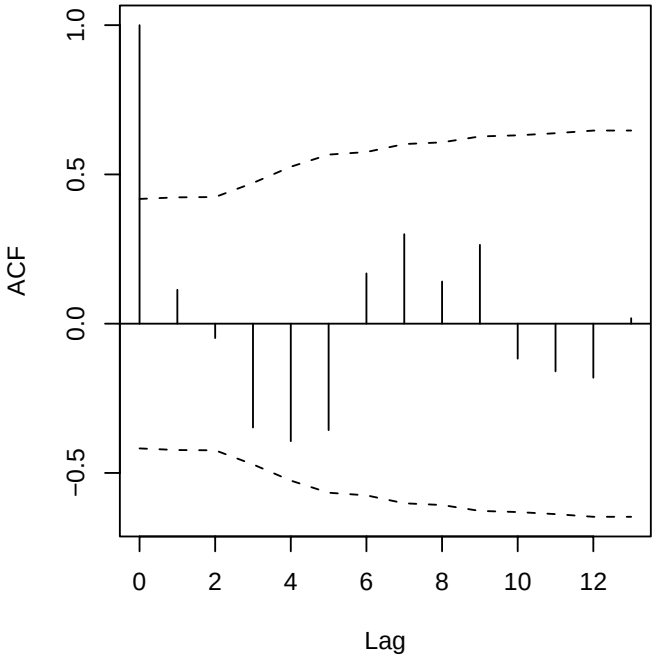
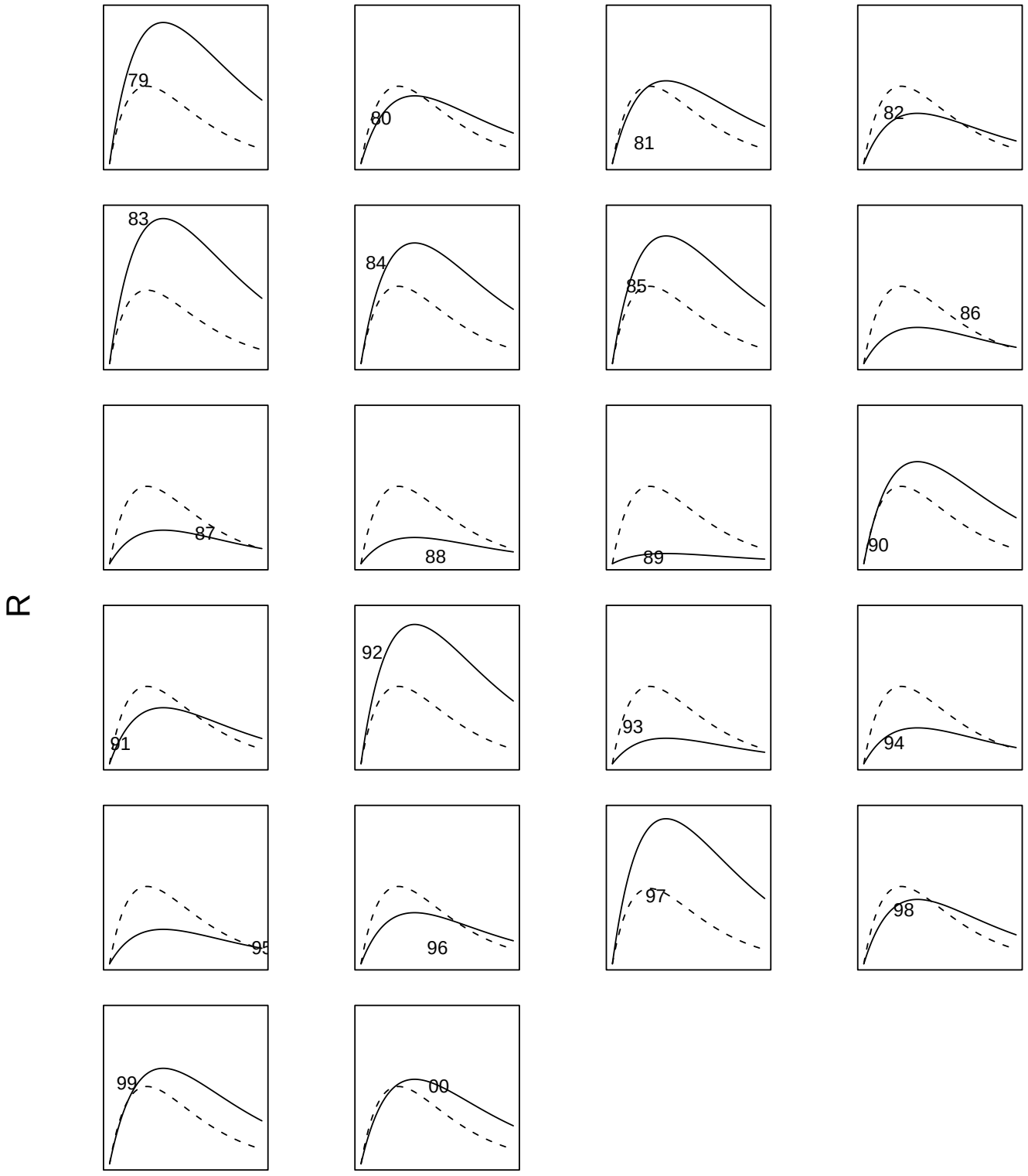


Figure B6. Brood−year−specific Ricker w/ survival.



SCIENTIFIC AND STATISTICAL COMMITTEE KLAMATH RIVER FALL CHINOOK CONSERVATION OBJECTIVE

Mr. Michael Mohr presented the "Klamath River Fall Chinook Stock-Recruitment Analysis" report by the Salmon Technical Team (STT) to a joint meeting of the Scientific and Statistical Committee (SSC) Salmon Subcommittee and the STT on October 12, 2005 in Portland. The report presents information on:

- Two Ricker-type stock-recruit analyses for Klamath River fall chinook salmon,
- A meta-analysis based on Ricker stock-recruit analyses and watershed area, and
- Correlation analyses of survival and flow during two time periods.

The analyses were technically sound and thoroughly documented.

The first Ricker-type stock-recruitment model was a standard analysis of recruits as a function of spawners. The second Ricker-type model included a measure of out-migration and early ocean survival. Including this survival measure adjusts for variability that is ostensibly not due to the density-dependent relationship between spawners and recruits and, in this case, substantially improved the fit of the model. Compared to model 1, the estimated spawners at maximum sustainable yield (S_{MSY}), for model 2 increased from 32,700 to 40,700 spawners. This latter is calculated using the mean of the logarithm of the survival measure, which results in a point estimate with an unrealistically small confidence interval. A simulation model could produce a more realistic point estimate of and confidence interval around the optimal escapement level for long term average harvest or other management goal. This would likely be larger than 40,700 spawners for model 2.

The meta-analysis was based on a study developed for the Pacific Salmon Commission that relates S_{MSY} (based on Ricker stock recruit functions) to watershed area. The Klamath Basin is south of and much larger than any of the systems in the original analysis and the results are based on extrapolations beyond the range of data used to develop the model.

The flow analyses correlated flow data from stations on the Trinity and Klamath Rivers with aggregate hatchery survival. Flows during juvenile out-migration and adult spawning migration were tested. Weakly significant correlations were found suggesting that higher flows related to higher survivals. Natural production is expected to be more sensitive to flows than hatchery production, but no natural survival data are available. Temperature in the Klamath Basin is known to be a problem for chinook salmon, but no appropriate time series of temperature data were available. In conclusion, the flow analysis is incomplete and necessary data are lacking. It does not provide an adequate basis for management decisions.

The stock-recruitment models estimated S_{MSY} as 32,700 spawners without an early life-history survival index and 40,700 spawners with an early life-history survival index. The habitat based model S_{MSY} was 70,900, however this was derived from a regression well outside the range of data used to develop the model. The analysis is thorough and informative, given the limitations of the data available. The SSC endorses the Ricker model analyses as the best available science that could be used to assess whether the 35,000 fish escapement floor is consistent with management goals.

PFMC-11/1/05

NATIONAL MARINE FISHERIES SERVICE REPORT ON USE OF EMERGENCY RULES

Ocean troll fisheries were severely constrained in 2005 in order to meet the 35,000 natural spawner escapement conservation objective for Klamath River fall Chinook. This action prompted a review of the escapement floor and consideration of a permanent modification to the conservation objective. Any such modification would require an amendment to the Salmon Fishery Management Plan (Salmon FMP). The Pacific Fishery Management Council (Council) deferred making this decision until the November meeting to allow consideration of additional information, including the possibility of using an emergency rule to provide flexibility to manage around the escapement floor. The Council directed NOAA's National Marine Fisheries Service (NMFS) to provide a report on this issue in time for discussion at the November meeting.

Before examining the required criteria for implementing an emergency rule, it should be noted that provisions exist under the Magnuson-Stevens Act to allow for public involvement during the rulemaking process. Emergency rule implementation severely limits this public participation and therefore, should only be used for extremely urgent, special circumstances where substantial harm to or disruption of the resource, habitat, fishery, industry participants, community, or public health would be caused during the time it would take to follow standard rulemaking procedures.

NMFS has established policy guidelines for determining whether the use of an emergency rule is justified under the authority of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). These guidelines set forth the criteria for determining whether an emergency exists and are consistent with the requirements of section 305(c) of the Magnuson-Stevens Act as amended by the Sustainable Fisheries Act.

In order to implement an emergency rule, the Secretary must have an administrative record justifying emergency regulatory action and demonstrating its compliance with the national standards. Although the only legal requirement for the use of an emergency rule is that an emergency must exist, this action should only be taken to address extremely rare circumstances that would lead to significant adverse impacts as previously detailed. The guidelines further state that an emergency action may not be based on administrative inaction to solve a long-recognized problem, and establish the following criteria to define an emergency as a situation that:

1) Results from recent, unforeseen events or recently discovered circumstances; and
2) Presents serious conservation or management problems in the fishery; and
3) Can be addressed through emergency regulations for which the immediate benefits outweigh the value of advance notice, public comment, and deliberative consideration of the impacts on participants to the same extent as would be expected under the normal rulemaking process.

If the preceding criteria for defining an emergency are met, the emergency action must then be justified under one or more of the following situations:

1) Ecological – (A) to prevent overfishing as defined in an FMP, or as defined by the Secretary in the absence of an FMP, or (B) to prevent other serious damage to the fishery resource or habitat; or
2) Economic – to prevent significant direct economic loss or to preserve a significant economic opportunity that otherwise might be foregone; or
3) Social – to prevent significant community impacts or conflict between user groups; or
4) Public health – to prevent significant adverse effects to health of participants in a fishery or to the consumers of seafood products.

In addition to meeting the emergency criteria and justification requirements, the emergency rule should indicate what measures could be taken or will be considered to permanently resolve the problem addressed by the emergency rule.

Implementation of an emergency action would, in effect, temporarily amend the FMP as detailed in the emergency rule language. Since the conservation objectives within the FMP were established to achieve optimum yield, prevent overfishing and assure the rebuilding of depressed salmon stocks, any emergency action would require confirmation from the NMFS Science Center directors that such action would continue to prevent overfishing, provide optimal yield, and conform to any affected rebuilding plans.

Once an emergency rule has been implemented, it can remain in effect for up to 180 days. An additional 180 day extension period is possible, providing there is an opportunity for public comment and the Council is following the standard procedure to address the emergency situation through an FMP amendment.

Curt Melcher

Agenda Item G.3.d
Supplemental KFMC Report
November 2005

KLAMATH FISHERY MANAGEMENT COUNCIL REPORT ON THE KLAMATH RIVER FALL CHINOOK CONSERVATION OBJECTIVE

The Klamath Fishery Management Council (KFMC) and the Klamath River Technical Advisory Team (KRTAT) have reviewed the Salmon Technical Team's (STT) report titled *Klamath River Fall Chinook Stock-Recruitment Analysis* (September 2005). The KFMC appreciates the opportunity to comment on this critical issue.

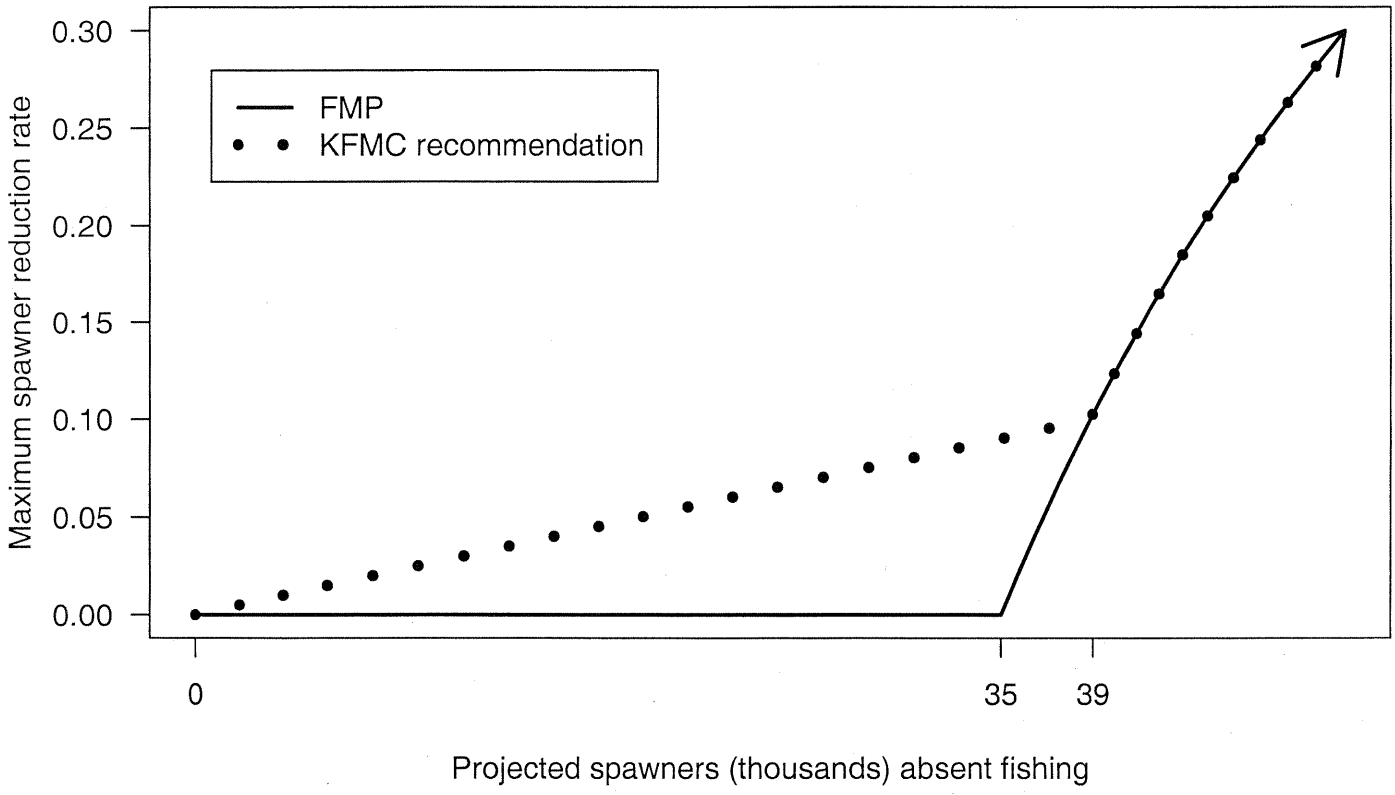
In general, we find that the technical basis of the stock recruitment analysis is sound and, given the limited time and data available to complete the analysis, is an adequate response to the PFMC's assignment. We believe that Model 2 of the analysis best represents the stock recruitment relationship of Klamath River fall Chinook. Based on the STT's analysis and the diverse results of each of the three stock-recruit models, the KFMC recommends that the current Salmon FMP conservation objectives for Klamath River fall Chinook (2/3 maximum spawner reduction rate and a minimum 35,000 fish natural spawning escapement floor) are appropriate and reflect the uncertainty inherent in the STT's stock-recruit analyses.

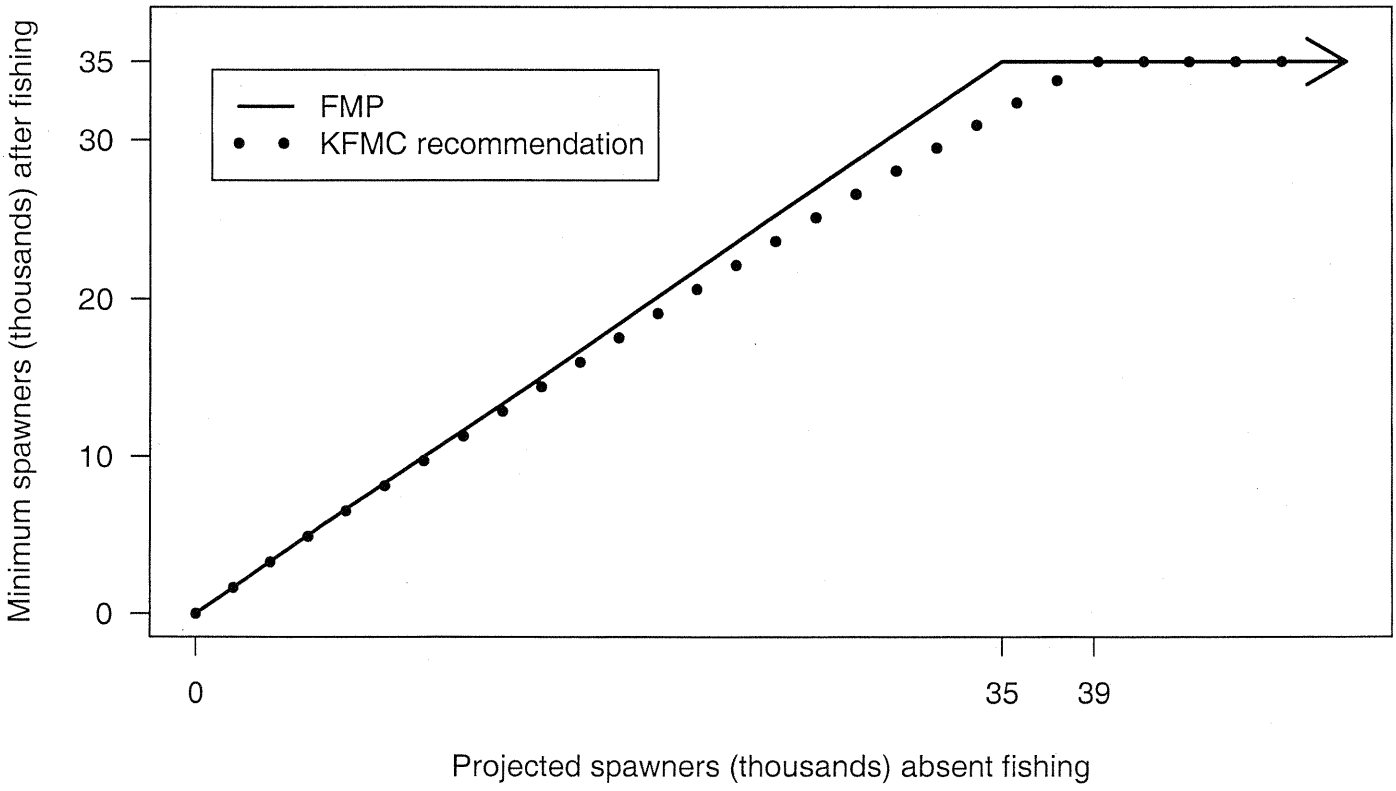
While we found that the STT's use of the available stock recruit data was sufficient to complete the primary assignment from the PFMC (maximum sustained yield stock-recruitment analysis), we believe that the correlation analysis (as assigned by the PFMC) was inconclusive and did not adequately reflect the breadth of available hydrological and life history data for Klamath River fall Chinook. Moreover, this analysis was confounded by the lack of a direct measure of smolt to adult survival for the natural production component. Further analyses of this nature need to be more comprehensive and involve pertinent experts within the basin.

The KFMC recognizes that significant uncertainty remains with regard to the ability of the PFMC and NMFS to implement *de minimis* fisheries. If there is not sufficient flexibility under the Magnuson-Stevens Fishery Conservation and Management Act to implement *de minimis* fisheries through emergency rule, the KFMC recommends that PFMC proceed with the plan amendment process, confined in scope to addressing the potential for *de minimis* fisheries. The KFMC also recommends that any such amendment regarding *de minimis* fisheries be based upon a prudent, precautionary approach regarding the protection of sub-stocks within the Klamath basin, and should be scaled to projected stock abundance.

The KRTAT (Prager and Mohr 1999) evaluated the use of a *de minimis* management policy during years of low abundance and concluded that "Such a policy had little, if any, discernable effect on average catch, year to year variability of catch, or median natural escapement." The KRTAT made no recommendation regarding the use of such a policy; however, they noted that while their study showed no adverse effect of fisheries up to a 20% spawner reduction rate, there could be disproportionate impacts to smaller sub-stocks, thus reducing long term yield. They recommended that if such a fishery was established, a maximum spawner reduction rate of 10% should be adopted, subject to review after a period of years.

Based on the KRTAT analysis (Prager and Mohr 1999), the KFMC recommends that whenever "without-fishing" natural spawner abundance is predicted to be 39,000 or less, *de minimis* fisheries should be considered, with a maximum spawner reduction rate of 10%. We also recommend that the *de minimis* fishing rate reduce linearly from 10% to 0% as a function of projected stock abundance. The KFMC also recommends that whenever *de minimis* fisheries are adopted, a technical review of the anticipated escapement shortfall shall be completed prior to the adoption of regulations for the following season. If fishery impacts are found to be a major cause of a substantial shortfall, *de minimis* fisheries shall not be proposed in that subsequent season.


Maximum spawner reduction rate
0.30
0.25
0.20
0.15
0.10
0.05
0.00
FMP
KFMC recommendation
0
35
39
Projected spawners (thousands) absent fishing


Minimum spawners (thousands) after fishing
35
30
20
10
0
FMP
KFMC recommendation
0
35
39
Projected spawners (thousands) absent fishing

Agenda Item G.3.f
Supplemental HC Report
November 2005

HABITAT COMMITTEE REPORT ON
KLAMATH RIVER FALL CHINOOK CONSERVATION OBJECTIVE

Based on a presentation by Dr. Scott Foott of the U.S. Fish and Wildlife Service, fish diseases appear to be a significant mortality factor affecting both juvenile and adult salmonids in the Klamath Basin. Of overriding concern is the effect of disease on Klamath fall chinook fish populations, and subsequently on ocean fisheries. Accordingly, the Habitat Committee makes the following recommendations to the Council:

- Adequate funding is needed to understand the link between human activities and these diseases, as well as the impacts of these diseases on salmonid populations.
- Research into these diseases should be included in the Council's research and data needs document. Specifically, information is needed on smolt numbers, as well as disease mortality factors, for incorporation into stock recruitment models.
- Specific studies addressing these issues may be appropriate under the remand process.

PFMC
10/27/05

SALMON ADVISORY SUBPANEL STATEMENT ON THE KLAMATH RIVER FALL CHINOOK CONSERVATION OBJECTIVE

The Salmon Advisory Subpanel (SAS) recommends the Council initiate a Fishery Management Plan amendment to address the need for *de minimis* fisheries when Klamath stock abundance is low. The SAS supports the Klamath Fishery Management Council proposal as one alternative to be considered during the amendment process. Scoping should be initiated at the March 2005 Council meeting in Seattle, and the SAS recommends issues be limited to changes to the Klamath River fall Chinook conservation objective to reduce workload issues and expedite the outcome.

Based on the presentation by Dr. Scott Foott at the Habitat Committee meeting October 25, it appears the juvenile outmigrants are significantly affected by pathogens in the mainstem Klamath River, in particular *Ceratomyxa shasta* and *Parvicapsula minibicornis*. Infections have only been detected in the mainstem Klamath River, and not in any of the four major tributaries (Shasta, Scott, Salmon, and Trinity rivers). The infection and subsequent mortality rates are very high for spring and summer outmigrants; however, fall releases of hatchery fingerlings show very low mortality rates. The key to reducing the infectious load appears to be control of the intermediate host, a small polychaete worm associated with algal mats which proliferate in the stable flow and bedload environment below Iron Gate Dam. The diseases associated with the pathogens are not transferred laterally between fish, and there is no indication of density dependence in infection or mortality rates. In other words, reduced juvenile production would not increase survival. In terms of adult equivalents, it is likely there are greater impacts to Klamath Basin fish populations from these diseases than from fisheries. Dr. Foott noted a need for increased research and monitoring to better understand the ecology of the basin, including improved juvenile abundance estimates for each of the major production areas. He noted his budget for research is only about $10,000-$28,000 annually.

The SAS considers disease problems in the Klamath Basin a major threat to the health of the Klamath ecosystem and the communities and fisheries which depend on it. We recommend the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and National Marine Fisheries Service direct additional funding to research and monitoring within the basin to help resolve this critical problem.

PFMC
10/31/05

Agenda Item G.3

PACIFIC COAST FEDERATION of FISHERMEN'S ASSOCIATIONS

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By Fax, Electronic Mail, Hand Delivery

Agenda Item G.3.g
Supplemental Public Comment
November 2005

28 October 2005

Mr. Donald Hanson, Chair
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220-1384

RE: Klamath River Fall Chinook Conservation Objective – Request for Initiation of a Fishery Management Plan (FMP) Amendment

Dear Chairman Hanson:

The Pacific Coast Federation of Fishermen's Associations (PCFFA) represents working men and women in the U.S. West coast commercial fishing fleet. Today, at the meeting of its Board, PCFFA Directors unanimously passed a motion supporting an amendment to the Pacific Fishery Management Council's Salmon Fishery Management Plan (FMP) related to the conservation of Klamath River fall-run chinook salmon. The PCFFA Board respectfully requests the PFMC, at its November 2005 meeting, approve the initiation of a Salmon FMP amendment.

Situation: We are faced with very poor recruitment of Klamath fall Chinook for 2006 and probably at least the next two years. It is likely that the predicted abundance of natural spawners will be below the 35,000 floor called for in the current Framework Plan in one or more of those years. This poor recruitment is due to high mortality of juvenile salmon in the river from the parasite *C. Shasta* and other more or less natural causes which are probably influenced by human control of flow regimes in the river. It is <u>not</u> due to low escapement numbers of the parents of these fish

This poor Klamath recruitment threatens to end the ocean commercial fishery between Cape Falcon, Oregon and Point Sur, California, the area managed for Klamath stocks (and over 90% of the ocean fishery for Chinook south of Washington regardless of the abundance of Sacramento fall Chinook and other stocks). The current FMP does not allow for fishing that would result in spawning numbers below the 35,000 floor, and we are informed that an emergency rule that would allow such fishing is unlikely at best.

Over 80 percent of the boats that historically fished salmon off Oregon and California are now gone as a result of restrictions imposed on ocean fisheries in the past twenty-five years. It is hard to imagine how the remainder would survive a total closure of the fishery. It is even harder to imagine the support businesses remaining in place (ice and fuel docks, gear stores, fish buyers/processors) if the fishery were to be re-opened after one or more years of total closure.

The ocean sports fishery in the Klamath Management Zone also faces a likely total closure, as do the in-river sports fishery and the tribal fisheries in the river (especially if there were two or more years of sub-35,000 predictions; in the first such year the tribes would probably be allowed to catch as many Klamath fish as the ocean fishery had caught the previous fall).

Remedy: PCFFA asks the PFMC to begin scoping a Framework Plan Amendment limited to considering *de minimus* fisheries that would result in escapements below the floor. Such fisheries would need to be large enough to be worth pursuing, but constrained to an overall harvest rate for all fisheries small enough not to impede recovery whenever the spawners left after fishing encountered favorable habitat conditions. We ask PFMC to concentrate its scoping efforts on determining what that overall harvest rate might be.

In short, PCFFA concurs with the Klamath Fishery Management Council (KFMC) statement on *de minimus* fisheries except that we believe the appropriate *de minimus* harvest rate should be the product of PFMC's scoping process, not the starting point except for descriptive purposes, i.e., "if you used this rate, here's how it would work."

PCFFA is <u>not</u> asking for a change in the two-thirds harvest rate under abundant conditions, nor in the 35,000 floor. We suggest a plan in which fisheries would be proportionally constrained as they are now whenever predicted abundance fell between around 105,000 natural spawners (the minimum number that allow full fishing), and (35,000 + d%), where d = the *de minimus* harvest rate. At predicted abundances of (35,000 + d%) or less, the new amendment would apply.

PCFFA <u>supports</u> keeping 35,000 as a conservation objective in that, if that number were not met in fact for three years running, an overfishing review would be triggered.

Finally, PCFFA does not want to create a situation in which fishing pressure triggers more fishing in the form of *de minimus* fisheries, or causes continued stock depression. We therefore concur with the KFMC recommendation concerning technical review of an escapement shortfall prior to proposing *de minimus* fisheries for a second season.

Conclusion. PCFFA believes a framework plan amendment is essential to assuring some level of ocean and Klamath in-river fishing in the next few years as efforts are made to correct serious and long-term problems related to flow, water quality and disease in the Basin impairing spawning and juvenile fish survival. At stake are both the survival of the fish and the fisheries.

PCFFA fully recognizes crafting of such an amendment will have to be done with great care and for that reason we have limited our request for such an amendment to development of a harvest rate to allow for *de minimus* fisheries while we work for long term measures for assuring healthy and abundant stocks of Klamath River Basin salmon. PCFFA is actively working to develop solutions with agencies and other stakeholders in the Basin, related to the flow, fish passage and disease issues, and is fully engaged as well in the Federal Energy Regulatory Commission (FERC) proceedings and initiatives outside of those proceedings related to dam operations on the river and their affect on water quality and fish passage.

For the reasons outlined above, PCFFA respectfully requests PFMC action at the November meeting to immediately initiate a Salmon FMP amendment. If you, other council members, staff or the fishery agencies have any questions regarding this request, please contact our offices or Mr. David Bitts, Ms. Barbara Emley or Mr. Duncan MacLean. Thank you.

Sincerely,

Chuck Wise
President

KLAMATH RIVER FALL CHINOOK CONSERVATION OBJECTIVE

At its September 2005 meeting, the Salmon Technical Team (STT) presented an analysis of Klamath River fall chinook stock-recruitment relationships (Agenda Item G.3.a, Attachment 1). The Council intent was to determine if there was sufficient new information to warrant consideration of a Salmon Fishery Management Plan amendment to change the conservation objective for Klamath River fall chinook. Subsequent testimony at the September meeting prompted the Council to delay action on the conservation objective to allow additional input into the decision, including:

1. Review of the STT analysis by the Scientific and Statistical Committee (SSC) (Agenda Item G.3.b, Supplemental SSC Report);
2. Klamath Fishery Management Council (KFMC) review of the analysis and recommendations on initiating an FMP amendment (Agenda Item G.3.d, Supplemental KFMC Report);
3. National Marine Fisheries Service (NMFS) review of emergency rule making and other procedures to facilitate management flexibility regarding requirements for annual achievement of conservation objectives (Agenda Item G.3.c, NMFS Report); and
4. Implication of a possible *Ceratomyxa shasta* epidemic and other pathological conditions in the Klamath basin.

The current conservation objective for Klamath River fall chinook as listed in Table 3-1 of the Salmon FMP is:

> "33%-34% of potential adult natural spawners, but no fewer than 35,000 naturally spawning adults in any one year. Brood escapement rate must average 33%-34% over the long-term, but an individual brood may vary from this range to achieve the required tribal/nontribal annual allocation. Objective designed to allow a wide range of spawner escapements from which to develop an MSY [maximum sustainable yield] objective or proxy while protecting the stock during prolonged periods of reduced productivity."

The Salmon FMP also states:

> "…changes or additions to the stock complexes and objectives for most natural stocks may be made without plan amendment. An exception is the 35,000 natural spawner floor for Klamath River fall chinook which may only be changed by FMP amendment."

<u>Council Action</u>:

1. **Determine if there is sufficient information to consider changing the Klamath River fall chinook conservation objective.**
2. **Provide further guidance for investigating factors affecting recruitment of Klamath River fall chinook.**
3. **Determine if there is sufficient flexibility in emergency rule making procedures to address unusual circumstances in the salmon management process.**
4. **Consider initiation of a Salmon FMP amendment.**

Reference Materials:

1. Agenda Item G.3.a, Attachment 1: Klamath River Fall Chinook Stock-Recruitment Analysis.
2. Agenda Item G.3.c, NMFS Report: NMFS Report on Use of Emergency Rules.
3. Agenda Item G.3.b, Supplemental SSC Report.
4. Agenda Item G.3.d, Supplemental KFMC Report.

Agenda Order:

a.	Agenda Item Overview	Chuck Tracy
b.	Report of the SSC	Bob Conrad
c.	NMFS Report on Use of Emergency Rules	Eric Chavez
d.	Report of the Klamath Fishery Management Council	Curt Melcher
e.	Agency and Tribal Comments	
f.	Reports and Comments of Advisory Bodies	
g.	Public Comment	
h.	**Council Action**: Consider Issues Relating to the Klamath River Fall Chinook Conservation Objective and Initiating an FMP Amendment	

PFMC
10/14/05