

INTEGRATED MODELING *FRAMEWORK (IMF) USER'S GUIDE*

Understanding and Running
the Winter-Run Chinook Salmon IMF Model
(Version 1.2)

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SUMMARY

This report presents both an instruction manual for use of version 1.2 for the Winter-run Chinook Integrated Modeling Framework (IMF) and a concise documentation of the scientific basis for calculation steps that compose the IMF. The IMF was developed by a team of fisheries consultants commissioned by water users, was programmed in MS Excel to promote ease of sharing, and was subjected to a collaborative review process with fisheries agencies. Version 1.2 of the IMF is a prototype of future versions that will be upgraded at least annually in response to new monitoring data and technical reviews by the fisheries agencies and interested scientists.

The IMF can be used to predict fish benefits achieved by changes to water management, harvest regulation, hatchery augmentation, and stream habitat alteration. The model user can supply economic information, and explore which suite of restoration actions, for a given level of investment, is likely to achieve the greatest increase in fish populations.

Use of the IMF to simulate historical conditions produced a good fit of predicted to observed run sizes and accounted for 74% of the variation in run sizes during 1972-2003. That simulation showed that the sharp drop in run size from 1968 to 1974 was driven by mortality of juveniles related to high population density, followed by adult losses from impaired adult passage at Red Bluff Diversion Dam (RBDD). Survival was also low from the spawn of 1976 and 1977 broods because of mortality resulting from high water temperature during egg incubation. The increasing run sizes since the 1992 brood resulted largely from improved passage at RBDD and the combined smaller effects of low rearing density, improved Delta passage, and reduced ocean harvest.

The spreadsheet is designed to offer ease of user inputs for many parameters, and to display graphs and tables of the simulation results. The spreadsheet is composed of six tabs, and only the first, or "Home" tab, requires user input to run a new simulation. Additional tabs are provided where the user can compare output from multiple simulation trials ("Trials" tab); view calculations at each step in the model ("Worksheet" tab); establish a new simulation as the benchmark for further comparisons ("Benchmark" tab); compile results from different simulations in tabular form for statistical or graphical analysis elsewhere ("Comparisons" tab); and reset all parameters to the default values ("Defaults" tab). On the "Home" tab, the user can alter a variety of inputs to reflect changes in flows, temperatures, Delta Cross Channel (DCC) gates, export flows, harvest rates, hatchery stocking, and stream habitat alteration.

The winter-run Chinook IMF is based on functions and rates that are substantiated by field sampling to the full extent possible. Simulation of each brood year proceeds as follows:

- Spawners produce fry based on the number of females in the spawning population, average fecundity, pre-spawning mortality, and 25% egg-to-fry survival.
- The survival of fry in the upper river to smolts arriving at the Delta is a function of fish density. This survival is calculated from a Beverton-Holt function that was derived from the historical data set of winter-run Chinook spawner abundance.



- Hatchery fish are released as smolts at Caldwell Park in the upper river, experience post-release mortality as a consequence of naïve behavior, and then are assigned 52% survival to the Delta.
- Survival of natural and hatchery smolts through the Delta is predicted as a function of river flow (cfs at Freeport), river temperature (°F) near Ryde, water export volume (combined Federal and State export facilities), turbidity, salinity (a function of river flow), and DCC gate position (open or closed). Parameters for this function were those estimated by Newman (2003) from an analysis of paired CWT releases of fall Chinook in the lower Sacramento River.
- Adults return to spawn at three age classes – age 2 through 4, based on differential ocean harvest and maturity rates of natural and hatchery fish from each age class according to the cohort analysis of CWT recoveries from winter-run Chinook (Grover et al. 2004).

The model in its present form represents a collection of working hypotheses that need to be tested against additional data. The modeling process revealed what we can determine with the most confidence and what remains most uncertain in our understanding of winter-run Chinook population biology in the Sacramento River. Subsequently, the need for action or for more study was determined by scoring functions and parameter values in the model by three criteria: (1) quality of substantiating evidence, (2) impact on simulation outcomes, and (3) ability of managers to influence the parameter. From these scores, we identified factors that should receive highest priority for study, or monitoring.

Highest priority for studies should be given to:

- Juvenile Survival in Different River Reaches
- Emigration Survival to Delta
- Hatchery Fish Fitness
- Delta Survival
- % Maturing at Each Age Among Wild Fish
- Ocean Harvest Rate
- Freshwater Harvest Rate

Highest priority for monitoring should be given to:

- Spawner Abundance
- Egg Survival Related to Incubation Temperature
- Emigration Survival to Delta
- Hatchery Fish Fitness
- Delta Survival
- Ocean Survival Rate
- Ocean Harvest Rate



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UNDERSTANDING AND RUNNING THE WINTER-RUN CHINOOK SALMON MODEL

INTRODUCTION

This report presents both an instruction manual for use of software version 1.2 for the Winter-run Integrated Modeling Framework (IMF), and a concise documentation of the scientific basis for calculation steps that compose the IMF. The IMF was developed by a team of fisheries consultants commissioned by water users, and was subjected to a collaborative review process with fisheries agencies. It has been the intent from this project's inception that the IMF be a tool for wide use among resource managers and water users to understand probable biological responses from ecosystem restoration and water management actions. The IMF is programmed in MS Excel to facilitate ease of collaboration with reviewers in the continuing process of model development. Primary purposes of this project are:

- Provide a basis for prioritizing restoration actions by developing a predictive tool, based on best available science, to compare probable responses of fish populations to a broad range of management actions.
- Identify the weakest links in our understanding of winter-run population biology, and provide a basis for prioritizing research activities.
- Clarify the types of monitoring activities that will be most helpful for insuring that restoration strategies are staying on track.
- Identify measures to accelerate recovery and/or track recovery of ESA-listed salmonids.

In addition to fish benefits achieved by changing water management, the IMF will also track and accumulate benefits from harvest regulation, hatchery augmentation, and land use modification. The IMF allows simulation of multiple strategies to recover fish populations, and results can inform decision makers on which suites of restoration actions are likely to achieve the greatest fish benefits with the available investment. The IMF will supply information needed to determine both the biological and economic effectiveness of proposals and implemented actions.

Version 1.2 of the IMF is a prototype of future versions that will be upgraded at least annually in response to new monitoring data and technical reviews by the fisheries agencies and interested scientists. Version 1.0 was introduced as a beginning life cycle model that linked many of the functional relationships presently used by fisheries agencies to describe specific life stages of winter-run Chinook. Model version 1.0 was distributed to fisheries agencies and interested scientists for review, and the winter-run Project Work Team responded with a number of written comments. Version 1.0 was revised in response to those comments, and the revised version is described in this report as Version 1.2. This report also responds to one of the agency comments that requested the documentation for the model be compiled in a single report.



Our strategy is to progressively update the model during the year, and sustain ongoing review by fisheries agencies and interested scientists in the course of that development.

This report is divided into five parts. Part 1 describes the conceptual framework that guided later development of the quantitative model. Part 2 presents a brief summary of the model performance for simulating observed population trends for winter-run Chinook since 1972. Part 3 is a users manual for the computer model. Part 4 describes the functions and parameter values in the model, and discusses the evidence that substantiates these functions. Part 5 addresses recommendations for studies or monitoring. Model users are encouraged to study all five parts before running the model or interpreting results.

PART 1: CONCEPTUAL FRAMEWORK

Ultimately, it is intended that the IMF be broadened to cover a mixture of managed fish populations inhabiting the Delta, but the Agency Advisory Committee for this project suggested a Pilot Study should focus first on Central Valley Winter-run Chinook salmon, a species listed as threatened under the Endangered Species Act and one for which much information and data already exist. It was expected that this Pilot Study would enable interested parties to become familiar with the conceptual details of the model and how it could be used for integrating ecosystem and water management actions, responses, and costs.

The winter-run Chinook IMF supplies an analytical foundation needed to integrate piecemeal information on life-cycle dynamics and ecological processes into a whole framework. That framework describes the pathways and magnitude of response through which management actions affect fish populations and their habitat. Thus, whether a manager proposes that flows be changed, exports be changed, or harvest rates be changed, the IMF provides a tool for accumulating the effects of a full suite of actions and estimating the net proportional change in fish populations that is likely over time.

The difference in purpose between the conceptual framework and the quantitative model is important, because there is not full continuity of life-cycle details between the two (Figure 1). The conceptual model reflects our best understanding of how the population functions, regardless of our ability to quantify the many functions. The quantitative model focuses on assembly of functions that have been or can be quantified with the available evidence. By comparing what we would like (the conceptual model) to what we have (the baseline quantitative model), we see the monitoring, analysis, and model development that are needed to eventually bridge the gap.



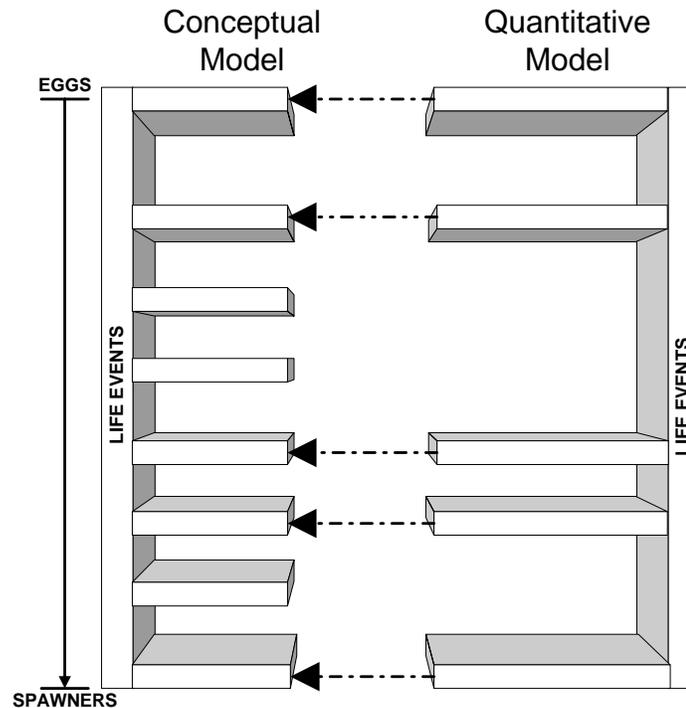


Figure 1. Schematic showing generalized relationship between functions in the Conceptual Framework compared to those in the Quantitative Model. The Quantitative Model often bridges several steps in the Conceptual Framework, depending on the sufficiency of substantiating evidence to quantify each life event.

Guidelines applied during development of the IMF included:

- The quantitative model should be developed from cause-effect relationships that are consistent with fish biology or ecological theory, and that are substantiated by field data;
- The quantitative model should build on analytical foundations already established in Central Valley modeling efforts, to the extent possible;
- The quantitative model should be constructed and parameterized through a collaborative process;
- The focus should be on factors that cause substantial response by fish or their habitat, not every possible factor;
- Cause-effect relationships should be included that relate to effects of proposed actions.

We now describe the life stages (Figure 2) and factors that influence them, beginning with spawning distribution.

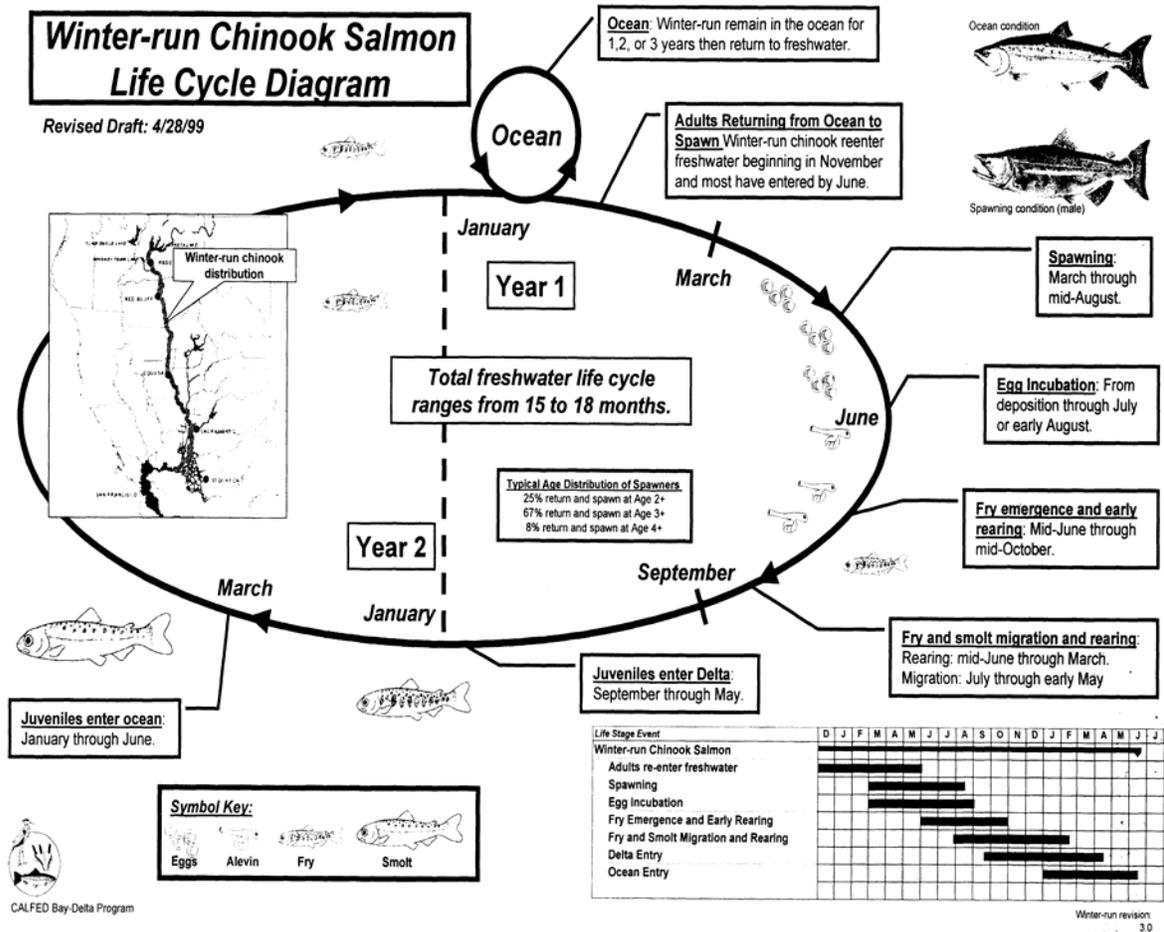


Figure 2. Life cycle of winter-run Chinook. Source: CALFED Bay Delta Program.

The conceptual framework for connecting winter-run population dynamics to management actions begins with spawning distribution and progresses through the full life cycle. Spawning distribution has varied between years, driven by at least three factors. Foremost is passage impairment at Red Bluff Diversion Dam (RBDD), followed by Anderson-Cottonwood Irrigation District (ACID) Dam. Passage problems have been largely corrected. Second is temperature that modulates the extent of upstream migration that is partially regulated by releases from Keswick Dam. Third is imprinting of recruits to areas where their parents spawned. Redd distribution shifted from 46% below RM 283 (Airport Rd Bridge) during 1987-92 to only 6% below that point since 1993 (Killam 2002). The shift in spawning distribution has likely resulted from improved passage at RBDD and because of temperature objectives at Shasta and Trinity dams.

Egg survival can be reduced by high temperature and flood flows. Egg mortality begins to increase at temperatures above 56°F and reaches 100% at about 62°F (USFWS 1999). Egg mortality also increases from gravel scour during floods, but such scour would rarely or never occur during mid summer when winter-run eggs are in the gravel.

Timing of fry emergence and migration have been related to spawning distribution, which determines temperature and development rate during incubation. Upon emergence from the gravel, there is an immediate dispersion of the majority, but not all fry, to downstream areas. The proportion dispersing and the distance dispersed are influenced by flow, particularly when flow and turbidity change together. Juveniles rear as they move downstream, with peak passage at RBDD as fry in September, as parr at Knights Landing in November-December, and as smolts at Chipps Island in March.

River temperature influences growth rate, size, and timing of smolting, and thereby, smolt-to-adult survival. Field studies elsewhere indicate that mean monthly maximum temperatures of 52-59°F (11-15°C) are optimal for growth of juvenile Chinook in natural streams (Bisson and Davis 1976, Brett et al. 1982, Cramer et al. 1985, Fustish et al. 1988). These temperatures prevail throughout much of the Sacramento River during the fall and winter months when winter-run juveniles rear in the river.

Vulnerability to entrainment losses at diversions along the river is related to the season and volume of water diverted, compared to the proportion of winter-run juveniles present in the area during the season of diversions. Some diversions have fish screens while others do not, so the proportion of fish affected by the diversion is related to the efficiency of any deterrence devices, in addition to the overlap between fish presence and water diversion. However, at present, losses of winter-run chinook at the multitude of diversions along the Sacramento River cannot be quantified because of a lack of diversion-specific data.

Survival during emigration is positively related to flow, negatively to temperature, and negatively to the number of channel junctions along the route. Survival through central Delta routes is substantially lower than through north Delta routes, even during winter (Pat Brandes and Dave Vogel, personal communication; Newman 2003). At channel splits, juveniles tend to follow the route of highest velocity, rather than the route of highest flow volume. The number of juveniles arriving at the export pumps is reduced as river flows increase, pumping decreases, and the Delta Cross Channel (DCC) gates are closed. Estimates of the number of smolts reaching the lower Delta are tentative because of small sample size. Over time, estimates of smolts reaching the lower Delta have amounted to roughly 10% of juveniles that passed RDBB.

Winter-run Chinook mature primarily at age 3 and 4 (Grover et al. 2004). Age 5 spawners are rare, and age 2 spawners are predominantly precocious males. Winter-run are vulnerable to both sport and commercial harvest, and experience lower harvest rates than fall-run Chinook because of smaller size-at-age of winter-run fish.

The general pathways through which management actions can influence winter-run Chinook include hatcheries, harvest, habitat modification, and hydro (i.e. water operations) modification. Specific pathways through which human actions influence Chinook abundance in the Central Valley include habitat removal/restoration, contaminant releases, flow control, temperature control, RBDD operation, water diversions, DCC gate position, Delta export pumping rates, harvest restriction, and hatchery supplementation.



PART 2: TESTING THE IMF WITH HISTORICAL OBSERVATIONS

Before reading the full documentation of a life-cycle model, most scientists are likely to wonder if the model shows promise for reasonably simulating real populations. We tested the Winter-run IMF for its ability to simulate historically observed population trends. We ran simulations of winter-run population abundance during 1972 to 2003 by inputting actual environmental conditions (not run sizes) observed each year, and allowing the model to predict the adult run-size for each of those years. No observed values for numbers of fish or their survival were input after 1971 for this test, so prediction errors in any year would have continued to accumulate through the 31 years of this “hindcast” simulation.

HINDCAST FIT TO OBSERVED RUN SIZES

The model results approximated historical run sizes, including the three distinct periods of different population trends (Figure 1). These periods and population trends were: (1) a sharp decline during 1972- 1980, (2) an extended period of zero (flat) growth at low population size during 1983-1996, and (3) an increasing trend during 1997-2003. Large one-year increases in run size during 1977, 1979, and 1982 were not captured by the hindcast simulation. The simulation accounted for 74% of the variation in the observed run sizes during 1972-2003, as determined by regression of predicted on observed run sizes.

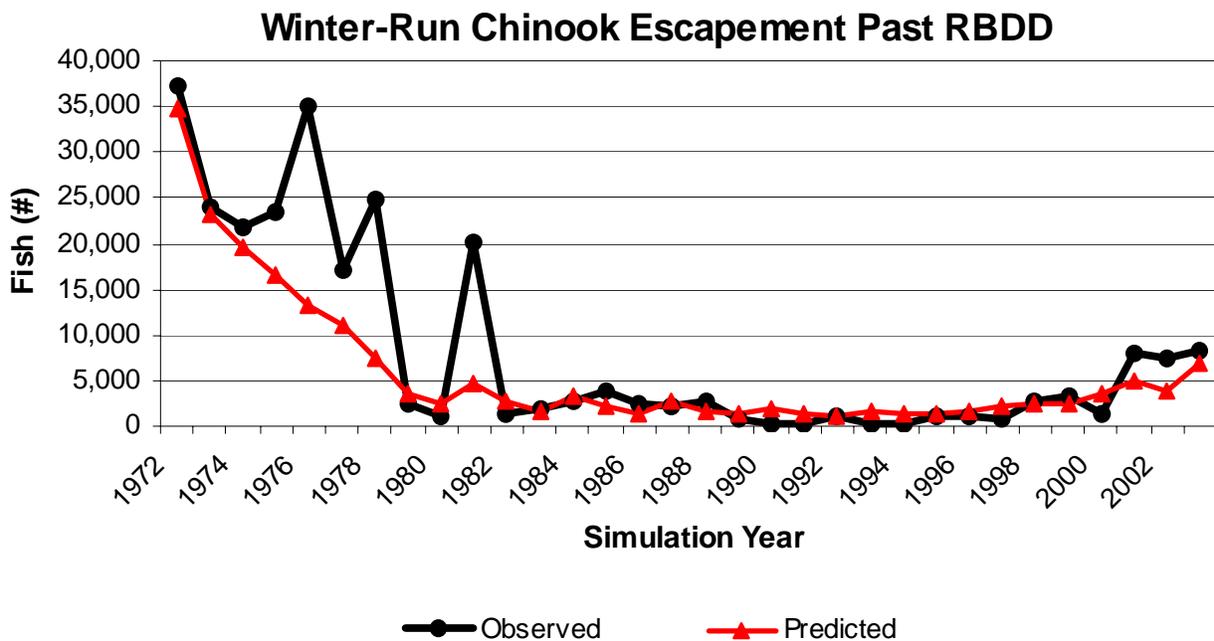


Figure 3. Run size past Red Bluff Diversion Dam predicted in the hindcast simulation compared to that actually observed during 1972-2002.

HINDCAST INPUTS

Input values for a hindcast simulation (e.g. flow, temperature, and gate openings) are the actual values observed each year, and thus, vary between years. This differs from input values for a predictive simulation where values are fixed at one value across all future years (i.e. a deterministic simulation). Input variables that had to be supplied for each year of the hindcast simulation were the following:

- Number of spawners at the start of the simulation period,
- Percent of spawning below RBDD,
- Percent egg mortality above RBDD,
- Freeport flow (Jan.),
- Export/flow (Dec.- Apr.),
- DCC gate position (Dec. – Apr.),
- Turbidity in the delta (Dec-Apr),
- Harvest fraction in freshwater, and
- Harvest fraction in ocean.

Information sources used to obtain historical values for the above variables are fully described in Appendix 1, Technical Memorandum 1.

Historical estimates of spawning escapement were used to “seed” the model for years 1968-1971. Simulated run sizes for 1972-2002 were then predicted by the model and compared to historical estimates for those years as a preliminary test of model accuracy. Seeding the model entails using the first four years of observed spawning escapement as the parents that begin a life cycle, and then allowing the model to simulate the number of their offspring that survive to become parents for the next generation. By the fifth year of simulation, the spawners are the offspring of the first 2 years for which spawners were input. For example, the first year of spawners used to seed the model was 1968, and the model simulated the number of offspring that survived to be age-3 spawners in 1971 and age-4 spawners in 1972. Because winter-run spawners are rarely older than age 4, all spawners in the hindcast simulation after 1972 were generated by the simulation based on observed spawner data from 1968-1971.

We used observed returns of winter-run Chinook to RBDD as the historical benchmark values to which simulations could be compared. We used the official run sizes that have been jointly reviewed and adopted by the fisheries agencies. These estimated run sizes were based on RBDD counts from 1968-1995, and by mark-recapture estimates from carcass-surveys of spawners from 1996-2002 (USFWS 2001). Estimates of spawning escapement are more fully explained in Appendix 1, Technical Memorandum 1.



FACTORS DRIVING HINDCAST TRENDS

The simulation of historical returns provided estimates of the proportionate role that various survival factors played in driving the historical trends in abundance of winter-run Chinook. We calculated the mean value from 1968 to 2000 for each of the survival factors that varied appreciably over those three decades, and then calculated the percentage difference from the mean that occurred each year for each factor. That is:

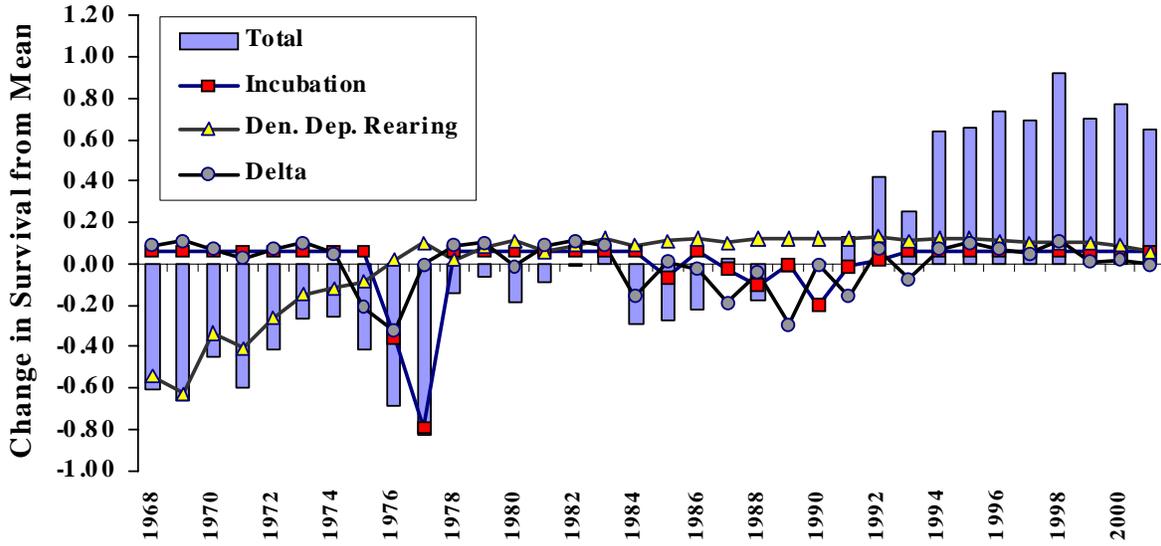
$$\% \text{Survival}_{\text{year } i} / \% \text{Survival}_{\text{mean}} = \% \text{Survival Difference}_{\text{year } i}$$

The main survival factors that varied included survival of incubating eggs, fry-to-smolt survival, Delta passage survival, ocean harvest, freshwater harvest, and RBDD passage. The graph of overall difference in survival from the mean for all survival factors (Figure 4) shows that survival was 30% to 80% below average for the 1968-1977 broods, within 30% of average during 1978 to 1991 broods, and 20% to 100% above average for the 1992-2000 broods.

Factors having the largest effect on survival during 1968 to 1974 broods were (1) passage at RBDD causing a 20% below average survival (40% of run blocked with all eggs lost) (Figure 4), and (2) density-dependent survival from fry-to-smolt (20% to 60% below average survival in years of 35,000 to 114,000 spawners) (Figure 4; additionally, see the section on the density dependent fry-to-smolt stock recruit relationship discussed in PART 4 of this report). Survival dropped dramatically for the 1975-1977 broods because of egg mortality from high temperatures (Figure 4). The large survival increase during the 1992-2000 broods was predominantly the 20% above average survival for passage at RBDD (egg loss was eliminated) (Figure 4), and the combined small improvements in survival for incubating eggs, fry-to-smolt, Delta passage, and harvest (Figure 4). Harvest reductions in recent years did not have a larger effect because most harvest is on age 3 fish, which had about 35% harvest rate (65% survival rate) up to the late 1990's. Once the harvest rate on age 3 dropped to 21% in recent years, that increased harvest survival to 79%, but the change from 65% survival up to 79% survival is only a 14% change in survival.



Annual Changes in Juvenile Survival



Annual Changes in Adult Survival

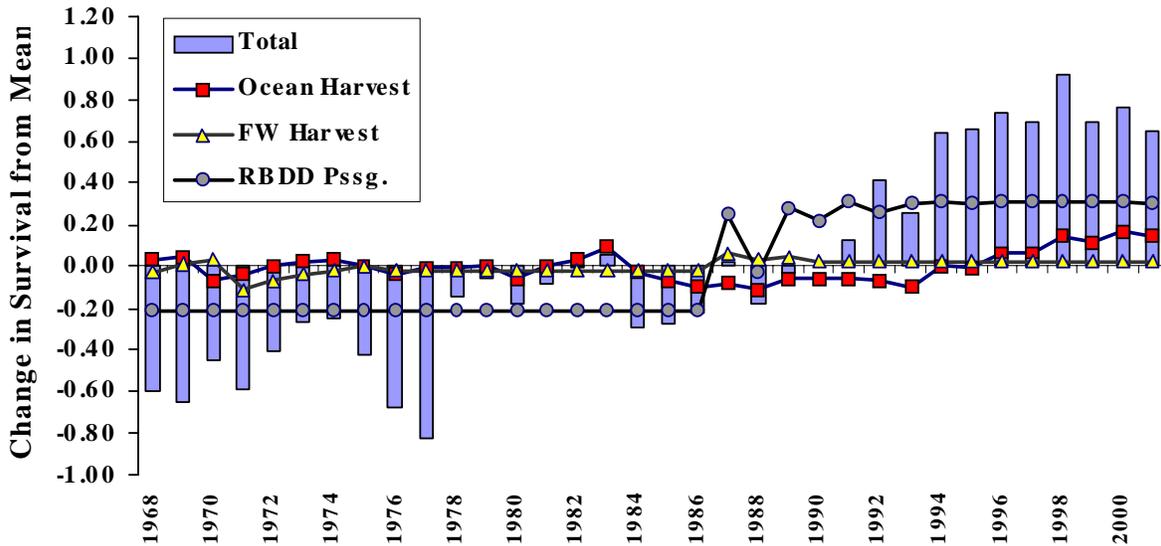


Figure 4. Percent difference from mean survival for each brood year 1968-2000, for various factors included in the winter-run IMF. Survival values were derived from hindcast simulation.

PART 3: BASICS OF RUNNING THE MODEL

OVERVIEW OF COMPUTER MODEL

The IMF for Winter-Run Chinook Salmon has been programmed to run simulations using an Excel spreadsheet, so that natural resource managers can use the model within familiar software. The use of a spreadsheet enables model users with average computer skills to view all equations, and to follow step-by-step through the logic and functions of this mechanistic model.

As the model becomes more complex, so will the model spreadsheets. At some point, this complexity – and the analysis needs of interested stakeholders - may surpass the ability of a spreadsheet to be an effective platform. This spreadsheet would then serve as a prototype for development of a more sophisticated simulator using a more appropriate platform – which will likely be less transparent to the typical user (i.e., be more “black box”). So, up to that point, this spreadsheet simulator is intended to be a more effective way to communicate, facilitate review of the IMF, and actively involve people in model construction.

The model has been constructed as a prototype, not as a market-ready version programmed to withstand naïve use. The user must apply reasonable input values in combinations that might reasonably occur, or the model will yield unreasonable results. Because this model should be subject to regular improvements, programming was only extended to a point sufficient to provide convenient displays of information for informed users.

The quantitative model progresses through the following generalized steps, which are described more fully later in this report:

- The life cycle begins with the number of spawners, which must be supplied by the user for the first four years of simulation. The proportion of spawners that are females, the number of eggs per female, and the average survival of eggs to emergent fry are used to calculate the number of fry;
- The survival of fry in the upper river to smolts arriving at the Delta is a function of fish density. This survival is calculated from a Beverton-Holt function that was derived from the historical data set on spawner abundance of winter-run Chinook;
- Hatchery fish are released as smolts at Caldwell Park in the upper river, experience post-release mortality as a consequence of naïve behavior, and then are assigned 52% survival to the Delta;
- Survival of natural and hatchery smolts through the Delta is assumed to be a function of river flow (cfs at Freeport), river temperature (°F) near Ryde, water export volume, turbidity, salinity (a function of river flow), and DCC gate position (open or closed). Parameters for this function were those estimated by Newman (2003) from an analysis of paired CWT releases of fall Chinook from Courtland to Chipps Island; and
- Adults return to spawn at three age classes – 2 years, 3 years, and 4 years, based on differential ocean harvest and maturity rates of natural and hatchery fish from



each age class according to the inter-agency cohort analysis of CWT recoveries from winter-run Chinook (Grover et al. 2004).

The spreadsheet simulator is composed of six sheets:

- Home – the primary sheet for supplying model inputs and viewing results;
- Trials – a sheet to help the user compile output from multiple simulations;
- Worksheet – the sheet containing all IMF computations;
- Benchmark – a repository of “Worksheet” calculations for a “benchmark” trial;
- Comparisons – a summary sheet of multiple simulation inputs and outputs; and
- Defaults – a sheet containing default values that will be used in each input cell that is not altered by the user.

Operation of the simulator is conducted primarily through the “Home” and “Trials” worksheets. For its intended use, the architecture of this simulator is fairly “open” and fault tolerance is limited. Therefore, it is suggested that the user limit operation via these pages and the instructions that follow. Review of the model, however, is encouraged via the Worksheet tab and through information provided in this report or its references.

SPREADSHEET TAB DESCRIPTIONS, DEFINITIONS, AND DEFAULTS

“Home” Tab

The “Home” tab shows on its left side the simulation parameters that are input, and on its right side the simulation results that are output. Thus, this tab is the primary location for providing model inputs and graphically viewing the model outputs. Detail regarding each input parameter follows.

The “Home” tab offers a single table in which the model user can alter a number of key input parameters highlighted in orange, and the model will automatically re-run the simulation with the user supplied values. The input parameters are linked to the “Worksheet” tab for the purposes of model calculations as described in subsequent sections; specific links are identified in Table 1. These highlighted input parameters on the “Home” tab were intentionally chosen to provide potential IMF users with a wide range of parameters to evaluate, based on the diverse interests of potential IMF users. The primary purpose of these input parameters is to allow IMF users to evaluate how variation in each parameter will affect predicted winter run abundance (or other population metrics of interest). Thus, each IMF user has the capability of evaluating a specific action or suite of actions for their predicted effects on winter-run Chinook, by altering appropriate input parameter values.

Default values for each input parameter have been provided as a courtesy to potential IMF users, so the model will run even if users do not supply values for all input parameters (Table 1). These defaults represent values that commonly occur, and their substantiating evidence is presented in PART 4 of this manual. Thus, default values provide the most benefit to those IMF users that are only interested in evaluating the predicted effects for limited number of parameters on winter-run Chinook. On the other hand, all input values supplied by the user override the courtesy default values.



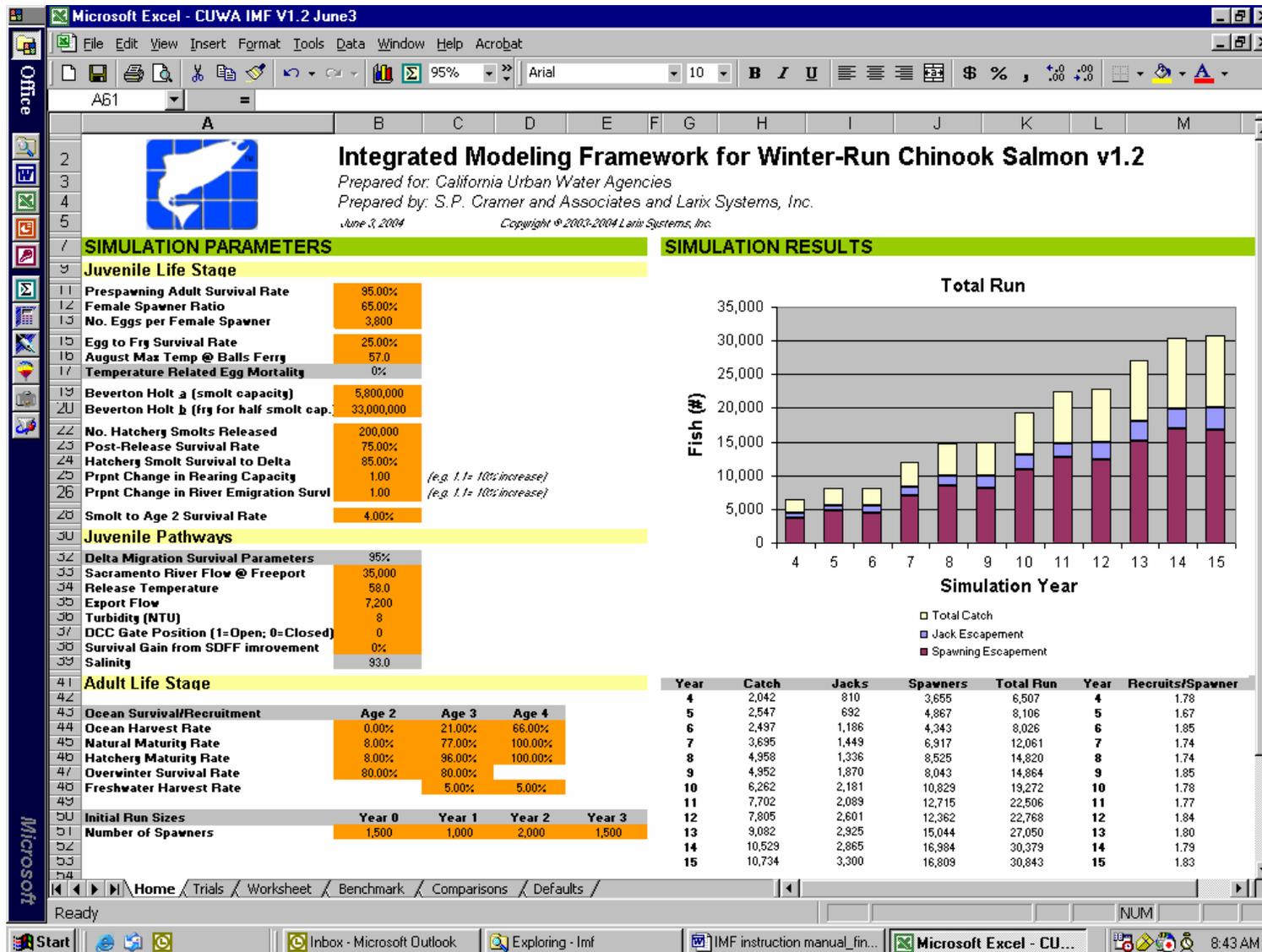


Figure 5. Depiction of “Home” tab in IMF. Inputs (simulation parameters) are displayed on the left side and a summary of selected outputs (simulation results) are displayed on the right side.



Table 1. Detailed description of the default IMF input parameters (or parameters calculated based on input parameters) found on the “Home” tab. The input parameters are linked to the IMF calculations in the “Worksheet” tab.

| “Home” Row # | “Work sheet” Row # | Input Description and Substantiation | Default Value |
|----------------------------|--------------------------|---|--|
| Juvenile Life Stage | | | |
| 51 | 14 | <i>Number of spawners:</i> These values seed the model at the lower range of observed run sizes. Choice of these initial values allows room for population growth in first few generations, but has little effect on simulated run size after 20-30 years under typical conditions. | Yr0=1,500 Yr1=1,000 Yr2=2,000 Yr3=1,500 |
| 11 | 16 | <i>Prespawning Adult Survival Rate:</i> This survival rate estimates the number of returning adults that survive to spawn. The default value was based on CDFG winter run Chinook spawner surveys in the Sacramento River from 1996-2001; these surveys estimated prespawn mortality ranging from 0-5%. To be conservative, we used the upper end of this range or 5% prespawning mortality. | 0.95 |
| 12 | 17 | <i>Female Spawner Ratio:</i> Represents the percent of adult females in the spawning population. CDFG spawner surveys from 1996-2001 show female percent ranged from 0.72 to 0.90 and averaged 0.83. However, carcass surveys are usually biased high in favor of females, because they remain near the redd. We assumed 65% females in the run as a default to provide a conservative estimate of this parameter compared to the carcass survey estimates. | 0.65 |
| 13 | 19 | <i>No. Eggs per Female Spawner:</i> Indicates the average fecundity of winter Chinook based on observations of spawning females at the Livingston Stone National Fish Hatchery. Observations at the hatchery indicate that fecundity varies annually. | 3,800 |
| 15 | 21 | <i>Egg to Fry Survival Rate:</i> We used the same 25% survival used by NMFS in the Juvenile Production Estimate (JPE). Juvenile trapping at RBDD indicated an average 29% egg-to-fry survival. | 25% |
| 17 | 22 | <i>Egg Survival from High Temperature:</i> This survival is calculated as a function of temperature in August at Balls Ferry. The temperature default was set at 57F so their would be no egg mortality from high temperature, as has approximately been the case since the initial provision of colder water from Lake Shasta and the subsequent installation of the temperature control device at Shasta Dam. | 100% |
| 25 | 28 | <i>Fractional Change in Rearing Capacity:</i> The model user can adjust this to represent benefits from recovery actions that add rearing habitat. Default is 1.0, which represents no effect. As an example, 1.1 would represent a 10% increase in capacity of rearing habitat. | 1.0 |
| 26 | 29 | <i>Fractional Change in River Emigration Survival:</i> The model user can adjust this to represent benefits from recovery actions that protect migrating juveniles. Default is 1.0, which represents no effect. As an example, 1.1 would represent a 10% change in survival. | 1.0 |



| "Home" Row # | "Work sheet" Row # | Input Description and Substantiation | Default Value |
|-------------------------|--------------------|---|---|
| 19 20 25 26 | 30 | <i>Smolts Arriving to Delta (Beverton Holt):</i> Juvenile survival during the time they are fry above RBDD to the time they arrive as smolts entering the Delta is a function of how close the fry abundance is to filling the capacity for rearing habitat. The Beverton-Holt function that calculates this survival was derived from historical data on spawner abundance, as described in the text. | Refers to Home page. Cap: 5,800,000 smolts Fry for ½ capacity 33,000,000 fry |
| 32 | 31 | <i>Delta Emigration Survival Rate:</i> Survival during passage through the Delta is based survival of CWT groups related to environmental variables, as estimated by Newman (2003). The default survival value of 95% is the calculated outcome from setting Delta environmental values at their median values during winter. Delta environmental values are input on the Home Page (rows 33-39) and defaults are set at: Freeport flow = 35,000cfs; turbidity = 8 NTU, temperature = 58F; exports = 7,500 cfs; DCC gates = 0 (closed). | 95% |
| 22 | 36 | <i>Hatchery Smolts Released:</i> The USFWS Biological Assessment of hatchery programs at the Coleman and Livingston Stone National Fish Hatcheries states the annual release goal for winter-run Chinook is 200,000. | 200,000 |
| 23 | 37 | <i>Post-Release Survival Rate:</i> Assumed survival following near-term mortality because of naïve behavior of hatchery smolts. | 0.75 |
| 24 | 39 | <i>Hatchery Smolt Survival to Delta:</i> Default is average survival from Battle Creek to Ryde estimated from 6 years of paired CWT releases of late-fall Chinook at Battle Creek and Ryde. | 52% |
| 28 | 45 | <i>Smolt to Age 2 Survival Rate:</i> No estimates of this early ocean survival are available for wild winter-run Chinook. We assumed this survival was 4%, which is within the range of estimates from CWT recoveries of fall Chinook from Coleman Hatchery (Cramer and Chapman 2002) | 0.040 |
| Adult Life Stage | | | |
| 44 | 48 63 78 | <i>Ocean Harvest Rate:</i> These harvest rates are age specific and are based on a recently published cohort analysis for 1998-2000 brood years (Grover et al. 2004). The default values represent the average harvest rate for the 1998-2000 brood years. | Age 2 – 0 Age 3 – 0.21 Age 4 – 0.66 |
| 45 | 54 69 84 | <i>Natural Maturity Rate:</i> These maturity rates are age specific and are based on a cohort reconstruction from age composition of 2001 wild spawners. 'Maturity' indicates ocean departure (i.e. migration back to freshwater). | Age 2 – 0.08 Age 3 – 0.77 Age 4 – 1.0 |
| 46 | 56 71 86 | <i>Hatchery Maturity Rate:</i> These maturity rates are age specific and are based on a recently published cohort analysis for 1998-2000 brood years (Grover et al. 2004). The default values represent the average maturity rate for the 3 brood years. | Age 2 – 0.08 Age 3 – 0.96 Age 4 – 1.0 |
| 47 | 51 66 81 | <i>Overwinter Survival Rate:</i> This survival parameter represents ocean survival from one age class to the next, after harvest and maturity rates were applied. The default value was the same as that assumed by Grover et al. (2004) and commonly applied by PFMC. | Age 2 -0.80 Age 3 -0.80 Age 4 -0.80 |
| 48 | 90 | <i>Freshwater Harvest Rate:</i> This parameter accounts for any harvest of winter-run Chinook in the Sacramento River that may occur prior to the non-retention regulation that begins annually on January 1 st . This harvest rate also accounts for illegal harvest that may occur. The default value is based on recent data from the BRT (2003) and various analyses of historic in-river harvest rates. | 0.05 |



“Trials” Tab

Use of the “Trials” tab is optional and its purpose is to allow the user to graphically compare output from two different simulations: a defined “Benchmark” simulation and the most recent “Trial” scenario (Figure 6). The “Trials” tab is relatively self-explanatory with directions embedded within the tab next to the automated buttons. A user defined “Benchmark” scenario can be saved by following the directions in the “Trials” tab or the instructions in the subsequent “Comparing Scenarios” Section. After input parameters have been modified in the “Home” tab based on the IMF user’s desires, clicking the “Refresh Sheet” button will refresh the graph in the “Trials” tab to compare the most recent scenario and the “Benchmark”. Additionally, the “Trials” tab is linked to the “Comparisons” tab via the “Save Trial” button. Use of this button graphically displays the most recent scenario within the “Trials” tab and compares it to the “Benchmark” results and also transfers the inputs and outputs from the scenario to the “Comparisons” tab, where a list of each trial is maintained. More specific directions on creating a “Benchmark” scenario and comparing trial scenarios are included in the subsequent “Comparing Scenarios” Section.

Economic Analysis

A function is provided on the “Trials” tab for the user to supply his or her own estimates of cost for a management action that is simulated. The model provides no economic information, so this function is purely discretionary and inputs must be supplied by the user. The model provides an input cell on row 28 of the “Trials” Tab (Figure 3), where the user can enter an estimate of cost (millions of dollars) for the action being simulated. The model will express this cost as a cost per adult fish gained by the action, and will display a graph of this value for 25 years of action. This is not an economic model, and it makes no attempt to calculate an economic value gained from the action. Rather, this is a biological model so it only predicts the biological change that will arise from an action.



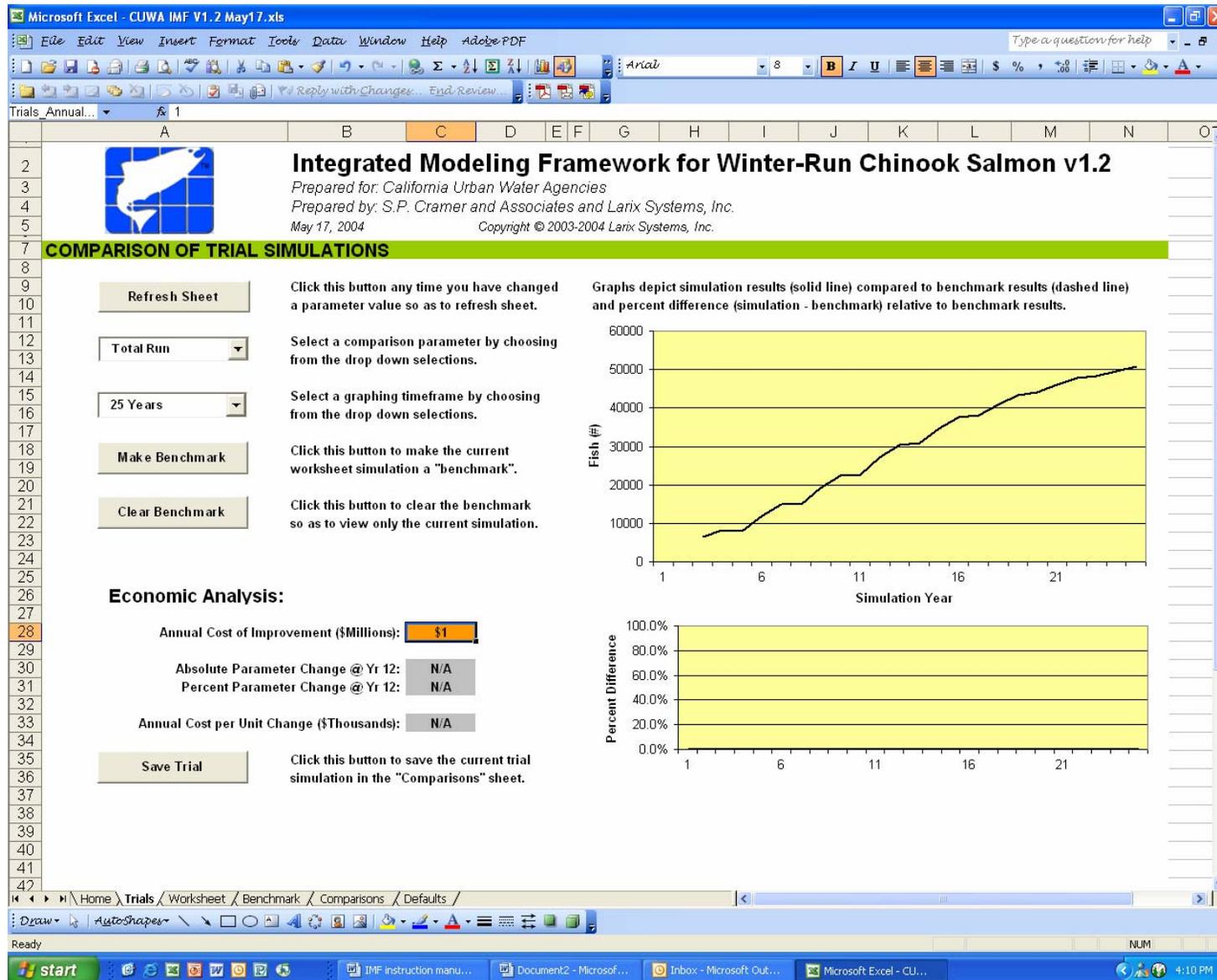


Figure 6. Depiction of "Trials" tab in IMF.



“Worksheet” Tab

The “Worksheet” tab is where calculations that simulate the full life cycle are carried out. This tab displays all of the step-by-step calculations in the model and obtains input values directly from the “Home” tab (Table 1, Figure 7, Figure 8, and Figure 9). Each simulation year begins with a number of spawners that produce a certain number of fry based on the number of females in the spawning population, average fecundity, spawning mortality, and egg mortality. The fry produced in each simulation year are then converted to smolts arriving at the Delta based on a Beverton-Holt function that calculates fry-to-smolt survival. Hatchery fish are released at Caldwell Park in the upper river as smolts and face a post-release mortality and further mortality during migration to the Delta. Natural and hatchery smolts passing Courtland are next subjected to a Delta survival function based on the work of Newman (2003). An additional mortality factor is applied for smolt-to-age 2 survival that accounts for high mortality during early ocean rearing.

Adult fish are subject to age-specific harvest rates, maturity rates, and overwinter survival that determines the number of natural and hatchery fish escaping in each age class. The IMF shifts fish from “Simulation Year” in the juvenile stage to “Run Year” as adults to account for each year’s annual escapement. The first “Run Year” escapement is calculated for simulation year 4, based on age 2, 3, and 4 adults represented in the escapement. Escapement for any given run year ‘x’ is composed of age 2 fish from brood year ‘x-2’, age 3 fish from brood year ‘x-3’, and age 4 fish from brood year ‘x-4’. Age 2 fish comprise the “Jack Escapement” while age 3 and age 4 fish comprise the “Spawning Escapement”.



| Parameter/Simulation Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|--|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| LIFE CYCLE SIMULATION | | | | | | | | | | | |
| Egg to Fry | | | | | | | | | | | |
| <i>Spawning Year - Age 0</i> | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Number of Spawners | 1,500 | 1,000 | 2,000 | 1,500 | 2,805 | 4,017 | 3,494 | 5,056 | 6,622 | 6,125 | 7,873 |
| Prespawning Adult Survival Rate | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| Female Spawner Ratio | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| Number of Female Spawners | 926 | 618 | 1,235 | 926 | 1,732 | 2,481 | 2,157 | 3,122 | 4,089 | 3,782 | 4,862 |
| No. Eggs per Female Spawner | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 | 3,800 |
| Number of Eggs Produced | 4.E+06 | 2.E+06 | 5.E+06 | 4.E+06 | 7.E+06 | 9.E+06 | 8.E+06 | 1.E+07 | 2.E+07 | 1.E+07 | 2.E+07 |
| Egg to Fry Survival Rate | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Egg Survival from High Temperature | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| Number of Fry Produced | 9.E+05 | 6.E+05 | 1.E+06 | 9.E+05 | 2.E+06 | 2.E+06 | 2.E+06 | 3.E+06 | 4.E+06 | 4.E+06 | 5.E+06 |
| Smolt Outmigration | | | | | | | | | | | |
| Fractional Change in Rearing Capacity | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Fractional Change in River Survival | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Smolts Arriving to Delta (Beverton Holt) | 1.51E+05 | 1.01E+05 | 1.99E+05 | 1.51E+05 | 2.76E+05 | 3.87E+05 | 3.39E+05 | 4.78E+05 | 6.11E+05 | 5.70E+05 | 7.12E+05 |
| <i>Delta Survival Rate</i> | 95% | 95% | 95% | 95% | 95% | 95% | 95% | 95% | 95% | 95% | 95% |
| Natural Smolt to Bay | 1.43E+05 | 9.62E+04 | 1.89E+05 | 1.43E+05 | 2.61E+05 | 3.67E+05 | 3.22E+05 | 4.54E+05 | 5.80E+05 | 5.41E+05 | 6.76E+05 |
| Hatchery Smolt | | | | | | | | | | | |
| No. Hatchery Smolts Released | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 |
| Post-Release Survival Rate | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Number of Hatchery Smolt Above RBDD | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 | 150,000 |
| Hatchery Smolt Survival to Delta | 52% | 52% | 52% | 52% | 52% | 52% | 52% | 52% | 52% | 52% | 52% |
| Hatchery Smolt to Bay | 78,000 | 78,000 | 78,000 | 78,000 | 78,000 | 78,000 | 78,000 | 78,000 | 78,000 | 78,000 | 78,000 |

Figure 7. Depiction of “Worksheet” tab, rows 7-40, in IMF (Part 1 of 3).



| | A | B | C | D | E | F | G | H | I | J | K | L |
|----|---|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|
| 42 | Adult | | | | | | | | | | | |
| 43 | | | | | | | | | | | | |
| 44 | <i>Catch Year - Age 2</i> | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 45 | Smolt to Age 2 Survival Rate | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 |
| 46 | <i>Natural Recruits</i> | 5,719 | 3,846 | 7,560 | 5,719 | 10,460 | 14,677 | 12,876 | 18,158 | 23,191 | 21,623 | 27,035 |
| 47 | <i>Hatchery Recruits</i> | 3,120 | 3,120 | 3,120 | 3,120 | 3,120 | 3,120 | 3,120 | 3,120 | 3,120 | 3,120 | 3,120 |
| 48 | Age 2 Ocean Harvest Rate | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 49 | <i>Natural Catch</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | <i>Hatchery Catch</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | Age 2 Overwinter Survival Rate | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 |
| 52 | <i>Natural</i> | 4,575 | 3,077 | 6,048 | 4,575 | 8,368 | 11,742 | 10,301 | 14,527 | 18,553 | 17,298 | 21,628 |
| 53 | <i>Hatchery</i> | 2,496 | 2,496 | 2,496 | 2,496 | 2,496 | 2,496 | 2,496 | 2,496 | 2,496 | 2,496 | 2,496 |
| 54 | Age 2 Natural Ocean Maturity Rate | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 |
| 55 | <i>Natural Maturing</i> | 366 | 246 | 484 | 366 | 669 | 939 | 824 | 1,162 | 1,484 | 1,384 | 1,730 |
| 56 | Age 2 Hatchery Ocean Maturity Rate | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 | 0.080 |
| 57 | <i>Hatchery Maturing</i> | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| 58 | Total Spawner Escapement - Age 2 | 566 | 446 | 684 | 566 | 869 | 1,139 | 1,024 | 1,362 | 1,684 | 1,584 | 1,930 |
| 59 | | | | | | | | | | | | |
| 60 | <i>Catch Year - Age 3</i> | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 61 | <i>Natural Recruits</i> | 4,209 | 2,831 | 5,564 | 4,209 | 7,698 | 10,802 | 9,477 | 13,364 | 17,068 | 15,915 | 19,898 |
| 62 | <i>Hatchery Recruits</i> | 2,296 | 2,296 | 2,296 | 2,296 | 2,296 | 2,296 | 2,296 | 2,296 | 2,296 | 2,296 | 2,296 |
| 63 | Age 3 Ocean Harvest Rate | 0.210 | 0.210 | 0.210 | 0.210 | 0.210 | 0.210 | 0.210 | 0.210 | 0.210 | 0.210 | 0.210 |
| 64 | <i>Natural Catch</i> | 884 | 594 | 1,168 | 884 | 1,617 | 2,269 | 1,990 | 2,807 | 3,584 | 3,342 | 4,178 |
| 65 | <i>Hatchery Catch</i> | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 |
| 66 | Age 3 Overwinter Survival Rate | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 | 0.800 |
| 67 | <i>Natural</i> | 2,660 | 1,789 | 3,517 | 2,660 | 4,865 | 6,827 | 5,989 | 8,446 | 10,787 | 10,058 | 12,575 |
| 68 | <i>Hatchery</i> | 1,451 | 1,451 | 1,451 | 1,451 | 1,451 | 1,451 | 1,451 | 1,451 | 1,451 | 1,451 | 1,451 |
| 69 | Age 3 Natural Ocean Maturity Rate | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 |
| 70 | <i>Natural Maturing</i> | 2,048 | 1,378 | 2,708 | 2,048 | 3,746 | 5,257 | 4,612 | 6,504 | 8,306 | 7,745 | 9,683 |
| 71 | Age 3 Hatchery Ocean Maturity Rate | 0.960 | 0.960 | 0.960 | 0.960 | 0.960 | 0.960 | 0.960 | 0.960 | 0.960 | 0.960 | 0.960 |
| 72 | <i>Hatchery Maturing</i> | 1,393 | 1,393 | 1,393 | 1,393 | 1,393 | 1,393 | 1,393 | 1,393 | 1,393 | 1,393 | 1,393 |
| 73 | Total Spawner Escapement - Age 3 | 3,270 | 2,632 | 3,896 | 3,270 | 4,883 | 6,318 | 5,705 | 7,502 | 9,214 | 8,681 | 10,522 |
| 74 | | | | | | | | | | | | |
| 75 | <i>Catch Year - Age 4</i> | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 76 | <i>Natural Recruits</i> | 612 | 411 | 809 | 612 | 1,119 | 1,570 | 1,378 | 1,943 | 2,481 | 2,313 | 2,892 |

Figure 8. Depiction of “Worksheet” tab, rows 42-73, in IMF (Part 2 of 3).



| | A | B | C | D | E | F | G | H | I | J | K | L |
|-----|---|--------------|--------------|--------------|--------------|--------------|--------------|--------------|---------------|---------------|---------------|---------------|
| 74 | | | | | | | | | | | | |
| 75 | Catch Year - Age 4 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 76 | Natural Recruits | 612 | 411 | 809 | 612 | 1,119 | 1,570 | 1,378 | 1,943 | 2,481 | 2,313 | 2,892 |
| 77 | Hatchery Recruits | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 | 58 |
| 78 | Age 4 Ocean Harvest Rate | 0.660 | 0.660 | 0.660 | 0.660 |
| 79 | Natural Catch | 404 | 272 | 534 | 404 | 739 | 1,036 | 909 | 1,282 | 1,638 | 1,527 | 1,909 |
| 80 | Hatchery Catch | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 38 |
| 81 | Age 4 Overwinter Survival Rate | 0.800 | 0.800 | 0.800 | 0.800 |
| 82 | Natural | 166 | 112 | 220 | 166 | 304 | 427 | 375 | 528 | 675 | 629 | 787 |
| 83 | Hatchery | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| 84 | Age 4 Natural Ocean Maturity Rate | 1.000 | 1.000 | 1.000 | 1.000 |
| 85 | Natural Maturing | 166 | 112 | 220 | 166 | 304 | 427 | 375 | 528 | 675 | 629 | 787 |
| 86 | Age 4 Hatchery Ocean Maturity Rate | 1.000 | 1.000 | 1.000 | 1.000 |
| 87 | Hatchery Maturing | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| 88 | Total Spawner Escapement - Age 4 | 173 | 121 | 224 | 173 | 304 | 421 | 371 | 517 | 656 | 613 | 762 |
| 89 | | | | | | | | | | | | |
| 90 | Freshwater Harvest Rate | 5.00% | 5.00% | 5.00% | 5.00% |
| 91 | Number Harvested (Age 3) | 172 | 139 | 205 | 172 | 257 | 333 | 300 | 395 | 485 | 457 | 554 |
| 92 | Number Harvested (Age 4) | 9 | 6 | 12 | 9 | 16 | 22 | 20 | 27 | 35 | 32 | 40 |
| 93 | | | | | | | | | | | | |
| 94 | Total Catch | | | | 1,666 | 2,172 | 2,122 | 2,807 | 3,876 | 3,869 | 4,651 | 5,899 |
| 95 | | | | | | | | | | | | |
| 96 | Escapement | | | | | | | | | | | |
| 97 | | | | | | | | | | | | |
| 98 | Run Year | | | | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 99 | Jack Escapement | | | | 684 | 566 | 869 | 1,139 | 1,024 | 1,362 | 1,684 | 1,584 |
| 100 | Spawning Escapement | | | | 2,805 | 4,017 | 3,494 | 5,056 | 6,622 | 6,125 | 7,873 | 9,731 |
| 101 | Total Escapement | | | | 3,489 | 4,583 | 4,363 | 6,195 | 7,646 | 7,487 | 9,557 | 11,315 |
| 102 | Adult Recruits/Spawners | | | | 1.84 | 1.68 | 1.86 | 1.78 | 1.74 | 1.85 | 1.80 | 1.77 |
| 103 | | | | | | | | | | | | |
| 104 | Total Run | | | | | | | | | | | |
| 105 | | | | | | | | | | | | |
| 106 | Run Year | | | | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 107 | Total Run Size | | | | 5,155 | 6,755 | 6,485 | 9,002 | 11,522 | 11,357 | 14,207 | 17,214 |
| 108 | | | | | | | | | | | | |

Figure 9. Depiction of “Worksheet” tab, rows 75-107, in IMF (Part 3 of 3).



Benchmark

The optional “Benchmark” tab is formatted similar to the “Worksheet” tab; it serves as a repository of IMF calculations for the current “benchmark” trial in use.

Comparisons

The optional “Comparisons” tab is a summary sheet where the user can compile multiple simulation inputs and outputs. The “Comparisons” tab is linked to the “Trials” tab. The inputs and outputs of any benchmark scenario created in the “Trials” tab is automatically transferred to the “Comparisons” tab and labeled “Benchmark”. Additionally, the inputs and outputs from any scenarios ran in the IMF based on new inputs to the “Home” tab and saved in the “Trials” tab by using the “Save Trial” button will automatically be transferred to the “Comparisons” tab and displayed at the top of the list. The IMF assigns the name “Trial” to each new trial saved, thus, the IMF user is encouraged to assign a meaningful name to each trial after it is saved but before another trial is run to avoid any confusion among trials. Input parameter values from the “Home” tab are saved along with the model output values.

Defaults

Within the “Defaults” tab, any IMF user can restore the default values to the “Home” tab by clicking the “Use Defaults” button. The “Defaults” tab identifies the default input parameters that the model operates with if the user does not supply a new input value on the “Home” tab. This tab is connected to the “Home” tab. This tab is provided so that after a session in which the user has manipulated the input values, the user can instantly restore the default values, without having to re-enter them.

GETTING STARTED

The spreadsheet is deployed with Simulation Parameters entered on the “Home” tab or, in the absence of new inputs, with those recorded on the “Defaults” tab. Until the user modifies input values on the “Home” tab, simulation results displayed there reflect computations performed on the “Worksheet” tab applying default parameter values.

Varying Simulation Parameters

To vary Simulation Parameters, simply enter values directly into cells highlighted in orange on the “Home” tab. As these values are entered, the Simulation Results are immediately updated and displayed on the “Home” tab. At this point, the user is encouraged to simply vary key parameters in a systematic fashion to visualize the sensitivity of the model within an operating range. The user is also cautioned only to simulate values within the realm of possibility.



For example, the Delta survival function was developed with a specific range of data for each parameter as described in detail in Appendix 1 (IMF Technical Memorandum #3); for convenience, data used for the Delta survival function are included in Table 2. If an IMF user inputs values beyond the range of the data or outside the bounds of realism, the Delta survival function may not accurately estimate Delta survival and the resulting predictions of the IMF will be less reliable. This phenomenon may occur at any stage of the IMF where unrealistic values are used as input parameters in the “Home” tab.

Resetting Default Simulation Parameters

To reset Simulation Parameters to the default values, go to the “Defaults” tab and click on the “Use Defaults” command button. This will copy all default parameters to the “Home” tab. Simulation results are then immediately updated to reflect default settings.



Table 2. Values for environmental variables used to predict Delta survival of winter-run Chinook smolts during the first peak (peak flow passage) and second peak (March) in outmigration, 1968-2002. Temperature was assumed to be less than 58°F in all instances. “Peak” and “March” values are 10 and 31-day averages, respectively.

| Run Year | Start 10 days | Peak Flow Passage Conditions | | | | | | | March Conditions | | | | | Total Survival | |
|----------|---------------|------------------------------|---------|-------|----------|-----------|----------|----------|------------------|---------|-------|----------|-----------|----------------|----------|
| | | Frpt. Q | Exports | Gates | Salinity | Turbidity | Survival | Survival | Frpt. Q | Exports | Gates | Salinity | Turbidity | | Survival |
| 1968-69 | 12-Dec | 25,270 | 2,952 | 0.5 | 517 | 8.2 | 0.25 | 0.56 | 49,730 | 3,403 | 0.0 | 235 | 8.2 | 0.79 | 0.68 |
| 1969-70 | 13-Dec | 29,810 | 1,102 | 0.0 | 221 | 8.2 | 0.92 | 0.71 | 44,210 | 2,265 | 0.2 | 158 | 8.2 | 0.76 | 0.74 |
| 1970-71 | 19-Nov | 24,870 | 2,049 | 0.0 | 167 | 8.2 | 0.59 | 0.64 | 30,480 | 4,702 | 0.4 | 187 | 8.2 | 0.59 | 0.62 |
| 1971-72 | 23-Dec | 27,550 | 1,497 | 0.5 | 212 | 8.2 | 0.48 | 0.62 | 23,900 | 6,601 | 0.7 | 172 | 8.2 | 0.42 | 0.52 |
| 1972-73 | 11-Nov | 22,160 | 3,623 | 0.5 | 275 | 8.2 | 0.00 | 0.50 | 51,640 | 1,331 | 0.0 | 243 | 8.2 | 0.83 | 0.66 |
| 1973-74 | 8-Nov | 44,350 | 5,014 | 0.5 | 327 | 8.2 | 0.73 | 0.68 | 64,680 | 6,200 | 0.0 | 140 | 8.2 | 0.80 | 0.74 |
| 1974-75 | 11-Nov | 20,720 | 1,829 | 1.0 | 161 | 8.2 | -0.21 | 0.45 | 50,940 | 6,061 | 0.2 | 172 | 8.2 | 0.73 | 0.59 |
| 1975-76 | 11-Nov | 21,500 | 7,842 | 1.0 | 190 | 8.2 | -0.75 | 0.32 | 14,570 | 8,410 | 1.0 | 2,224 | 8.2 | 0.24 | 0.28 |
| 1976-77 | 1-Jan | 10,625 | 6,568 | 1.0 | 6,830 | 8.2 | -1.10 | 0.25 | 6,573 | 3,724 | 1.0 | 7,281 | 8.2 | 0.20 | 0.22 |
| 1977-78 | 16-Dec | 17,270 | 8,664 | 1.0 | 7,595 | 8.2 | -0.65 | 0.34 | 55,570 | 5,773 | 0.2 | 194 | 8.2 | 0.75 | 0.55 |
| 1978-79 | 11-Jan | 36,320 | 4,236 | 0.2 | 711 | 8.2 | 0.76 | 0.68 | 29,170 | 4,386 | 0.0 | 199 | 8.2 | 0.63 | 0.66 |
| 1979-80 | 24-Dec | 36,870 | 6,430 | 0.2 | 475 | 8.2 | 0.55 | 0.63 | 55,340 | 4,441 | 0.0 | 203 | 8.2 | 0.80 | 0.72 |
| 1980-81 | 4-Dec | 21,600 | 6,647 | 1.0 | 963 | 8.2 | -0.58 | 0.36 | 24,510 | 4,862 | 0.0 | 254 | 8.2 | 0.58 | 0.47 |
| 1981-82 | 12-Nov | 29,246 | 5,064 | 0.3 | 5,414 | 8.2 | 0.64 | 0.66 | 62,810 | 10,410 | 0.0 | 159 | 8.2 | 0.72 | 0.69 |
| 1982-83 | 18-Nov | 41,510 | 5,231 | 0.0 | 127 | 8.2 | 0.92 | 0.71 | 78,290 | 5,429 | 0.0 | 189 | 8.2 | 0.84 | 0.78 |
| 1983-84 | 11-Nov | 52,120 | 925 | 0.3 | 161 | 8.2 | 1.44 | 0.81 | 31,430 | 6,905 | 0.0 | 202 | 8.2 | 0.60 | 0.71 |
| 1984-85 | 8-Nov | 23,580 | 8,186 | 0.6 | 677 | 8.2 | -0.40 | 0.40 | 14,310 | 8,599 | 0.5 | 575 | 8.2 | 0.26 | 0.33 |
| 1985-86 | 24-Nov | 17,400 | 9,460 | 0.7 | 6,445 | 8.2 | -0.61 | 0.35 | 74,980 | 3,219 | 0.0 | 194 | 8.2 | 0.86 | 0.61 |
| 1986-87 | 4-Jan | 15,200 | 6,290 | 0.0 | 1,523 | 8.2 | -0.35 | 0.41 | 21,580 | 5,596 | 0.2 | 418 | 8.2 | 0.49 | 0.45 |
| 1987-88 | 3-Dec | 19,150 | 7,005 | 1.0 | 6,984 | 8.2 | -0.40 | 0.40 | 11,350 | 8,479 | 1.0 | 5,791 | 8.2 | 0.22 | 0.31 |
| 1988-89 | 24-Nov | 17,240 | 8,795 | 0.9 | 4,580 | 8.2 | -0.79 | 0.31 | 43,370 | 10,288 | 0.2 | 1,881 | 8.2 | 0.61 | 0.46 |
| 1989-90 | 21-Oct | 16,960 | 10,643 | 1.0 | 6,089 | 8.2 | -0.96 | 0.28 | 12,870 | 10,611 | 1.0 | 5,279 | 8.2 | 0.21 | 0.24 |
| 1990-91 | none | -- | -- | -- | -- | -- | -- | -- | 25,760 | 9,794 | 0.3 | 2,975 | 8.2 | 0.47 | 0.47 |
| 1991-92 | 6-Jan | 13,346 | 8,611 | 1.0 | 7,205 | 8.2 | -0.99 | 0.27 | 20,340 | 10,490 | 0.0 | 326 | 8.2 | 0.38 | 0.33 |
| 1992-93 | 9-Dec | 20,340 | 2,890 | 0.9 | 5,364 | 8.2 | 0.04 | 0.51 | 49,340 | 6,117 | 0.0 | 268 | 8.2 | 0.74 | 0.63 |
| 1993-94 | 7-Dec | 23,860 | 10,686 | 1.0 | 5,272 | 8.2 | -0.59 | 0.36 | 13,460 | 4,311 | 0.0 | 459 | 8.2 | 0.41 | 0.38 |
| 1994-95 | 4-Dec | 20,660 | 6,132 | 0.5 | 4,782 | 8.2 | -0.05 | 0.49 | 71,920 | 2,956 | 0.0 | 226 | 8.2 | 0.86 | 0.67 |
| 1995-96 | 18-Dec | 31,820 | 4,360 | 0.0 | 148 | 8.2 | 0.67 | 0.66 | 56,240 | 3,677 | 0.0 | 136 | 8.2 | 0.81 | 0.74 |
| 1996-97 | 10-Dec | 69,000 | 8,320 | 0.0 | 131 | 8.2 | 1.25 | 0.78 | 24,470 | 7,132 | 0.0 | 202 | 8.2 | 0.52 | 0.65 |
| 1997-98 | 24-Nov | 22,400 | 10,785 | 0.2 | 5,493 | 8.2 | -0.19 | 0.45 | 63,830 | 2,507 | 0.0 | 262 | 8.2 | 0.85 | 0.65 |
| 1998-99 | 23-Nov | 33,680 | 1,654 | 0.0 | 134 | 8.2 | 1.01 | 0.73 | 56,840 | 7,223 | 0.0 | 167 | 8.2 | 0.75 | 0.74 |
| 1999-00 | 11-Jan | 18,410 | 9,146 | 0.6 | 4,522 | 8.2 | -0.57 | 0.36 | 58,560 | 9,152 | 0.0 | 171 | 8.2 | 0.72 | 0.54 |
| 2000-01 | 9-Jan | 19,190 | 4,496 | 0.6 | 5,658 | 8.2 | 0.01 | 0.50 | 24,700 | 7,932 | 0.0 | 301 | 8.2 | 0.50 | 0.50 |
| 2001-02 | 24-Nov | 19,690 | 5,291 | 0.5 | 5,563 | 8.2 | 0.02 | 0.50 | 21,320 | 8,276 | 0.0 | 317 | 8.2 | 0.45 | 0.48 |
| 2002-03 | 14-Dec | 41,831 | 10,058 | 0.3 | 2,917 | 8.2 | 0.44 | 0.61 | 22,960 | 10,855 | 0.0 | 289 | 8.2 | 0.41 | 0.51 |



COMPARING SCENARIOS

Options on the “Trials” tab provide the user capability to store the results of successive iterations of varying Simulation Parameters in the “Comparisons” tab. These results are stored in a format facilitating further analysis outside of the simulator.

Making a Benchmark

The benchmark is a simulation run that will be used in display graphs for comparison to simulations with new inputs supplied by the model user. By choosing a particular simulation as a benchmark, the user can obtain graphs showing how much the results of new simulation changed compared to the benchmark simulation. Only one benchmark can be defined at a time in the simulator. Once you have arrived at a set of Simulation Parameters that you feel represents a basis for comparison, complete the following steps on the “Trials” tab:

- Click on “Refresh Sheet” to synchronize the “Trials” tab with the “Home” tab,
- Choose an output parameter from the drop down menu to use to compare multiple trials,
- Choose a graphing timeframe from the drop down menu with which to view the output parameter, and
- Click on “Make Benchmark”.

These actions will result in three outcomes. First, graphs on the “Trials” tab are refreshed to reflect “Home” tab input parameters as well as the comparison parameter and graphing timeframe choices. Second, the entire contents of the “Worksheet” tab will be saved to the “Benchmark” tab. Finally, Simulation Parameters and simulation results for the selected output parameter will be saved in the Comparisons sheet and identified as the “Benchmark” trial.

Making Comparisons

There are multiple reasons for making comparisons. Some IMF users may want to evaluate the sensitivity of the model to a set of Simulation Parameters. Others may want to evaluate effectiveness of improvements expressed via the Simulation Parameters. In any case, each successive scenario is compared to the “Benchmark” trial via the following steps:

- Modify Simulation Parameters as needed on the “Home” tab, and
- On the “Trials” tab, click the “Refresh Sheet” button to synchronize the “Trials” tab with the recent inputs on the “Home” tab.

At this point, results for the selected comparison input parameters are displayed on the graphs within the “Trials” tab, comparing the outcome under the current Simulation Parameters with those defined in the Benchmark trial. Endless comparisons



to the Benchmark trial can be performed with this procedure; recall that this procedure only provides a visual comparison of the two trials via the “Trials” tab graph display. If an IMF users desires to save the compared input parameters, the specified outputs (i.e. choices from the “Trials” tab dropdown menu) and the economic comparisons, then you must use the “Save Trial” button on the “Trials” tab and the input parameters, specified outputs, and economic analysis will be saved to the “Comparisons” tab. If multiple trials are being saved for comparison with the specified benchmark, the IMF user is encouraged to name each saved trial in the “Comparisons” tab prior to saving another trial. Because the IMF automatically labels each saved trial as “Trial”, providing trial-specific names for each saved trial will minimize any confusion in future comparisons.

If the reason for making a comparison is based on an economic analysis, the “Trials” tab also supports simple calculations of cost/fish gained as follows:

- Directly enter the “Annual Cost of Improvement” on the “Trials” tab.

This results in calculation of the “Absolute Parameter Change” and the “Percent Parameter Change” at Year 12; these formulas are linked to inputs from the “Worksheet” tab. This is presented as one metric among many that could be considered, thereby demonstrating the ability of the IMF to support this type of analysis. The model itself provides no economic information; it only uses cost values provided by the user.

This overall process of Making and Saving Comparisons can be performed repeatedly up to 100 times. Each time “Save Trial” is clicked, a record representing input parameters and results is compiled in the Comparisons sheet. This format of the Comparisons sheet is such that it facilitates further analysis and reporting of results specific to a certain set of comparisons. It is suggested that these results be copied to another spreadsheet for further analysis. No single express use of this format is intended and it demonstrates the ability of IMF to provide relevant output in a fairly robust manner.

Making a New Set of Comparisons

By clicking the “Clear Benchmark” button on the “Trials” tab, graphs can be reset to show only the current simulation based on the input parameters in the “Home” tab; all information in the “Benchmark” and “Comparisons” worksheets will be cleared. This is provided as a simple utility to reset these sheets in the simulator, if need be. An additional Benchmark trial can be set and a new series of trials can be performed following the instructions detailed above.



PART 4: MODEL STRUCTURE AND SUBSTANTIATION

STRUCTURE OVERVIEW

Model formulation generally accounts for three life cycle components:

- Juvenile production,
- Delta emigration, and
- Ocean and adult life stage.

Whenever possible, existing quantitative routines used by natural resource agencies for managing the winter-run Chinook population were adapted for use in this initial version of the IMF (Figure 10). The functions and supporting evidence for each life step in the model are described below.

Winter Run Model Submodels

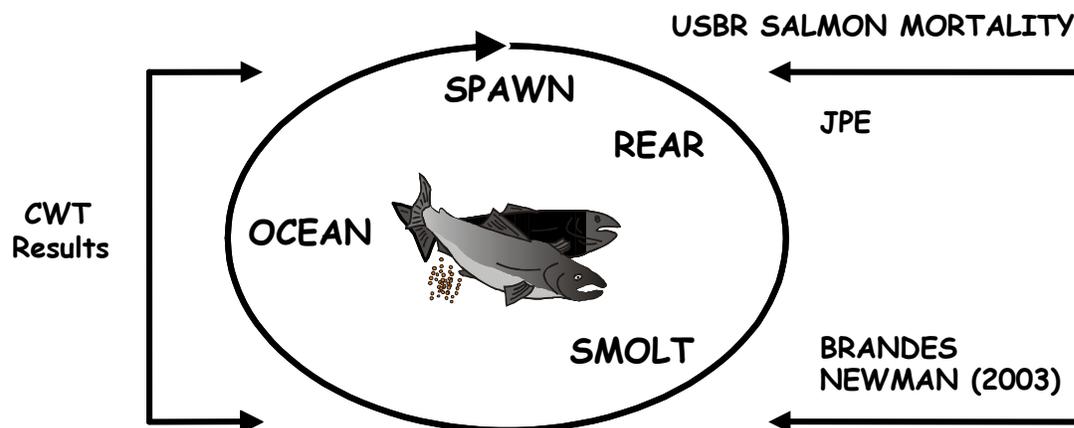


Figure 10. Submodels for winter-run Chinook salmon in the Central Valley from which parameters or functions were adapted for use in the IMF.

JUVENILE PRODUCTION

The life-cycle is initiated with numbers of fry calculated as a function of spawning adults, and simulation of juvenile production then proceeds through three stages:

1. Density-independent production of fry within the spawning area,
2. Density-dependent survival during rearing from fry to smolt, and
3. Environmentally-driven survival of smolts passing through the Delta.

Fry Stage

The prediction of fry production, and the parameter values used, are comparable to those in the JPE used by NOAA Fisheries for Endangered Species Act (ESA) consultations concerning water operations in the Central Valley (Figure 11). The JPE model proceeds as shown in Figure 11 to estimate the number of juveniles passing RBDD (referred to as 'smolts in river' in Figure 11). This is somewhat of a misnomer, as most juveniles are emergent fry when they pass RBDD (Gaines et al. 2002). The number of eggs produced each year within the IMF is calculated for this density-independent pathway as follows:

$$\text{Eggs} = \text{Spawners} \times 65\% \text{ Females} \times 95\% \text{ Pre-Spawn Survival} \times 3,800 \text{ eggs/female}$$

The percent females can be estimated from the sex of adult spawned-out carcasses, excluding grilse. CDFG spawner surveys from 1996 to 2001 showed the female percentage ranged from 72% to 90% and averaged 83% (Snider et al. 2002). However, there is a slight bias in spawned-carcass surveys to be more efficient at recovering females than males (females remain to defend their redd while males wander), and estimates of percent females are often substantially lower in the RBDD ladder counts than among carcass surveys. The bias for determining sex composition from these different sampling methods has not been resolved; 65% females was the value used in the model.

Pre-spawn survival refers to the percentage of adults, after having passed RBDD, that survived to spawn. CDFG estimates of unspawned winter-run Chinook during spawner surveys in the Sacramento River from 1996-2001 ranged from 0-5% (Snider et al. 2002). The 2001-02 JPE assumed 99% pre-spawning survival, based on the CDFG estimated pre-spawning survival for 2001. To be conservative, 95% pre-spawning survival was used in the IMF; this level of survival represents the lowest pre-spawning survival estimated during the 1996-2002 carcass surveys (Snider et al. 2002).

The number of eggs per female spawner varies from year-to-year, based on egg counts from winter Chinook females at the Livingston Stone National Fish Hatchery. Counts reached a high of 4,700 eggs/female in 2001; this fecundity estimate was used in the 2001-02 JPE (Figure 11). Note that the JPE uses different fecundity values each year based on the present year fecundity estimates at the Livingston Stone National Fish Hatchery. In 1999, fecundity estimates at the hatchery were 3,859 eggs/female. To be conservative, a default value of 3,800 eggs/female was used in the IMF; this value represents the lower bound of the range of fecundity estimates at the Livingston Stone National Fish Hatchery. Recall that default values have been provided as a courtesy and that IMF users are encouraged to evaluate the effects of different fecundity values.



Winter-run Chinook JPE

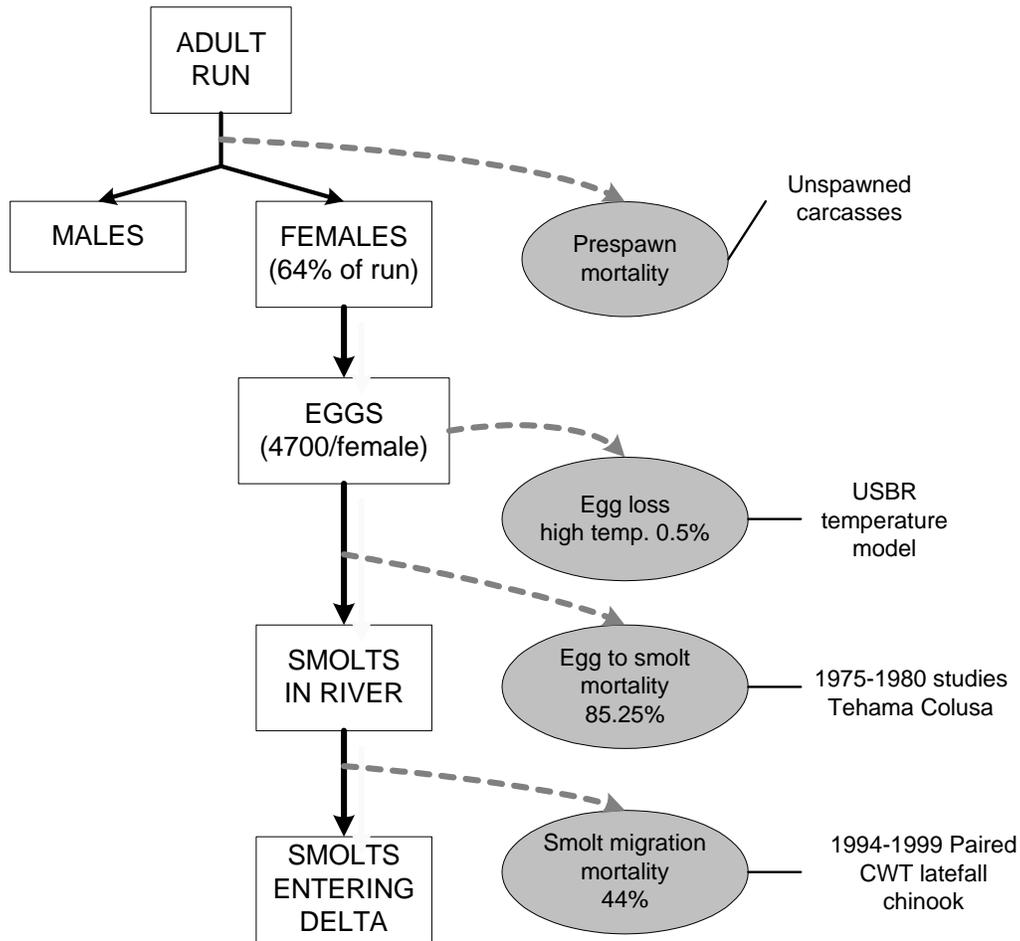


Figure 11. Diagram of the winter-run Chinook JPE model with its values for 2001.

Linearity of Egg-to-Fry Survival

Sampling with rotary screw traps in the tailrace of RBDD has confirmed that actual production of winter-run fry from the upper river is highly and linearly correlated to the number of fry estimated by JPE to be produced in the upper river (Figure 12); the observed fry estimates were developed by Martin et al. (2001). Winter-run juveniles passing RBDD included parr that had grown beyond the fry stage, so Martin et al. (2001) converted these parr to fry equivalents by dividing parr abundance by an assumed 59% survival from fry to parr. Parr represent an intermediate life stage between fry and smolt; within the IMF, this life stage is accounted for in the conversion of fry to smolts in the Beverton-Holt stock recruitment function. The linear relationship of modeled and observed fry production indicates that the assumption of constant survival from egg to juveniles passing RBDD has been reasonable for the run sizes and environmental conditions in recent years.

Egg-to-Fry Survival Values

The relationship shown in Figure 12 also provided an opportunity to estimate egg-to-fry survival from actual field sampling of winter-run Chinook above RBDD. Given the abundance of fry estimated at the screw traps, and the estimate of total eggs deposited, Martin et al. (2001) estimated that egg-to-fry survival ranged from 22% to 41% and averaged 29% during 1996-1999. To be consistent with these field studies and the JPE parameters, 25% egg-to-fry survival was used as the default value in the IMF.

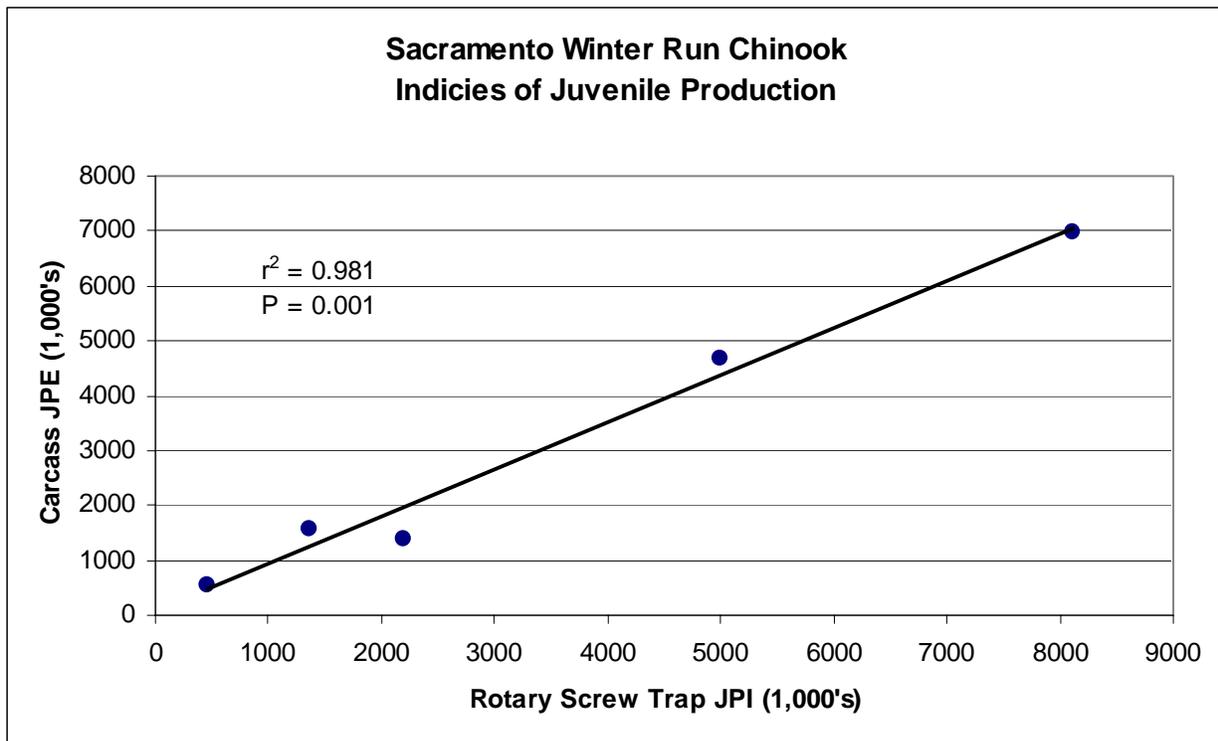


Figure 12. Relationship of JPE predictions of winter-run fry based on carcass survey escapement estimates to the observed abundance of winter-run fry (Juvenile Production Index, JPI) estimated from catches in rotary screw traps at Red Bluff Diversion Dam, 1995-1999 broods (data from Martin et al. 2001).

Temperature Effects on Egg Survival

Although spawner to fry survival has been constant in recent years, there were drought conditions in past years that resulted in lethal temperatures for some eggs, and such conditions may occur again in the future. Newly spawned and incubating winter-run Chinook eggs and fry are the most sensitive life stages to elevated water temperatures (NMFS 1997). Maximum survival of incubating eggs and pre-emergent fry occurs at water temperatures

between 40°F and 56°F, and egg mortality increases rapidly at 57.5°F. At sustained 62°F, egg mortality is 100% (Seymour 1956, Combs and Burrows 1957, and Hinze 1959; as cited in Boles 1988). The initial bypassing of colder water around the generators and subsequent installation of a temperature control device in Shasta Dam in 1997 has proven effective at reducing downstream temperatures. However, modeling by the USBR indicates that in dry and critically dry water years that incubation temperatures will reach lethal levels for eggs in some portions of the upper Sacramento River.

In order to estimate egg mortality because of high temperature in past years, and to prepare the model for handling such circumstances in the future, we developed a simple relationship between river temperature at Balls Ferry, and the proportion of eggs likely to die from thermal stress. The USBR developed a complex heat budget model to predict stream temperatures in the upper Sacramento River, and then used the predicted temperatures to estimate winter-run egg mortality because of lethal temperatures during 1989-1996. Their estimates were reported by NMFS (1997), and we found those estimates were highly correlated to average maximum temperature in August at Balls Ferry ($r^2 = 0.92$; Figure 13). The relationship showed that as average August maximum temperature exceeds 58.3°F, estimated egg mortality began to increase (Figure 13). We used this relationship (i.e. the equation shown in Figure 13) in the IMF to predict egg mortality, because it provided a reasonable predictor of mortality with the use of readily available data on temperature from a single station. Note that, at Balls Ferry temperatures of 62°F, water temperature upstream of Balls Ferry (i.e. where most spawning occurs) is lower. Thus, water temperatures at Balls Ferry need to be greater than 62°F for water temperature upstream to reach 62°F, resulting in egg mortality approaching 100% as indicated by the studies above. The egg mortality equation was developed within the temperature range of about 58-62°F and may not estimate egg mortality accurately using Balls Ferry temperatures outside this range; more data are necessary to confirm this. If detailed water management alternatives are to be evaluated in the future, it will be prudent to actually run temperature models developed by USBR for the upper river, and then to predict egg mortality rates by distinct stream reaches.



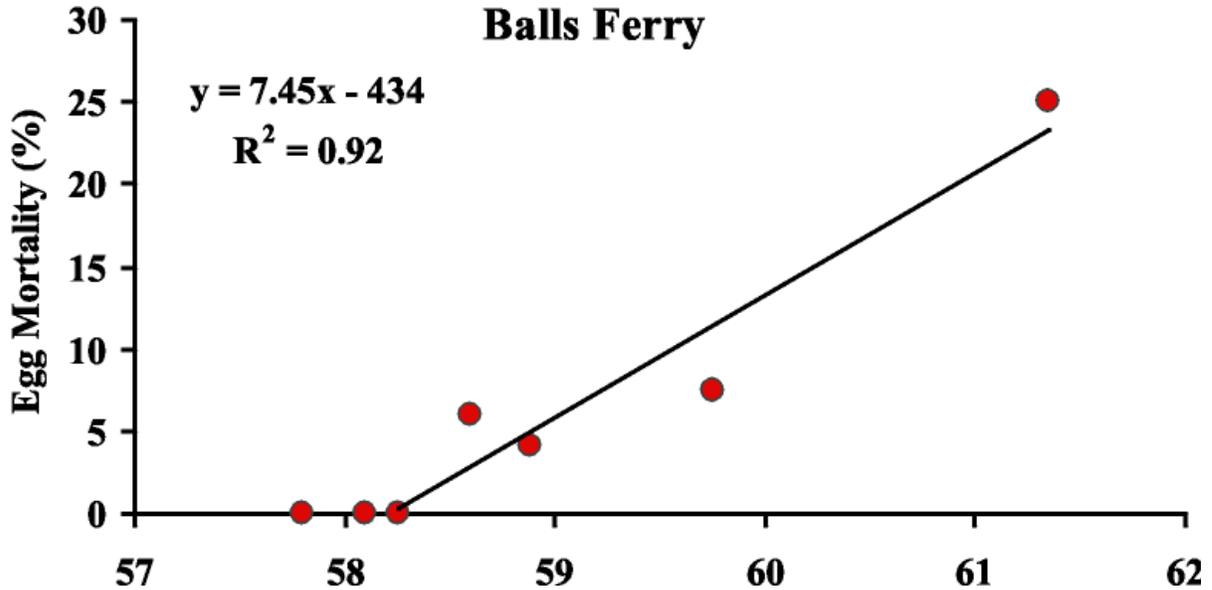


Figure 13. Relationship between August mean maximum daily temperature at Balls Ferry and egg mortality estimates. Egg mortality estimate are from 1989-1994, and 1995-1996 (NMFS 1997). Regression line applies to points of 58.3°F and greater (upper 5 points). Mortality below 58.3°F is 0%.

Fry-to-Smolt Rearing and River Emigration Stage

Our approach to estimating survival from fry-to-smolt is new for this version of the model, as described below. We tested a variety of approaches for modeling survival during rearing and emigration of winter-run juveniles. Sampling stations at successive distances downstream from RBDD often provided conflicting estimates of abundance with one another. The original IMF version (1.0) used a constant survival rate and envisioned accounting for movements of fish between reaches and different durations of residence in those reaches when suitable data became available. These data are not yet available, so a different approach was used in IMF version 1.2. However, the emigration accounting framework will be retained for possible future use if these data become available.

The new approach in Version 1.2 enables parameters to be estimated directly from historical observations of adult winter-run abundance. Studies of salmonid populations across the West Coast have typically found that density-dependent restriction on population growth occurs at the spawner-to-fry stage for populations that spend little time in freshwater, and at the fry-to-smolt stage for fish that spend several months in freshwater. These general findings would lead us to expect that any evidence of density-dependent mechanisms in the winter-run Chinook population would most likely be found during the fry-to-smolt stage. As explained below, by using historical run size estimates, along with data on harvest rates and effects of environmental events, we reconstructed estimates of historical fry and smolt abundances, and derived a reasonable fit to the classic Beverton-Holt curve as shown in Figure 14. This curve was fit by non-linear regression according to methods recommended by Hilborn and Walters

(1992). This relationship takes fry production in the upper river as inputs (note that there are no specific spatial boundaries on fry production as this estimate is based on annual female spawner estimates as described above), and estimates the number of smolts arriving at the Delta.

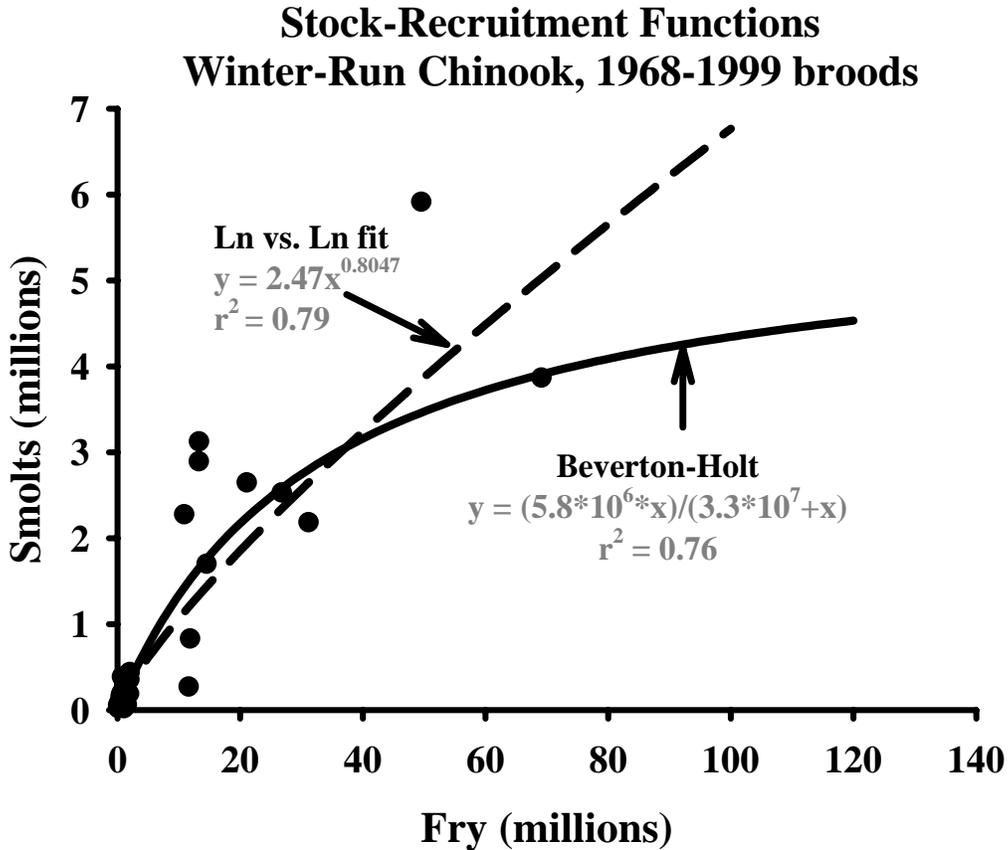


Figure 14. Reconstructed fry and smolt abundances for the 1968-2000 broods fit to a Beverton-Holt curve. A fit to a regression of Ln(smolts) versus Ln(fry) is also shown. The Beverton-Holt curve (solid line) is the relationship used in the IMF.

In order to estimate historical abundance of fry and smolts, we reconstructed their abundance each year from the abundance of spawners and the return of adult progeny 3 years later. The fry produced from each historical run back to 1968, were estimated, starting with total escapement past RBDD, applying the prespawning mortality rate, the percentage females, eggs per female, temperature mortality to eggs, and egg-to-fry survival (see Appendix 2) just as we have described for the model. The number of smolts that survived from those fry would have given rise to the adults that returned from that brood. Therefore, we estimated adult recruits for each brood first by dividing total adults in each run year into groups of age 2, age 3 and age 4 fish. We then assigned those fish to brood year and reconstructed the cohort back to their ocean abundance at the start of age 2, following the same procedure used in cohort analysis of CWT groups (Grover et al. 2004). This cohort reconstruction started with the oldest fish first, and then progressively worked back, subtracting the percentage hatchery fish,

expanding the natural fish for pre-spawning mortality, percentage of the run blocked below RBDD, harvest, and over-winter survival, before adding in the next younger age group and working back through the sequence again. Once the cohort was reconstructed back to age 2, these fish were expanded back to smolts at Chipps Island, assuming a 4% smolt-to-age-2 survival to maintain consistency with the IMF default value (Table 1). Finally, the cohort was expanded to smolts entering the Delta, using the Newman equation (2003) and the default environmental conditions in the Delta to estimate the Delta survival each year (see Appendix 3).

Both curves in Figure 14, each fitted by a separate statistical technique, are consistent with the interpretation that fry-to-smolt survival is density-dependent. If survival were constant across all abundances, then a straight line would provide the best fit to the data. In the $\ln(\text{smolts})$ vs $\ln(\text{fry})$ regression (dashed line), the exponent of X would be 1.0 if survival was the same for all abundance levels. That regression was calculated to determine if the relationship would be significant and have a slope less than 1.0, which it did (0.80). Although the data suggest that survival decreases at higher abundance, there are only two data points at higher abundance, and more data are needed to confidently define the form of the relationship at high abundances. Thus, smolt abundance was recommended as a high priority for future monitoring.

We also found that data on juveniles sampled in the rotary screw traps below RBDD suggest that growth of juveniles is density-dependent. Even with low abundance of spawners in the last decade, the mean length that juveniles achieve by either November 1 or December 1 are significantly and progressively less as juvenile abundance increases (Figure 15). In this regression, we used only the abundance of juveniles passing between October 1 to December 15 for the abundance calculation, because these were the fish that stayed above RBDD long enough to compete for rearing space. Fry passing RBDD before October 1 were still emergent fry (mean length < 35mm), and thus were gone from above RBDD before extended rearing competition began. We also checked differences in emergence timing and stream temperature between years as an explanation of the trends in Figure 15; however, neither emergence timing nor temperature during the growth period were correlated to the observed differences in length between years. In fact, by October, temperatures throughout the Sacramento River drop into the range that is optimal for juvenile Chinook growth, and the river is nearly homo-thermal in December and January (Figure 16).

The Beverton-Holt relationship between smolts and fry (Figure 14) can be converted to an equivalent expression for recruit adults versus parent spawners (Figure 17). This adult-to-adult form of the Beverton-Holt curve represents its most typical application and was derived by converting fry to parents and smolts to recruits using default survival rates in the IMF. The relationship presented in Figure 17 was not used in the IMF, but is presented here to show the two lines of evidence usually examined for evidence of density dependence (survival and growth); both show indications of density dependence. Note that the curve indicates the river could support up to 120,000 spawners before the point where recruitment fails to fully replace the number of parent spawners (i.e. less than 1 recruit per spawner based on the intercept with the 1:1 replacement line).



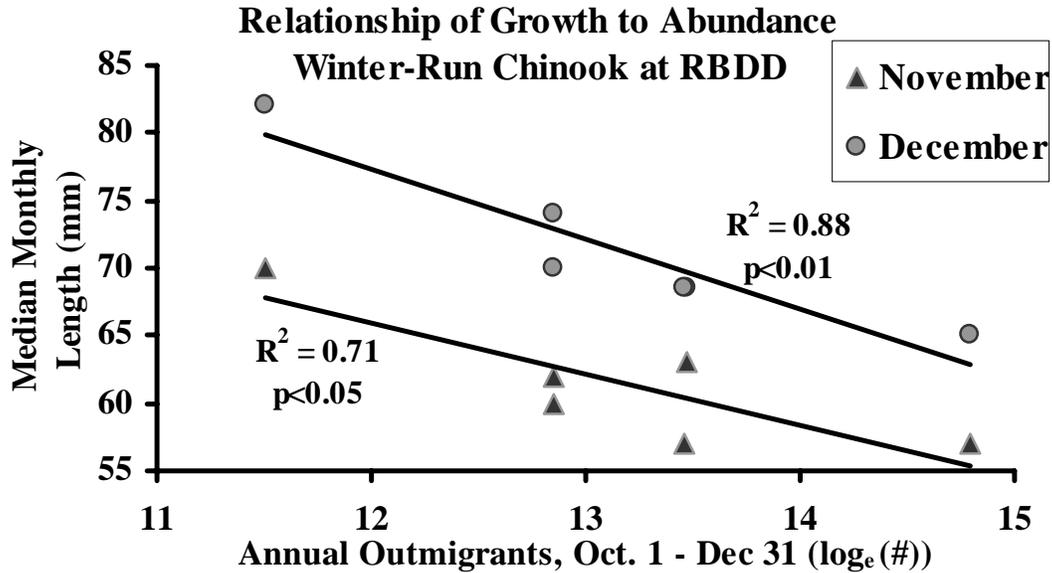


Figure 15. Mean length of winter-run Chinook juveniles at RBDD on November 1 and December 1 each year regressed on abundance of juveniles passing RBDD during October 1 to December 15, 1995-1999, and 2002. Decreasing slope suggests growth is density-dependent. This relationship in not used in version 1.2 of the IMF.

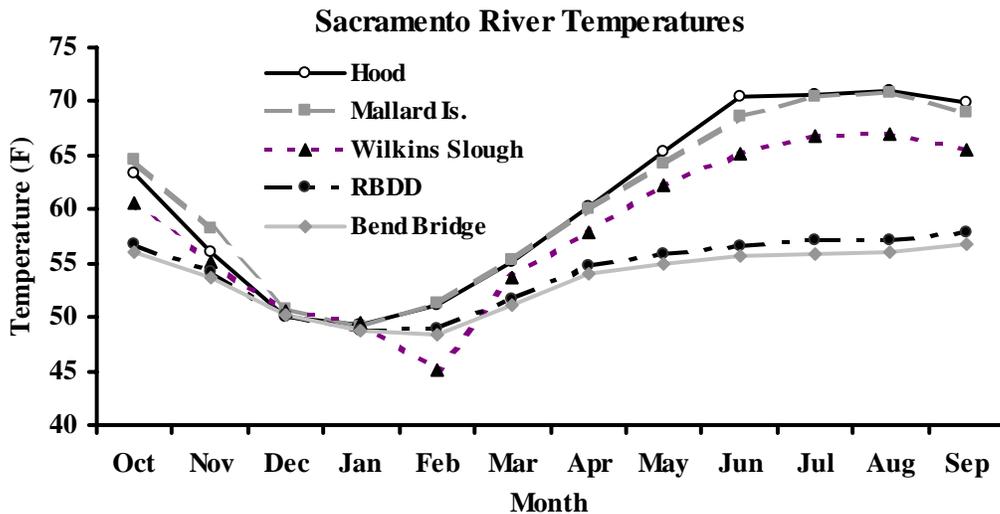


Figure 16. Annual temperature regime at various locations in the Sacramento River. Note that temperatures throughout the river are near the optimum range for juvenile salmonid rearing (50-60F) during November through March.

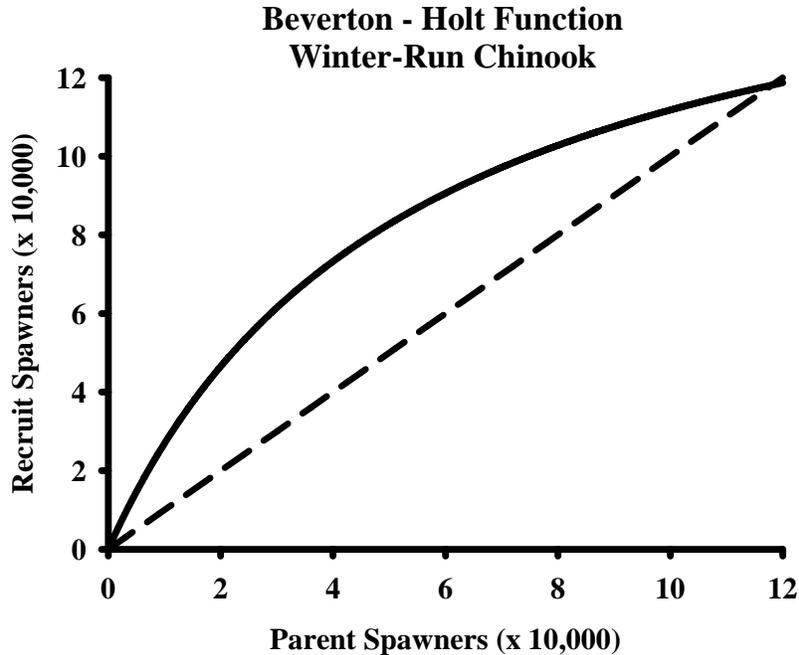


Figure 17. Stock-recruitment relationship for winter-run Chinook in the Sacramento Basin estimated for the 1968-2000 broods (derived from Figure 14). Only the Beverton-Holt fry to smolt relationship (Figure 14) is used in the IMF.

Water Diversion Effects

Field data clearly demonstrate that most juveniles move below RBDD as emergent fry and then move gradually downstream as they rear (Figure 18). Most winter-run Chinook leave RBDD as fry under 40mm in length and arrive in the Delta around March averaging about 120mm (Figure 18). Although, we considered adding functions to predict losses of juvenile Chinook passing irrigation diversions, the pattern of passage times indicates that winter run juveniles pass most sections of the river at times when water diversions are low or off (Figure 18). Anderson-Cottonwood Irrigation District (ACID), RBDD, and Glenn-Colusa Irrigation District (GCID) diversion facilities are within the area where fry are found and their operations overlap with early portions of fry presence. However, RBDD was screened and GCID was operating with outdated screens but at generally less than one third of their design flow during the times winter-run fry were present. Until 2001, when a new fish ladder was installed at ACID Dam, few fish spawned above that point. Thus, impacts of these diversions to juvenile winter-run Chinook would likely have been small. By the time winter-run juveniles reached the middle Sacramento River, most irrigation withdrawals were done for the season, as shown with arrival timing near Knights Landing (Figure 19). Although some winter-run juveniles were and are impacted by these diversions, the main effects of these diversions would be on other races of Chinook that are typically more abundant at diversions during periods of greater irrigation withdrawals. These comments provide an explanation of why we did not include steps in the winter-run IMF model to handle irrigation diversions, which would have little effect on simulation outcomes.

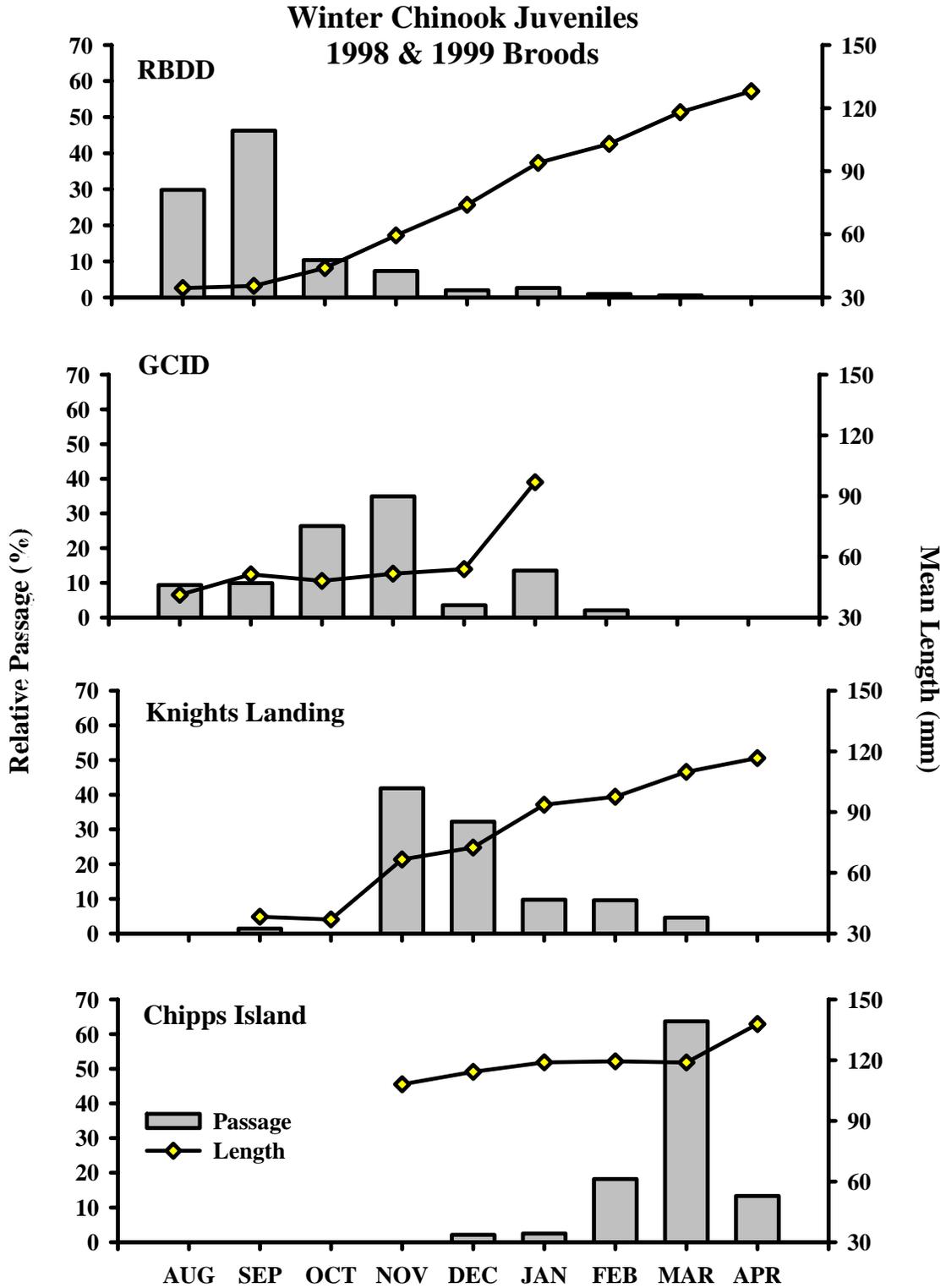


Figure 18. Relative passage, mean length, and timing of juvenile winter-run Chinook passing four sampling stations in the Sacramento River. Migration is progressively later and fish are progressively larger with distance downstream (data from Erin Chappel, DWR, Sacramento).

Monthly Flow Diversion at Wilkins Slough Reclamation District 108, 1987-91

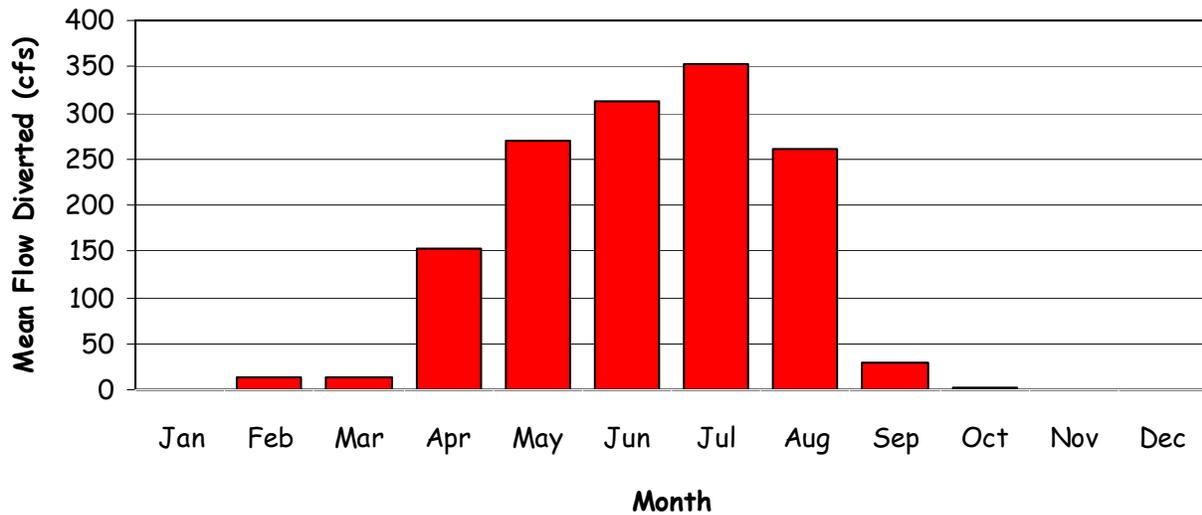


Figure 19. Temporal pattern of water diversions for irrigation in the mid Sacramento River, as exemplified by the diversion of Reclamation District 108 at Wilkins Slough, 1987-1991. Wilkins Slough is near Knights Landing.

Hatchery Fish

The IMF allows for inputs of the number of hatchery smolts to be stocked, and then mortality rates that account for both immediate and long-term loss that differs from the mortality rate assigned to natural fish. Hatchery fish are assumed to be stocked in the upper river at a time and size typical for smolting. Connected with that assumption, we also assume hatchery fish migrate directly to sea following release, and to not compete with natural fish for rearing space. Hatchery fish experience a 25% post-release mortality as a result of naïve behavior. Hatchery fish survival to the Delta is assigned as a constant of 52%, which is the average determined from six release groups of CWT-marked juvenile Chinook released in the late fall in Battle Creek (Table 3). The survival of those CWT releases is also used as the basis for assigning a river emigration survival of 52% in the JPE. Once hatchery smolts reach the Delta, they are subject to the same Delta survival function as natural fish.

Table 3. Survival from Battle Creek to the Delta (various locations) estimated from paired CWT releases of late-fall run Chinook. Survival is assumed equivalent to the differential in ocean recovery rates reported here.

| Year | Reach | Differential Ocean Recoveries |
|------|--------------------------|-------------------------------|
| 1994 | Battle Cr to Ryde | 0.37 |
| 1995 | Battle Cr to Ryde | 0.43 |
| 1996 | Battle Cr to Courtland | 0.48 |
| 1997 | Battle Cr to Miller Park | 0.44 |
| 1998 | Battle Cr to Ryde | 0.76 |
| 1999 | Battle Cr to Ryde | 0.63 |
| | Average = | 0.52 |

DELTA EMIGRATION

There has been much analysis of factors influencing survival of juvenile fall-run Chinook passing through the Delta, but little on juvenile winter-run Chinook that pass in a different season and at a larger size. Accordingly, we derived our approach from studies with juvenile fall-run Chinook, and assumed they were applicable to winter-run Chinook. A Delta survival function based on the work of Newman (1997, 2000, and 2003) was applied to the number of smolts that successfully reached the Delta (approximately near Courtland). Newman (2003) estimated coefficients for a number of factors that might affect smolt survival; we used those factors pertinent to our analysis that had statistically significant effects on survival, including river inflow, river temperature, export flow, DCC gate position, turbidity, and salinity (Table 4). The data used to derive this equation was previously provided in Table 2.

The equation used to estimate survival through the Delta, based on coefficients estimated by Newman (2003) is as follows:

$$\text{Survival} = 0.65 + 0.86 \cdot \log_e(\text{Flow}) - 0.81 \cdot \text{River Temp.} - 0.32 \cdot \text{Exports} + 0.37 \cdot \text{Turbidity} + 0.35 \cdot \text{Salinity} - 0.75 \cdot \text{Gate Position}$$

Where:

- Flow = Mean flow in cubic feet per second at Freeport.
- River Temp. = Mean temperature in Fahrenheit at Freeport.
- Export flow = Combined export flow to the State and Federal pumps.
- Turbidity = Turbidity of river in formazine turbidity units near Courtland.
- Salinity = Water salinity measured by conductivity, $\mu\text{mho/cm}$ at Collinsville (in the absence of actual salinity data, salinity was calculated based on a relationship with flow as described below).
- Gate Position = Average of daily positions of the Delta cross channel gates where each day a value of 0 or 1 signaled both gates closed or open, respectively.
- Survival = Logistic transform of proportion surviving to the bay.



Newman (2003) standardized all variables except the DCC position indicator using the following equation:

$$\text{Standardized Value} = (\text{Observation} - \text{Mean}) / \text{Standard Deviation}$$

Thus, we had to supply the means and standard deviations for each independent variable to apply the equation, so that environmental measurements could be converted to the appropriate units of measure for use in the model equations.

Table 4. Coefficients for environment variables used to estimate winter-run Chinook Delta survival. The relationship presented is the hierarchical formulation in Table 3 of Newman (2003). These coefficients estimate the logistic transform of survival. Coefficients of all variables except the gate indicator are for standardized variables.

| Covariate | β | SE |
|-------------------------|---------|------|
| Intercept | 0.65 | 0.10 |
| \log_e (River Flow) | 0.86 | 0.12 |
| River Temperature °F | -0.81 | 0.09 |
| Export Flow | -0.32 | 0.09 |
| Turbidity | 0.37 | 0.13 |
| Salinity | 0.35 | 0.09 |
| Gate Position Indicator | -0.75 | 0.15 |

The equation we used includes salinity, which Newman (2003) reported was highly correlated to flow ($r = -0.79$). Although the two variables are negatively correlated, they both have a positive effect on survival (i.e. coefficients are positive). The combination of these effects results in a non-linear relationship between predicted survival and flow, because increasing flow reduces salinity, which decreases the benefit of flow on survival. We determined the relationship between salinity and flow by regressing salinity at Collinsville since 2000 on Sacramento River flow at Freeport. The data set was limited to observations taken between December and March, because this is the primary time period when winter Chinook pass through the Delta. There was a strong negative exponential decline in salinity as flow increased ($p < 0.0001$) (Figure 20). This relationship is incorporated into the IMF so that simulations including different flows will account for changes that flow causes in salinity.

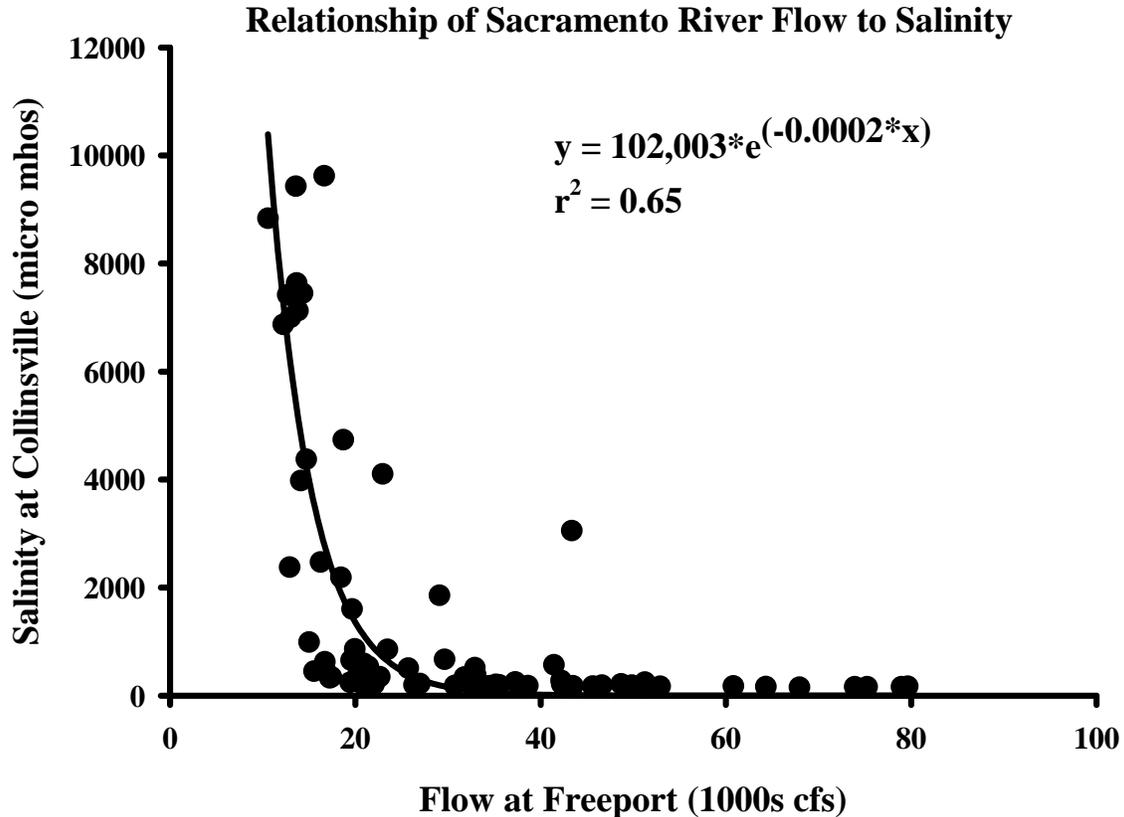


Figure 20. Relationship between Sacramento River flow and salinity in the Delta.

The predicted effects on Delta survival for several key factors across a range of their observed values are shown in Figure 21. In order to show the effect of one factor, other factors in the Newman equation were held constant near their mean value under winter conditions. When we varied flow in this analysis, we concurrently changed salinity according to the equation presented in Figure 20. The effect of temperature is not shown, because all temperatures in Newman's (2003) data set exceeded the range of temperatures that juvenile winter-run Chinook will encounter when passing through the Delta in December through March.

The lowest temperature in the dataset of Newman was 58°F, while the highest in the historical dataset for winter-run Chinook smolts was 59°F. There is little reason to expect that survival would continue to increase as temperature declined below 58°F, given that this temperature is within the optimum range for growth. Therefore, we assumed there was no further benefit to smolt survival as temperature dropped below 58°F (i.e. we assumed the temperature effect was the same as that at 58°F). In the data set used by Newman for fall Chinook survival through the Delta, high temperatures had the largest impact of all environmental variables. Because temperatures are much cooler during the period when winter-run juveniles emigrate, the predicted survival for winter-run (average 95%) is generally in the high range of survivals observed for fall-run smolts (Figure 22). Although the estimate of 95% survival is high, it is not unreasonable, given the most frequent survival observed from paired CWT tests with fall-run Chinook was 100% (Figure 22).

An interesting pattern of survival was related to the combination of flow and salinity. As flow increases from a minimum of 6,000 cfs to 15,000 cfs, survival decreases. Though flow has a positive effect on survival, increasing flow results in a decrease in salinity, which as a negative effect on survival. The benefits of increased flow begin to outweigh the cost of lower salinity at about 15,000 cfs, for which survival is at its predicted lowest of 80% (Figure 21). Predicted survival of smolts through the Delta rises to about 97% at 50,000 cfs, when all other factors are held constant at their mean.

The relationships of the exports, turbidity, and gate openings to survival are each nearly linear in the Newman equation (Figure 21). The range of export rates is predicted to result in survival of 85% at 9,000 cfs up to 95% at 2,000 cfs. The range of turbidity values produces a range in predicted survivals from 85% to 100%. The predicted survival with the DCC gates open was 83% and increased to 92% with the gates closed.



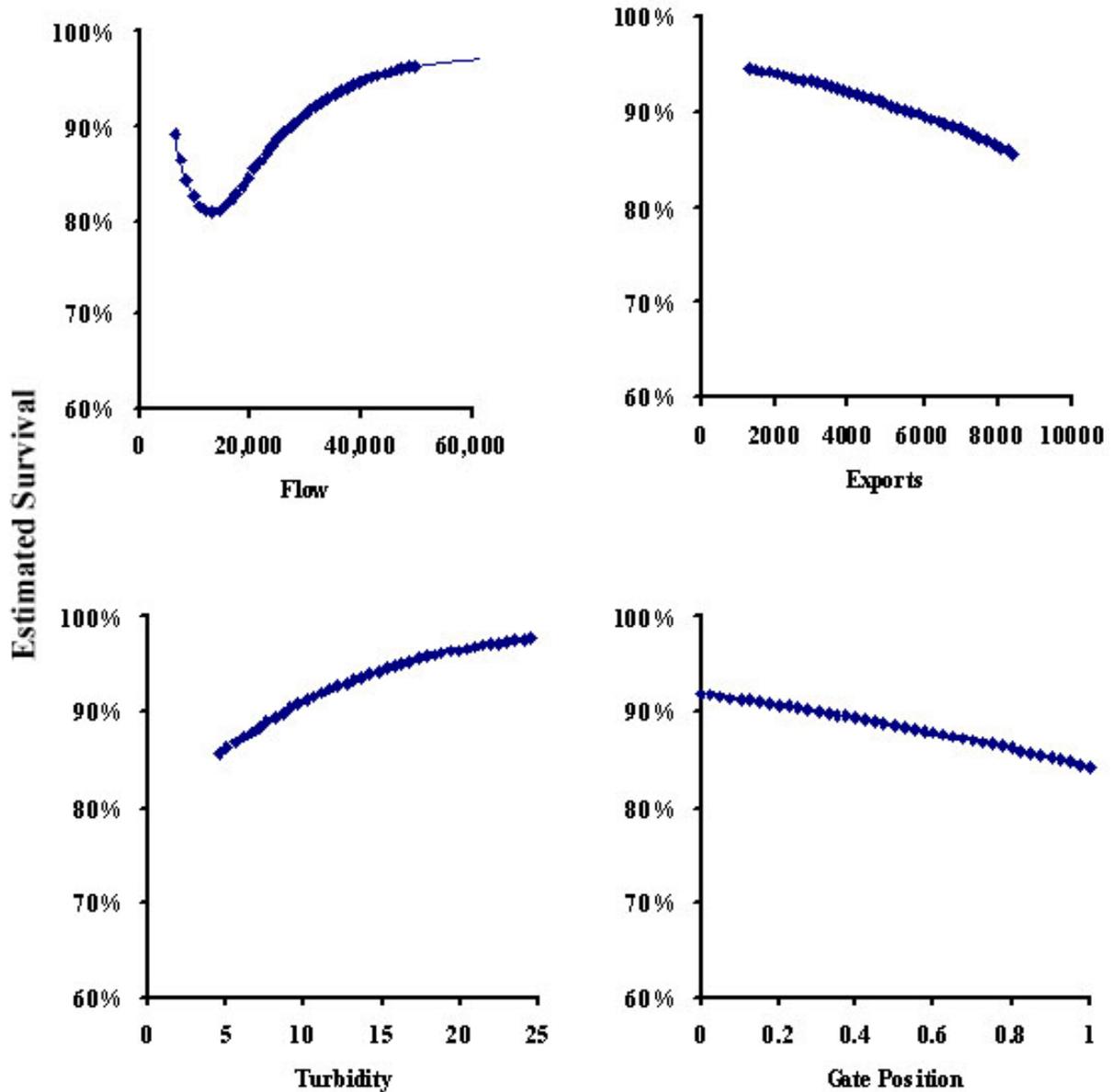


Figure 21. Change in winter-run Chinook salmon Delta survival predicted by the adapted Newman function used in the IMF. One variable was varied while others were held at their mean value observed during paired releases of CWTs analyzed by Newman (2003). The effect of flow includes a link of flow to salinity according to the equation in Figure 20. Values that each factor was held at while the one plotted was varied were: flow = 37,000; exports = 7,200; turbidity = 8 NTU; Gate position = closed.

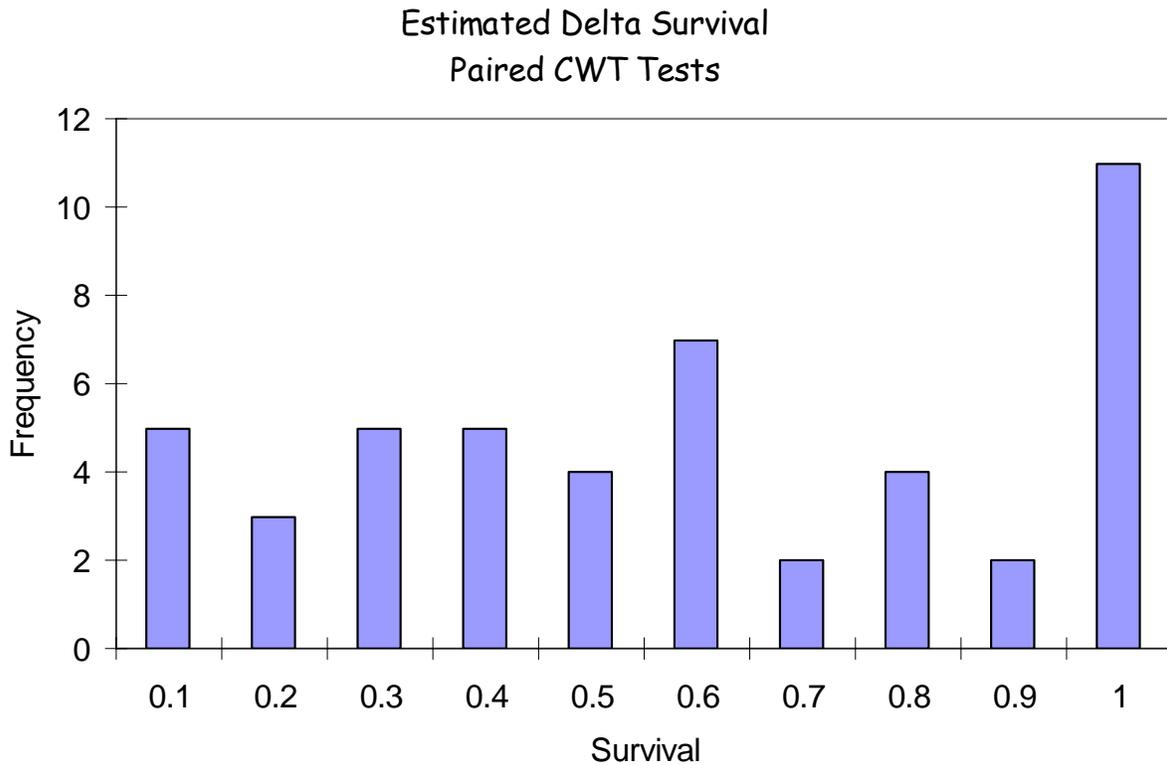


Figure 22. Frequency distribution of survival rates through the Delta estimated by Newman (2003) from paired CWT releases of fall-run Chinook. These are the survival rates which Newman (2003) then used in his analysis to determine environmental factors influencing survival rates through the Delta.

Environmental conditions during emigration of winter-run Chinook generally differ from those during emigration of fall-run Chinook that was analyzed by Newman (2003). The Sacramento River flow at Freeport ranged from 6,085 to 50,800 cfs during the CWT experiments analyzed by Newman (2003). Few of the fall Chinook CWT groups were released at flows greater than 35,000 cfs (Figure 23), while about one third flows during winter-run smolt passage since 1968 were greater than 35,000 cfs (Figure 23). Water temperatures during the paired CWT releases analyzed by Newman (2003) ranged from 58°F to 76°F, while water temperatures during winter-run emigration (November through March) were nearly always <58°F. Delta exports during emigration of CWT groups evaluated by Newman (2003) ranged from 1,289 to 6,821 cubic feet per second (cfs), and were generally in the same range during juvenile winter-run passage (Figure 23). Salinity during emigration of CWT groups evaluated by Newman (2003) ranged from 160-12,873 μ mhos, and was most often less than 1,000 μ mhos. The same held true for historical values during outmigration of winter-run Chinook smolts.

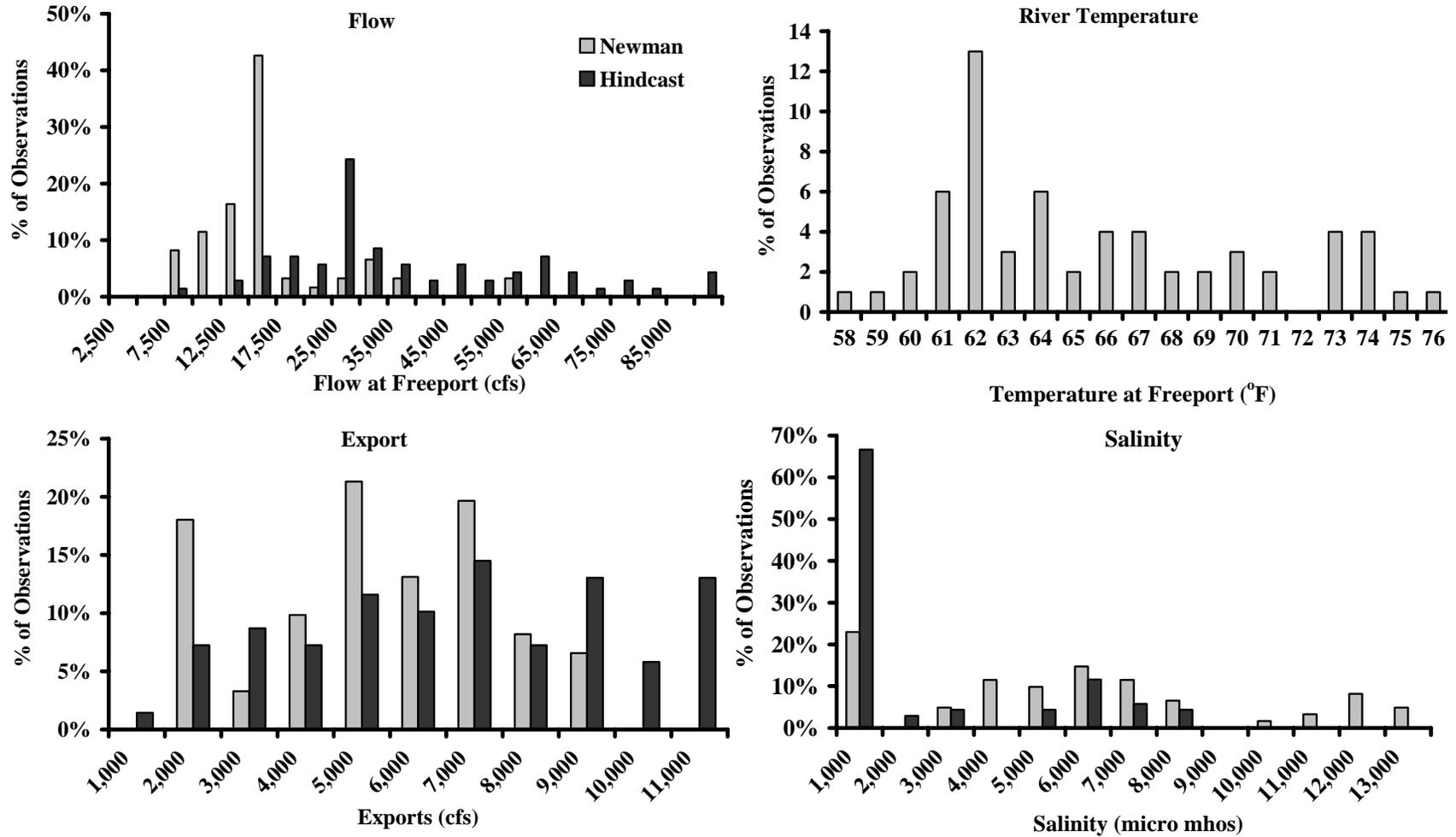


Figure 23. Frequency distributions of Sacramento River environmental values during the CWT releases analyzed by Newman (2003) compared to those observed during the period of winter-run outmigration, 1968-2001.

Estimation of Delta Survival Based on Chipps Island Trawl

Annual smolt production is the ultimate expression of freshwater production as all freshwater conditions culminate in the smolt abundance. Additionally, smolt abundance estimated in the model has a substantial effect on simulation results, so there is an urgent need for accurate data on winter-run smolt abundance to verify or correct the model. If smolt abundance could be estimated accurately, then we could verify both the fry-to-smolt function and the Delta survival predictions.

Trawl samples at Chipps Island have been used to estimate annual abundance of winter-run smolts, but the difficulty in distinguishing races of Chinook in the catch has evidently introduced large errors into those estimates. Variation between years in the estimated winter-run smolt abundance passing Chipps Island, did not fluctuate in a similar pattern to either the abundance of juveniles at RBDD, or the adult returns from those smolts Table 5. We have previously established that spawner escapement is highly correlated with juvenile passage at RBDD (Figure 12; Martin et al. 2001), so estimates of smolt abundance from the Chipps Trawl appear to be unreliable.

Table 5. Estimates of winter-run Chinook abundance as fry passing RBDD, smolts passing Chipps Island, and age 3 recruits in the ocean. Data for fry from Martin et al. (2001); for smolts at Chipps Island from, personal communication with R. Burmester (method 1, USFWS , Stockton), and for age 3 recruits from the run reconstruction described in this report.

| Brood Year | RBDD fry passage | Chipps Trawl | Age 3 Recruits |
|-------------------|-------------------------|---------------------|-----------------------|
| 1993 | | 201,613 | 934 |
| 1994 | | 640,174 | 1,267 |
| 1995 | 1,816,984 | 470,228 | 3,430 |
| 1996 | 469,183 | 306,391 | 3,876 |
| 1997 | 2,205,163 | 190,136 | 3,374 |
| 1998 | 5,000,416 | 262,137 | 9,940 |
| 1999 | 1,366,161 | 276,343 | 8,838 |
| 2000 | | N.A. | N.A. |
| 2001 | | 148,691 | N.A. |

We deduce the problem likely arises from misclassification of race for Chinook captured in the trawl, rather than from errors in expansion of the catch. Expanded catches of CWT-marked Chinook in the Chipps Trawl have been highly correlated with recoveries of the CWT groups in ocean fisheries, which indicates that expanded catches are good indicators of smolt abundance. On the other hand, fish length has been used to distinguish race of Chinook in the Chipps Trawl, and several studies have shown that length is not a reliable discriminator for winter-run Chinook in the Delta where several races of Chinook are mixed, winter-run being the least abundant.

OCEAN AND ADULT LIFE STAGE**Smolt-to-Age 2 Survival**

Total number of smolts reaching the ocean and surviving to age 2 is scaled by the smolt-to-age-2 survival rate, for which we set the default value at 4%. Recent smolt-to-age-2 survivals estimated by cohort analysis of CWT recoveries were in this range for Coleman Hatchery fall Chinook (Cramer and Chapman 2002). It is important to realize that this rate is applied to smolts after they have passed through the river and Delta. Thus, the numbers of hatchery fish released would already have diminished considerably before the smolt-to-age-2 survival rate is applied, because of immediate mortality at release, mortality migrating through the river to the Delta, and mortality through the Delta. On average, these additional mortalities applied in the IMF would result in an overall survival of hatchery fish from release to age 2 of 1.6%.

Harvest Rates

Ocean harvest rates are the percentage of the population at each age harvested in the ocean; these rates are used in the model to account for fish removed by the commercial troll and recreational fisheries. Not all winter Chinook in the ocean are susceptible to harvest. Younger and smaller fish are less likely to be harvested than older and larger fish, because (1) the large lures used are more attractive to larger fish, and (2) fish cannot be retained until they are a minimum size (currently 20 inches in the sport fishery and 26 inches in the commercial fishery; PFMC 2004).

Winter Chinook enter the ocean on about their first birthday, which begins their second year of life. In that first summer in the ocean, they are too small to be subject to harvest (age 2 harvest = 0). In their second ocean summer (third year of life), winter Chinook begin to reach the size where they can be legally harvested, and thus a certain portion of the run is harvested. Fish harvested in that second ocean summer are used to calculate age 3 harvest rates. Some fish spend an additional winter in the ocean and are subject to one more season of marine harvest as “four year olds.” Because age 4 fish all exceed minimum lengths for retention by fisherman, they are more susceptible to harvest. All the remaining age 4 fish that were not harvested return to freshwater to spawn (Figure 24).

Harvest rates are typically estimated from recovery rates of coded-wire tags (CWT), but tag recoveries have only been sufficient from winter-run Chinook to estimate harvest rates from the 1969-71 broods and the 1998-2000 broods. PFMC has reported results of a winter-run Chinook cohort analysis for brood years 1998-2000 (Grover et al. 2004), and we incorporated the average values from that analysis for age-specific average harvest rates (Table 6) as defaults in the IMF.



Sacramento Winter-Run Chinook Salmon Life Stage Sequence

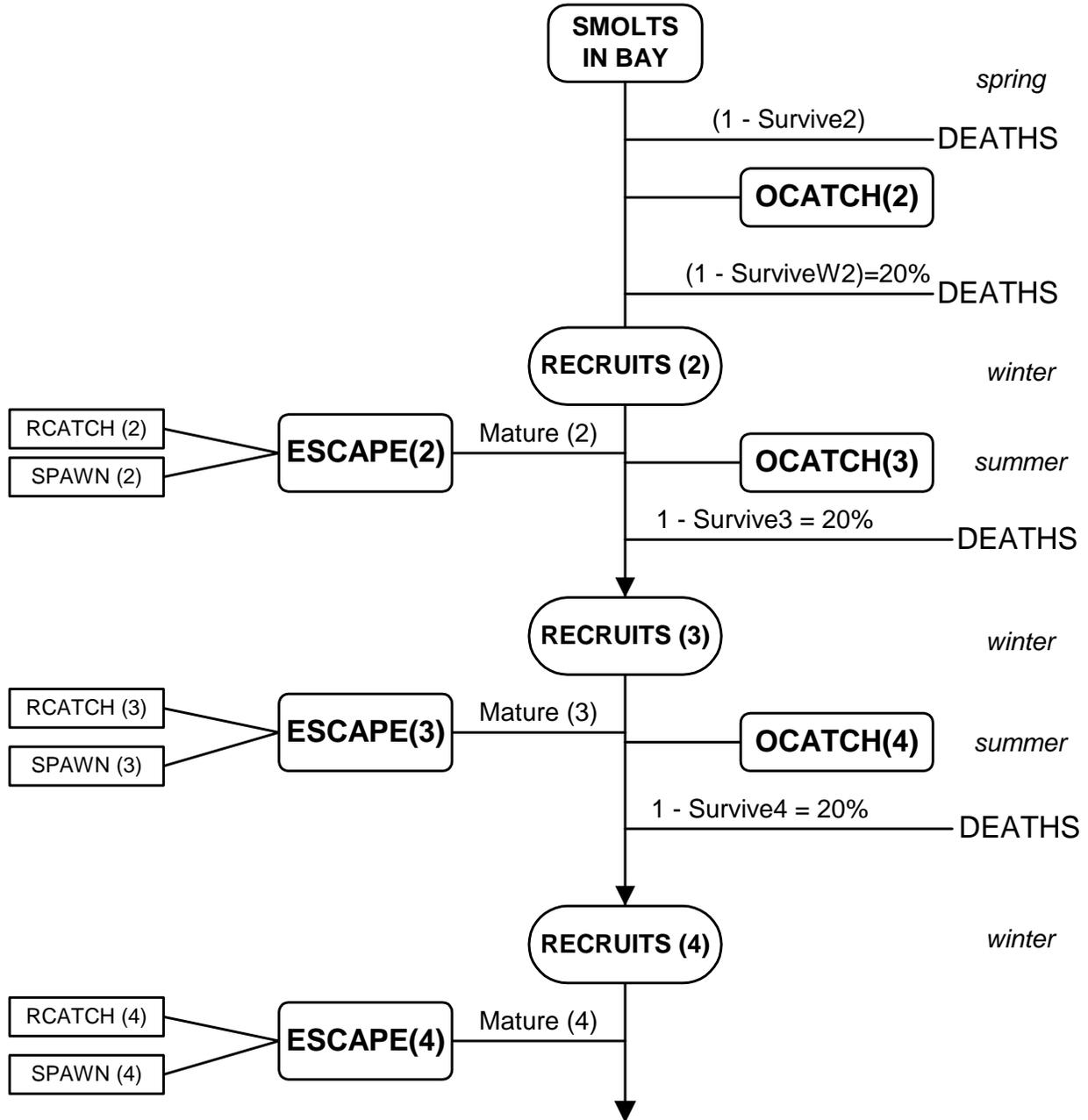


Figure 24. Maturity, harvest, and spawning events in the life of winter-run Chinook salmon.

Fraction Maturing at Each Age

Because the age composition of winter-run hatchery fish differed slightly from natural fish, the IMF uses separate maturity rates for hatchery and natural fish. We applied the maturity rates in Table 6 estimated by Grover et al. (2004) to hatchery fish. The maturity rates for naturally-produced fish were derived from the age composition of naturally-produced winter-run Chinook spawning in 2001, as determined from scales. The 2001 data represent the only recent data available on age composition of natural spawners. The age composition was used to reconstruct the cohort and estimate the proportion of fish alive in the ocean at each age that returned to spawn at that age (this proportion is the age-specific maturity rate, in other words, an ocean exit rate). Procedures similar to those of Grover et al. (2004) were used to reconstruct the naturally-produced cohort. The average harvest fractions at each age were assumed the same as those estimated by Grover et al. (2004). The calculated maturity rate at age 3 was lower for natural fish (Table 7) than for hatchery fish. This is a common difference when comparing hatchery and wild populations, because accelerated growth of juvenile hatchery fish often causes many fish to mature at a younger age, than under natural conditions. A cohort reconstruction from the marking studies with natural winter-run Chinook from the 1969-70 broods, also estimated that 70% of natural fish matured at age 3 (Barroco et al. 1989). Thus, the IMF uses maturity rates at age 3 of 70% for natural fish and 96% for hatchery fish.

Table 6. Age specific harvest and maturity rates for winter-run Chinook, as estimated by cohort analysis of CWT groups. From Grover et al. (2004).

| Brood Year | Age Class | 1998 | 1999 | 2000 ¹ |
|-----------------|-----------|------|------|-------------------|
| Maturation Rate | 2 | 0.01 | 0.17 | 0.06 |
| | 3 | 0.96 | 0.96 | 0.97 |
| | 4 | 1.00 | 1.00 | 1.00 |
| Harvest Rate | 2 | 0.00 | 0.00 | 0.00 |
| | 3 | 0.23 | 0.20 | 0.21 |
| | 4 | 0.57 | 0.74 | NA |

¹ Estimates for the 2000 brood were preliminary or not available because the brood escapement was not complete.

Table 7. Age composition determined from spawned carcasses of winter-run Chinook in the in 2001, and the fraction of fish estimated to have returned to spawned, based on cohort analysis with the data on age composition. See text for explanation. Data on age composition are preliminary (personal communication, R. Titus, CDFG Sacramento).

| Age Class | Composition Among Carcasses | Estimated Percentage Maturing at age |
|-----------|-----------------------------|--------------------------------------|
| 2 | 13.1% | 8% |
| 3 | 82.8% | 77% |
| 4 | 4.1% | 100% |



ADULTS IN FRESHWATER

Although freshwater harvest of winter-run Chinook is currently prohibited through time and area closures, the NOAA Fisheries Biological Review Team (2003) reported that winter-run Chinook harvest can occur prior to the closures. For example, based on CWT analysis, inriver harvest in 2001 may have been as high as 24%. A 5% freshwater harvest mortality was incorporated into the IMF, based on estimates of historical freshwater harvest rates (10%) and recent changes in the time period of harvest closure (i.e. now beginning January 1st). This harvest mortality is applied to fish returning at age 3 and age 4 before they are also assigned another 5% mortality while holding in the river prior to spawning. The numbers of fish that survive freshwater harvest and prespawning mortality then become spawners in the IMF to begin the next life cycle.

PART 5: ASSESSMENT OF INFORMATION AND PRIORITIES

The model in its present form represents a collection of working hypotheses that need to be tested against additional data. From the inception of this project, we have envisioned that the model is a continuing work-in-progress to be systematically reviewed and updated as new information becomes available. In the process of assembling substantiating evidence with which to build the model, we have identified what we can determine with the most confidence and what remains most uncertain in our understanding of winter-run population biology.

As a basis for establishing priorities for information needs, we have scored the functions and parameter values in the model for three criteria: (1) quality of substantiating evidence, including the adequacy of sample sizes within or between years, (2) impact of the function or parameter on simulation outcomes, and (3) ability of managers to influence the parameter. The highest priority for action goes toward those parameters that have high or moderate impact on simulation outcomes, and have a high or moderate chance of responding to management action. The lowest priority for action goes to those factors that have low impact on simulation outcomes and have low chance of responding to management actions. Variables with low data quality, particularly those that have high impact on simulation outcomes, should receive priority for study.

These clarifications of what we know and do not know have led to a better understanding of two types of action that managers might consider: (1) studies to gain understanding; and (2) monitoring to track restoration, regulation, or progress. We also assigned qualitative scores for these types of action, based on the previous scores of for information quality and impact (Table 8). Those factors with highest priority for actions that restore or regulate have moderate to high impact on simulation results, and moderate to high probability of being controlled by management actions. Those factors with a high priority for study have low quality data, but cause a moderate to high impact on simulation results. On the other hand, factors with moderate to high quality of data, and moderate to high impact on simulation results are scored as high priority for monitoring. Additionally, monitoring is a low priority for those factors for which we



have low quality information, and which appear to have low to moderate impact on results.

Recommended studies include:

- **Survival in Reaches.** At present, it is unknown whether survival during freshwater is consistent among river reaches. Appropriate priorities for habitat restoration cannot be determined until we establish the causes and distribution of mortality during rearing.
- **Emigration Survival to Delta.** Survival to the Delta is presently modeled only as a function of population density, but there is much scatter in the data used to parameterize that function. If other factors are found to substantially influence migration survival, there may be management actions that could reduce causes of high mortality.
- **Hatchery Fish Fitness.** The role of hatchery fish in the NOAA Fisheries 1997 Recovery Plan for winter-run Chinook is premised on the idea that these fish have the same fitness as hatchery fish to reproduce when they spawn naturally. If hatchery fish are less fit genetically than wild fish, their stocking could detract from population recovery. The contribution of hatchery fish to natural spawning must be determined so that incorrect accounting for the hatchery fish does not mask other factors affecting success of the population.
- **Delta Survival.** Available data are not sufficient to estimate Delta survival for winter-run Chinook, so we have used a surrogate survival function based on data from fall-run Chinook. Studies are needed to validate whether the surrogate function is accurate for winter-run Chinook. Further, finer detail of fish passage routes and survivals in each are needed in order to assess potential benefits of various restoration actions proposed in the Delta. The possibility that some juveniles rear in the Delta for extended periods is also a factor that would influence effectiveness of restoration measures.
- **% Maturing Each Age – Natural.** The maturity rate at age 3 for wild fish appears to differ from that for hatchery fish, and this difference influences model outcomes. Population recovery is quicker the higher the percentage of fish maturing at age 3 rather than age 4. Fish maturing at age 4 suffer much higher harvest mortality than at age 3. Maturity rate can be determined from thorough assessment of age among wild spawners for at least 3 consecutive years.
- **Freshwater Harvest Rate.** There is conflicting evidence about the magnitude of freshwater harvest rates, and they can strongly affect adult abundance. Creel surveys combined with genetic sampling of harvest fish will be necessary to refine freshwater harvest rate estimates.

Recommended monitoring includes:

- **Spawner Abundance.** This is the most important signal of population health.
- **Egg Survival - Incubation Temperature.** Egg survival can have a large impact on population performance, as it did for the 1976 and 1977 broods. Incubation temperature should be monitored, and egg survival can be monitored through sampling of juvenile abundance passing RBDD. Action has been taken to install the Shasta Dam temperature control device, and temperature is presently maintained at favorable levels in all but critically dry years.



- **Emigration Survival to Delta.** Monitoring of juveniles leaving the upper river (passing RBDD) and reaching Sacramento can provide estimates of survival. However, racial composition of juveniles captured in rotary screw traps and Sacramento trawl catch must be accurately determined before estimates of mortality during migration can be refined.
- **Hatchery Fish Fitness.** Tracking of hatchery fish fitness, both for initial returns and for natural production, will be needed to account for hatchery contribution to the run. Hatchery fish fitness for survival and reproduction in the wild can be influenced by hatchery breeding and rearing techniques. If fitness is low, hatchery practices can be modified.
- **Delta Survival.** Human costs for managing this variable are high, so it is important to track response to management actions, as well as to environmental variation. Changes in Delta operations appear to have resulted in high survival for winter-run Chinook at present. Because Delta operations are under human control, it is important that careful management of those operations be sustained. If new studies indicate that Delta survival is substantially lower than we have estimated, different actions to protect winter-run may be warranted.
- **Ocean Survival Rate.** Fluctuation in ocean survival rate may be large, so that variation can confound the accounting for effects from all management actions over the life cycle of winter-run Chinook. In order to accurately track population response to management actions, the potentially large effects of ocean survival must be accounted for. This can be accomplished from estimates of smolt abundance leaving the Delta compared to adult returns to catch and escapement.
- **Ocean Harvest Rate.** Harvest is a key management control point, so numbers of fish being caught should be monitored to be sure harvest regulations are achieving their intent. Detection of natural or artificial marks will be necessary to estimate ocean harvest of winter-run Chinook. Recent reductions in harvest rate have aided rebuilding the winter-run population, although recent harvest estimates were higher than expected (Grover et al. 2004).



Table 8. Scoring of our understanding and priorities for action on factors influencing population trends for winter-run Chinook salmon.

| Variable | Data Quality | Impact on Results | Manageable | Action Priority | | |
|---------------------------------|--------------|-------------------|------------|------------------|-------|---------|
| | | | | Restore/Regulate | Study | Monitor |
| Spawner Abundance | M | H | L | L | L | H |
| Eggs per Female | M | L | L | L | L | L |
| Percentage Females | M | M | L | L | L | M |
| Egg Survival - Incubation Temp. | H | H | H | H | L | H |
| Rearing Capacity | L | M | L | ?? | M | L |
| Rearing Duration by Reach | L | L | M | ?? | M | L |
| Survival in Reaches | L | H | M | M | H | L |
| Emigration Survival to Delta | L | M | M | ?? | H | H |
| Hatchery Fish Fitness | L | H | H | H | H | H |
| Delta Survival | M | M | M | H | H | H |
| Ocean Survival Rate | L | H | L | H | L | H |
| Ocean Harvest Rate | M | H | H | H | L | H |
| % Maturing Each Age - Natural | L | H | L | L | H | M |
| % Maturing Each Age – Hatchery | H | L | H | L | L | M |
| Freshwater Harvest Rate | L | H | H | H | H | L |
| Pre-spawning Mortality | L | L | M | ?? | M | M |
| Contaminant Stress | L | L | M | M | M | M |

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APPENDICES

APPENDIX 1. TECHNICAL MEMORANDUMS 1, 2 AND 3.



Technical Memorandum

| | |
|--------------|--|
| To: | Zach Hymanson; Brent Walthall; Tim Quinn; Steve Macaulay; Steve Cramer; Sam Luoma; Russ Bellmer; 'Ronald M. Yoshiyama'; Roger Guinee; Rick Sitts; Richard Denton; Paul Devries; Paul Cadrett; Pat Brandes; Michael. E. Aceituno; Michael Carlin; Lisa Holm; Lisa Culjis; Laura KingMoon; Kim Taylor; John Coburn; Joe Miyamoto; Pat Coulston; Jim White; Jim Smith; Elaine Archibald; Dudley Reiser; Doug Wallace; Doug Demko; Diana Jacobs; David Harlow; Dan Odenweller; Chuck Armor; Bruce Oppenheim; Alice Low |
| From: | Steve Cramer |
| CC: | Pat Brandes; Randy Brown |
| Date: | November 20, 2003 |

Testing the Model: Spawner Abundance

Historical Observations Compared to Simulated Runs

Introduction

This is the first in a series of Technical Memorandums that explains how we applied the Winter-run Chinook Integrated Modeling Framework (Winter-run IMF) to historical data as a test of model accuracy. Our best opportunity, at present, to determine if the Winter-run IMF reasonably simulates population trends is to run the model with historical conditions and see how well the simulated population tracks with observed populations since counts began at Red Bluff Diversion Dam (RBDD). We refer to this exercise as a hindcast simulation. The only difference between a hindcast and a normal simulation with this model is that input values for a hindcast simulation are the actual values observed each year, while input values for a normal simulation are fixed at one value across all years (this is called a deterministic simulation). Input variables that must be supplied each year for a hindcast simulation are the following:

- Percent of Spawning Below BDD
- Percent Egg Mortality above RBDD
- Freeport Flow (Jan.)
- Export/Inflow Ratio (Dec.-Apr.)
- DCC Gate Position (Dec. Apr.)
- Ocean survival (smolt-to-age 2)
- Harvest Fraction in Freshwater
- Harvest Fraction in Ocean



We will distribute a series of Technical Memorandums to the Steering Committee and Winter-run Project Work Team that describe how we obtained inputs used in these simulations. This first memorandum explains how we determined the number of winter-run spawners for each year of record. These spawners are not the simulated values, but rather the observed values to which our hindcast simulations will be compared. Once the historical estimates of spawning escapement were gathered, they were used to: 1) “seed” the model, and 2) compare to annual spawning escapements simulated by the model. Seeding the model entails using the first four years of observed spawning escapement as the parents that begin a life cycle, and then allowing the model to simulate the number of their offspring that survive to become parents for the next generation. By the fifth year of simulation, the spawners are generated from the offspring of the first 2 years for which spawners were input. For example, the first year of spawners used to seed the model was 1968, and the model simulated the number of offspring that survived to be age-3 spawners in 1971 and age-4 spawners in 1972. Because winter-run spawners are rarely older than age 4, all spawners in the hindcast simulation after 1972 were generated by the simulation that started with only the first four years of observed spawners.

Observed Spawner Escapements

We used observed returns of winter-run Chinook to RBDD as the historical benchmark values to which simulations could be compared. Spawning escapement of winter Chinook in the upper Sacramento has been estimated since 1967 via counts at the fish ladder at RBDD; however, counts since 1987 have only covered a portion of the run. Beginning in 1987, the gates at RBDD have been raised for various durations in late-winter and early spring to assist upstream passage of adult winter-run Chinook. This meant that not all fish passed through the ladder, and thus not all fish were counted. Methods were derived to expand counts at RBDD, based on an expectation of average run timing. The accuracy of those methods was poor, due in part to variation in run timing between years. This extrapolation to assumed run timing can lead to large errors in estimation (43% to 230%; NMFS 1997). Alternative estimates of spawner abundance became possible in 1996, when surveys of spawned-out carcasses were initiated, and continued in subsequent years. Spawning escapement estimates via carcass surveys have been deemed more reliable (USFWS 2001).

Three models are used to estimate population size from the carcass survey data, the Peterson, the Jolly-Seber, and Schaefer models. USFWS recommends using the Peterson estimate for tracking long term trends in the population abundance. The Jolly-Seber model is recommended for use when the most accurate single year estimate is required. The Jolly-Seber method has more rigorous data requirements which may not be met in all years that carcass surveys are conducted (USFWS 2001). Since 1996 when carcass surveys began, the requirements of the Jolly-Seber model could only be met in 2000-2002.

Thus, for the historical run sizes to be compared to IMF simulations, we used RBDD counts from 1968-1995, and carcass-survey estimates of spawners from 1996-2002 (Figure 1). We used the carcass estimate based on the Peterson model during 1996-1999, and based on the Jolly-Seber model for 2000-2002 estimates. These sets of estimates are those recommended by fisheries agencies for use when estimating annual escapement. Estimates by all methods through 2001 are displayed in Table 1.



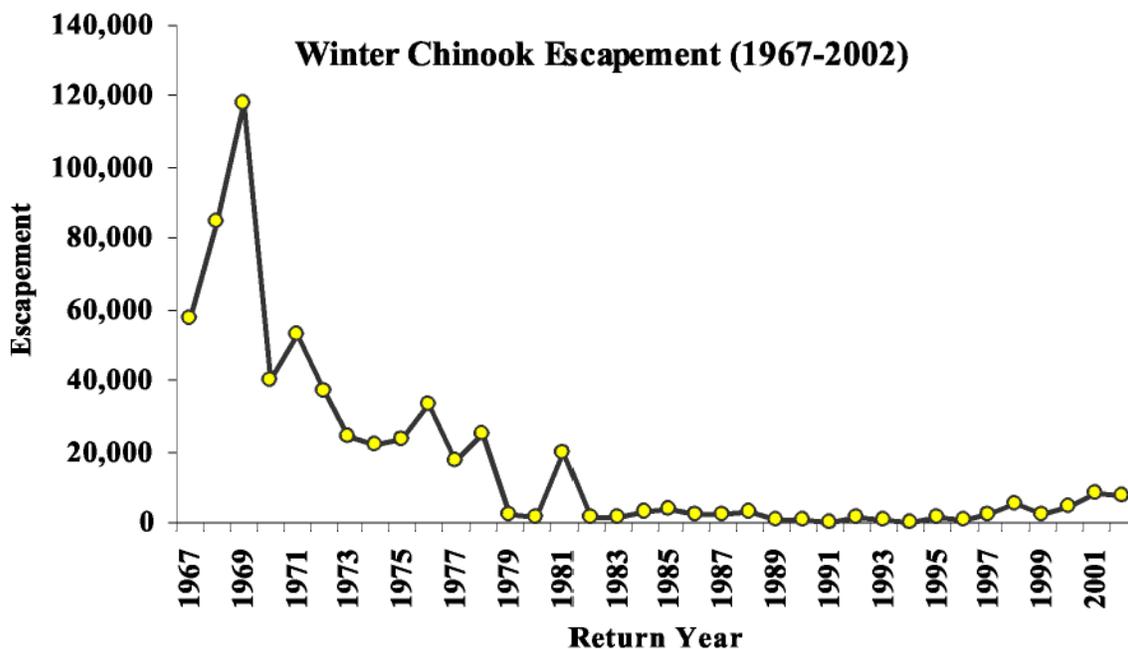


Figure 1. Escapement of winter Chinook in the upper Sacramento River. Data from 1967-1995 is from RBDD ladder counts. Data from 1995-2002 is from spawning ground carcass survey estimates.



Table 1. Estimates of winter Chinook spawner escapement in the upper Sacramento River. Bolded values are those presented in Figure 1 and used as the benchmark for comparison to simulation output. Carcass surveys began in 1996, and Jolly-Seber estimates have only been feasible since 2000.

| Year | RBDD Counts | | | Carcass Survey | | | Jolly-Seber | | |
|------|-------------|---------|---------|----------------|--------------------|--------|-------------|--------|-------|
| | Grilse | Adults | Total | Grilse | Peterson Adults | Total | Grilse | Adults | Total |
| 1967 | 24,985 | 32,321 | 57,306 | | | | | | |
| 1968 | 10,299 | 74,115 | 84,414 | | | | | | |
| 1969 | 8,953 | 108,855 | 117,808 | | | | | | |
| 1970 | 8,324 | 32,085 | 40,409 | | | | | | |
| 1971 | 20,864 | 32,225 | 53,089 | | | | | | |
| 1972 | 8,541 | 28,592 | 37,133 | | | | | | |
| 1973 | 4,623 | 19,456 | 24,079 | | | | | | |
| 1974 | 3,788 | 18,109 | 21,897 | | | | | | |
| 1975 | 7,498 | 15,932 | 23,430 | | | | | | |
| 1976 | 8,634 | 26,462 | 33,096 | | | | | | |
| 1977 | 2,186 | 15,028 | 17,214 | | | | | | |
| 1978 | 1,193 | 23,669 | 24,862 | | | | | | |
| 1979 | 113 | 2,251 | 2,364 | | | | | | |
| 1980 | 1,072 | 84 | 1,156 | | | | | | |
| 1981 | 1,744 | 18,297 | 20,041 | | | | | | |
| 1982 | 270 | 972 | 1,242 | | | | | | |
| 1983 | 392 | 1,439 | 1,831 | | | | | | |
| 1984 | 1,869 | 794 | 2,663 | | | | | | |
| 1985 | 329 | 3,633 | 3,962 | | | | | | |
| 1986 | 496 | 2,101 | 2,597 | | | | | | |
| 1987 | 277 | 1,909 | 2,186 | | | | | | |
| 1988 | 1,008 | 1,878 | 2,886 | | | | | | |
| 1989 | 125 | 571 | 696 | | | | | | |
| 1990 | 43 | 387 | 430 | | | | | | |
| 1991 | 19 | 192 | 211 | | | | | | |
| 1992 | 80 | 1,160 | 1,240 | | | | | | |
| 1993 | 137 | 250 | 387 | | | | | | |
| 1994 | 124 | 62 | 186 | | | | | | |
| 1995 | 29 | 1,268 | 1,297 | | | | | | |
| 1996 | 629 | 708 | 1,337 | 156 | 664 | 820 | | | |
| 1997 | 352 | 528 | 880 | 165 | 1,888 | 2,053 | | | |
| 1998 | 924 | 2,079 | 3,002 | 110 | 5,391 | 5,501 | | | |
| 1999 | 2,466 | 822 | 3,288 | 441 | 1,821 | 2,262 | | | |
| 2000 | 789 | 563 | 1,352 | 178 | 6,492 | 6,670 | 116 | 4,227 | 4,343 |
| 2001 | 3,827 | 1,696 | 5,523 | 1,216 | 11,581 | 12,797 | 760 | 7,236 | 7,996 |
| 2002 | -- | -- | -- | -- | -- | -- | -- | -- | 7,337 |



To begin the hindcast simulation, we seeded the model with spawner escapements from 1968-1971. We did not start with the 1967 run because some data needed as inputs to the model were not available for 1967.

RBDD Effects on Passage & Spawning Success

Although we have reasonable estimates for the number of adult winter-run passing RBDD each year, this does not account for all the spawners in the river, and not all spawners were successful. Some fish spawned below RBDD and some of the eggs deposited were killed in some years by exposure to lethal temperatures. In order for the hindcast simulation to predict the number of fish passing RBDD, it must account for the number of returns that spawned below RBDD, and the proportion of eggs that died from high temperatures. The issues of fish spawning below RBDD and eggs dying from exposure to high temperature have largely been resolved by actions in the Recovery Plan, so we have not included cause-effect relationships in the baseline IMF to predict these effects. Therefore, to account for these historical issues in our hindcast simulations, we used best available data to assign values for these effects in each year.

When simulating the historical return of spawners from the ocean, we included a factor to deduct the percentage of the run that was blocked from passing RBDD. Impaired passage at RBDD was a major factor for the decline of winter Chinook populations. Studies in the 1980's found that the RBDD fish ladders were ineffective in attracting adult salmon to migrate past RBDD (Hallock et al. 1982, Vogel and Smith 1986, USFWS 1987, Vogel et al. 1988). Several radio tagging studies estimated that RBDD blocked 43-44% of winter run Chinook that approached the dam. Authors concluded that fish blocked by the dam had difficulty locating the entrance to the fish ladder. Adults obstructed by the dam are forced to spawn below the dam where high temperatures often lead to 100% mortality (NMFS 1997). Although some eggs deposited below RBDD survived in some years, we have assumed in the hindcast that no offspring survive from spawning below RBDD.

Beginning in 1986, gates of RBDD have been raised for varying periods during winter Chinook passage to reduce the percentage of the run blocked by the dam. Initially, gates were opened periodically between mid-December and April. Since then, the "open window" has been expanded to begin in mid-September and end in mid-May (Figure 2). USBR plans continued operation of gates open from mid-September through mid-May in the future (USBR 2003). Run timing data from 1970-1988 indicates that on average, 85% of the winter run Chinook has passed RBDD by mid-May.



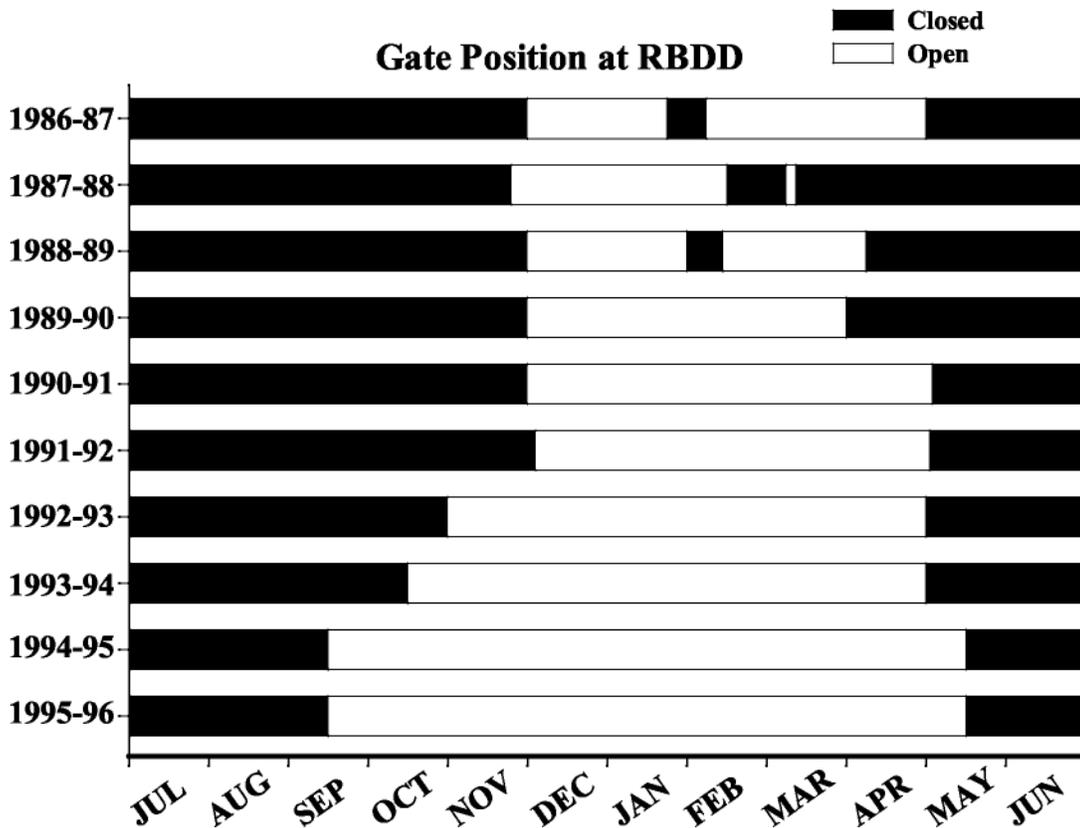


Figure 2. Gate position at RBDD from the 1986-87 to 1995-96 migration years. Figure re-created from NMFS (1997).

Aerial counts of winter run redds were initiated in 1987 by CDFG, and those counts show that more fish spawned above RBDD in years that RBDD gates remained open later in the migration season. In 1987, the gates were closed on April 5 when 60% of the run had passed RBDD. Aerial redd counts showed that 4.4% of winter Chinook redds were located below RBDD in that year. In 1988, the gates were closed earlier on March 12, when only 24% of the run had passed RBDD. That year, 25.7% of redds were located below RBDD. The longer the gates were open, and the earlier the run timing, the higher the proportion of redds above RBDD was. Subsequent data showed that extending the period with the gates open decreased the percentage of redds below RBDD.

Since the RBDD gates were first lifted in the 1987 return year, we assumed that 40% of the run was blocked from passing RBDD prior to that year. This assumption was based on the radio-telemetry survey data cited earlier because the distribution of redds were not surveyed prior to 1987. In each year since 1987, we assumed that the percentage of the run blocked by RBDD was equal to the percentage of all winter Chinook redds that were constructed below the dam (NMFS 1997; Table 2).



Temperature Induced Egg Mortality

Water temperatures in the upper Sacramento River where winter Chinook spawn have reached levels lethal to Chinook eggs in some years, and the hindcast simulation had to account for these egg losses. Newly spawned and incubating winter-run Chinook eggs and fry are the most sensitive life stages to elevated water temperatures (NMFS 1997). Maximum survival of incubating eggs and pre-emergent fry occurs at water temperatures between 40°F and 56°F, and egg mortality increases rapidly at 57.5°F. At sustained 62°F, egg mortality is 100% (Seymour 1956, Combs and Burrows 1957, and Hinze 1959; as cited in Boles 1988).

Limited data on river temperatures has hindered the estimation of egg mortality for winter-run Chinook prior to 1989, though losses due to warm temperatures certainly occurred. In 1989, egg mortality was estimated at 4-8%, in 1990 estimates were 20-30%, and 5-10% in 1991 (NMFS 1997). Modifications of CVP operations reduced mortalities after 1992 to an estimated 4.2%, and to near zero from 1993-1996 (NMFS 1997). However, modified operations to improved incubation temperatures required that water be released from Shasta Reservoir without power generation. This operation soon proved to be costly, and an alternative method to releasing cool water from the reservoir was sought.

In 1997 a temperature control device was installed in Shasta Dam that allowed operators to release cold water from the bottom of the reservoir while still generating power. The device allows managers the ability to alter the temperature of releases to a certain degree, and thus influence winter Chinook egg incubation temperatures. The device has proven effective at reducing downstream temperatures, though modeling by the USBR indicates that in dry and critically dry water years that incubation temperatures will reach lethal levels for eggs.

For the hindcast model, it was necessary to estimate egg mortalities before operations of Shasta Reservoir improved incubation conditions. Limited temperature data indicated that there were several years where high temperatures resulted in excessive egg mortality. Using estimates of egg mortality from 1989-1996 (NMFS 1997) we were able to correlate estimated egg mortality to average August maximum temperature at Balls Ferry ($r^2 = 0.92$). The relationship showed that as average August maximum temperature exceeds 58.3°F, estimated egg mortality begins to increase (Figure 3).



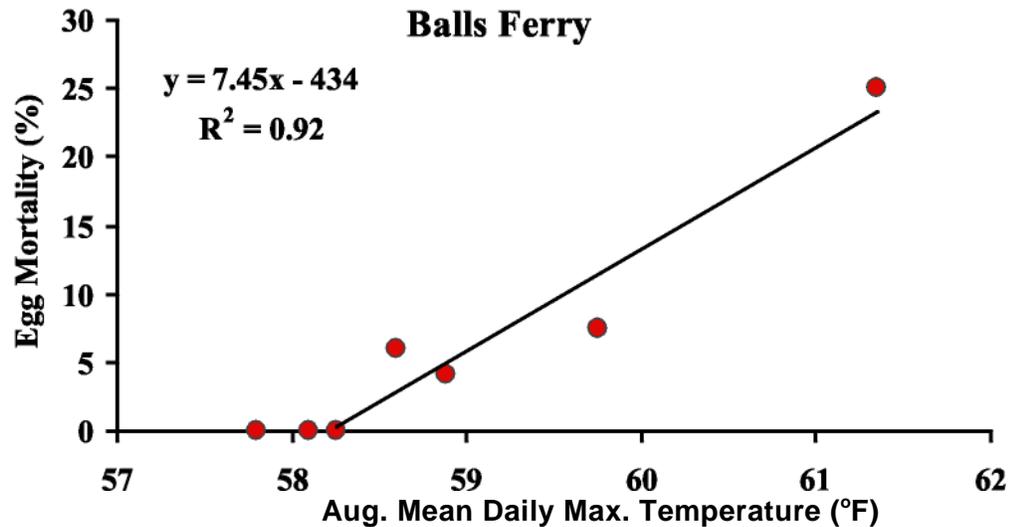


Figure 3. Relationship between August mean maximum daily temperature at Balls Ferry and egg mortality estimates. Egg mortality estimate are from 1989-1994, and 1995-1996 (NMFS 1997). Regression line applies to points of 58.3°F and greater (upper 5 points). Mortality below that point is 0%.

Sporadic temperature data from Keswick Dam, Balls Ferry, Jellys Ferry, Bend Bridge and RBDD from 1970-1989 showed that there were several years where egg mortality would have been significant. Egg mortality would have been greatest in the summers of 1976 and 1977 when the averages of daily maximum temperatures during August at Balls Ferry were 63.5°F and 69°F, respectively. In 1977, daily temperatures were consistently above 60°F for all of July. Even as far upstream as Keswick Dam, August monthly maximum temperatures were 60.8°F in 1976 and 67.3°F in 1977 (Turek 1990). Temperatures from both locations in each year were well above the threshold where mortality begins to occur. Though the temperatures at Balls Ferry were outside the bounds incorporated into the regression, the regression estimated that mortality in 1976 and 1977 were 39% and 80% respectively. Given the extreme temperatures and duration that they were encountered, we believe that these estimates of mortality are conservative.

Other years prior to 1989 where temperatures indicated that significant egg mortality may have occurred included 1985, 1987, and 1988. Temperature data at Balls Ferry for 1987 and 1988 were applied to the regression presented above to estimate mortality in those two years at 8% and 16% respectively. No temperature data from Balls Ferry were available for 1985. Examination of August temperature data at Bend Bridge indicated that water temperatures in 1985 were warmer than those in 1987, and cooler than in 1988. Based on these data we assumed that egg mortality in 1985 was intermediate to those years at 12%.



Annual egg mortality rates used in the hindcast simulation are presented in Figure 4 and Table 2.

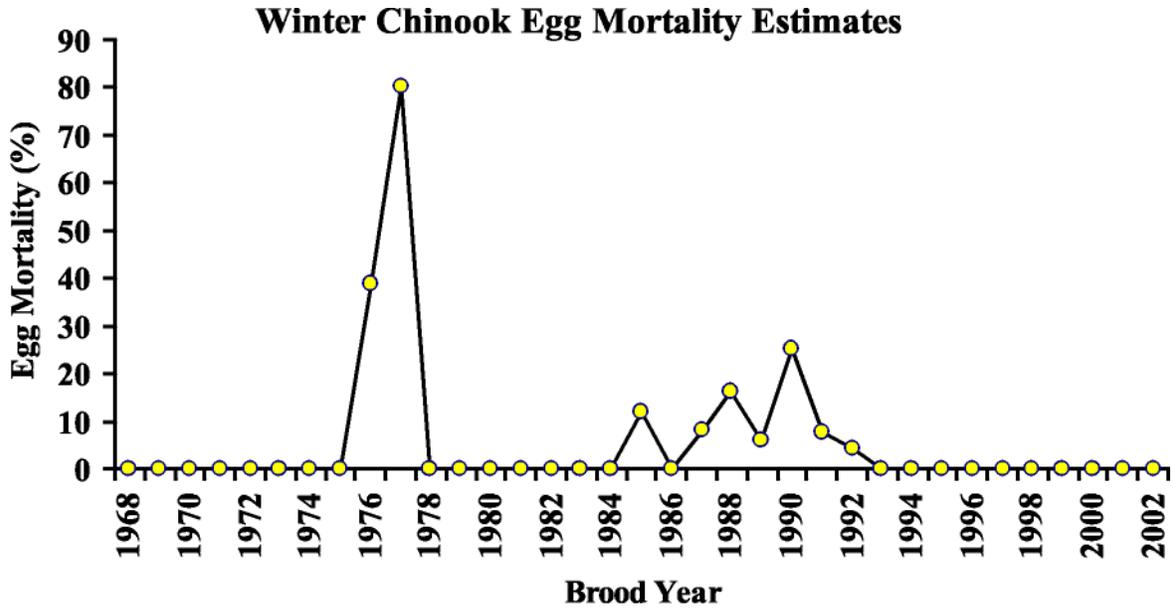


Figure 4. Estimates of egg mortality incorporated into the hindcast model.



Table 2. Annual values used in the hindcast simulation for the % of spawning run blocked by RBDD and the percentage of egg mortality incurred by winter-run Chinook spawning above RBDD. All eggs spawned below RBDD were assumed to die.

| Year | % Blocked by | Egg |
|------|--------------|------|
| 1968 | 40.0 | 0.0 |
| 1969 | 40.0 | 0.0 |
| 1970 | 40.0 | 0.0 |
| 1971 | 40.0 | 0.0 |
| 1972 | 40.0 | 0.0 |
| 1973 | 40.0 | 0.0 |
| 1974 | 40.0 | 0.0 |
| 1975 | 40.0 | 0.0 |
| 1976 | 40.0 | 39.0 |
| 1977 | 40.0 | 80.0 |
| 1978 | 40.0 | 0.0 |
| 1979 | 40.0 | 0.0 |
| 1980 | 40.0 | 0.0 |
| 1981 | 40.0 | 0.0 |
| 1982 | 40.0 | 0.0 |
| 1983 | 40.0 | 0.0 |
| 1984 | 40.0 | 0.0 |
| 1985 | 40.0 | 12.0 |
| 1986 | 40.0 | 0.0 |
| 1987 | 4.4 | 8.0 |
| 1988 | 25.7 | 16.0 |
| 1989 | 2.2 | 6.0 |
| 1990 | 7.2 | 25.0 |
| 1991 | 0.0 | 7.5 |
| 1992 | 3.7 | 4.1 |
| 1993 | 0.8 | 0.0 |
| 1994 | 0.0 | 0.0 |
| 1995 | 0.5 | 0.0 |
| 1996 | 0.0 | 0.0 |
| 1997 | 0.0 | 0.0 |
| 1998 | 0.0 | 0.0 |
| 1999 | 0.0 | 0.0 |
| 2000 | 0.0 | 0.0 |
| 2001 | 0.4 | 0.0 |
| 2002 | 1.0 | 0.0 |



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Technical Memorandum

| | |
|-------|--|
| To: | Zach Hymanson; Brent Walthall; Tim Quinn; Steve Macaulay; Steve Cramer; Sam Luoma; Russ Bellmer; 'Ronald M. Yoshiyama'; Roger Guinee; Rick Sitts; Richard Denton; Paul Devries; Paul Cadrett; Pat Brandes; Michael. E. Aceituno; Michael Carlin; Lisa Holm; Lisa Culjis; Laura KingMoon; Kim Taylor; John Coburn; Joe Miyamoto; Pat Coulston; Jim White; Jim Smith; Elaine Archibald; Dudley Reiser; Doug Wallace; Doug Demko; Diana Jacobs; David Harlow; Dan Odenweller; Chuck Armor; Bruce Oppenheim; Alice Low |
| From: | <i>Steve Cramer</i> |
| CC: | Pat Brandes; Randy Brown |
| Date: | November 25, 2003 |

Testing the Winter-run Chinook Model:

Historical Harvest Rates

Introduction:

This is the second in a series of Technical Memorandums that explains how we applied the Winter-run Chinook Integrated Modeling Framework (Winter-run IMF) to historical data as a test of model accuracy. In this memorandum we will discuss data, assumptions, and analysis used to develop marine and freshwater harvest rates used in the simulation of historical conditions.

Marine Harvest:

Ocean harvest rates (the percentage of the population at each age harvested in the ocean) are used in the model to account for fish removed by the commercial troll and recreational fisheries. Not all winter Chinook in the ocean are susceptible to harvest. Younger and smaller fish are less likely to be harvested than older and larger fish, because (1) the large lures used are more attractive to larger fish, and (2) fish cannot be retained until they are a minimum size (currently 22 inches in the sport fishery and 26 inches in the commercial fishery).

Winter Chinook enter the ocean as they become one year old. In the summer of the year that the fish enter the ocean, they are too small to be subject to harvest. In their second summer, winter Chinook begin to reach the size where they can be legally harvested, and thus a certain portion of the run is claimed by harvest in their second summer. Fish harvested in this summer are called three year old fish, though in fact



they are just over two years old¹. In the following winter a majority of winter Chinook return to freshwater to spawn. However, some fish spend an additional year in the ocean and thus are subject to one more season of marine harvest. These fish are harvested as “four year olds.” Since four year olds all exceed minimum lengths for retention by fisherman, they are more susceptible to harvest. The remaining fish that are not harvested return to freshwater to spawn.

Harvest rates are typically estimated by recovery rates of coded-wire tags, but no tagged winter-run Chinook were released during the 1971-1995 broods. Tagged fish were released from the 1969-71 broods and the 1995 to present broods, and harvest recoveries of those fish indicated that the fraction harvested was correlated to the Central Valley Index (CVI), as we will discuss. Tag recoveries of winter run Chinook made it possible to directly estimate their harvest rates at age 3 in 1972, 1973, and 2001. Therefore, we used the CVI to derive harvest rates for winter-run Chinook during most of the 1970's through the 1990's.

What is the Central Valley harvest index and why is it useful?

The CVI is an annual index of the fraction of Chinook harvested in the ocean from all runs of Central Valley Chinook combined (winter, fall, late-fall and spring). The CVI is calculated as the total ocean harvest south of Point Arena divided by Chinook escapement (all stocks) in the Central Valley. The CVI is useful for historical assessment because data have been collected to calculate it for more than 30 years. Cramer (1990) showed that direct estimates of ocean harvest rates based on recoveries from CWT's of Central Valley Chinook track closely with the CVI. The CVI is a primary measurement used by the Pacific Fishery Management Council to monitor the effectiveness of their regulations for controlling ocean harvest. Because the CVI harvest index is calculated in the same manner every year, it provides a reliable indicator of trends in ocean harvest of Central Valley Chinook.

How and why are winter-run Chinook harvest rates different from the CVI harvest index?

The CVI does not distinguish specific runs of Chinook, and it is dominantly composed of fall-run Chinook. Particular runs may be harvested at a lesser or greater rate than the CVI, but because the runs all mix in the same fisheries, it is likely that rates unique to each run will rise and fall together between years.

The few tagging studies with winter-run Chinook indicate they are currently and historically have been harvested at a rate less than that of the CVI. Ocean hook scar rates of winter Chinook examined at RBDD from 1971-1984 averaged 70% of that of fall Chinook and 77% of that of spring Chinook (Hallock and Fisher 1985). These data indicate that fewer winter Chinook were being hooked by harvest gear in the ocean than the other races incorporated into the CVI. Also, CDFG estimated from a fin clip mark-

¹ There have been some discrepancies in the past on the age nomenclature of these fish. We refer to these fish as three years old because that is how they are referred to in the CDFG winter Chinook harvest model. Others (including Hallock and Fisher 1985) have referred to these fish as age 2.



recapture study that winter Chinook harvest was 78% of that averaged for all Chinook stocks combined off of the California coast in 1971 and 1972 (Barraco 1997). Further, in recent years harvest regulations have been specifically designed to reduce harvest of winter-run Chinook. NOAA Fisheries estimated that harvest of age 3 fish of the 1998 brood was only 21%, which we estimated to be approximately 60% of the CVI harvest index.

Winter-run Chinook tend to be harvested at a lower rate, because they are several months younger and smaller at each age during the harvest season than other chinook runs. The CDFG harvest model assigns the birthday of winter Chinook as February 1, while other spring and fall runs are assigned their “birthday” on the previous September 1. As the result of less growing time in the ocean, mean lengths of winter-run Chinook during the ocean harvest season are several inches shorter than fall Chinook (Figure 1). The length patterns show that most winter-run Chinook do not reach the 26-inch minimum size limit for commercial fisheries until late summer of their age 3 year, so this accounts for their low harvest rate in commercial fisheries.

Length and Age of Central Valley Chinook

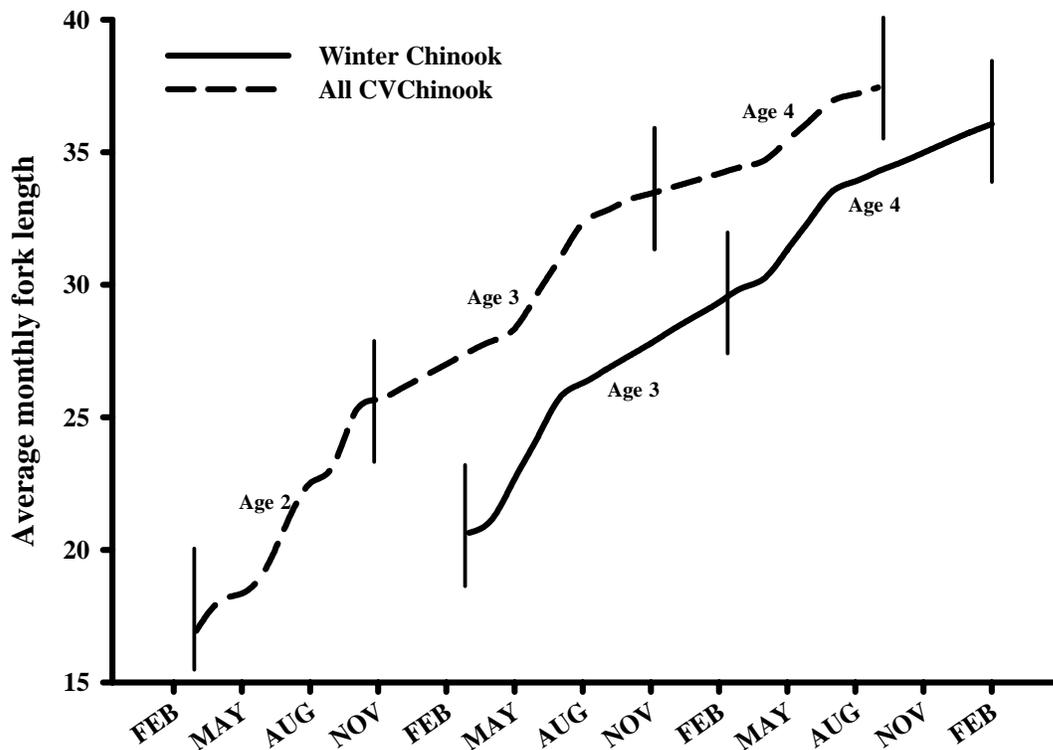


Figure 1. Average fork length and age by month of both winter Chinook and all Central Valley Chinook. Data from Barrroco et al. (1989). Lengths derived from marked fish sampled from ocean landings.



Recreational harvest of Central Valley Chinook is primarily between April and November, and commercial harvest is in May to September. Since winter Chinook enter freshwater in the winter and early spring, they avoid all of the commercial season and most of the recreational season in their year of maturity. As a result of the earlier season opening and smaller legal size limit in sport fisheries, about 70% of the ocean harvest of winter-run Chinook occurs in the sport fisheries. The small size at age and early entry to freshwater combine to cause a lower harvest rate at each age on winter-run Chinook than for other Central Valley stocks. Age 2 fish are too small to be harvested, and their harvest rate is assumed to be 0%.

How did we estimate annual harvest rates for winter-run Chinook?

In years for which ocean harvest rates could not be estimated directly from tag recoveries of winter-run Chinook, we assumed that harvest rate of winter-run was a constant fraction of the CVI harvest rate index. We estimated this fraction based on the fin-clip study reported by Hallock and Fisher (1985), which showed the ocean harvest rate of age 3 fish averaged 35.4% in 1972 and 1973 (Barrocco et al 1989). That rate was 50% of the CVI harvest index for 1972 and 1973. Thus, we assumed the harvest of age 3 winter-run Chinook from 1970 to 1999 was half of the CVI harvest index.

The relative harvest rate at age 4 for winter-run Chinook was similarly based on harvest rates estimated by Barrocco et al. (1989) from the data of Hallock and Fisher (1985). The ratio of harvest rates for age 4 to age 3 winter-run Chinook was 1.54:1. We applied this ratio to each year, and estimated the annual harvest rate of age 4 winter Chinook to be 1.54 times that of age 3 winter Chinook. The assumption that winter-run harvest rates remained a constant fraction of the CVI seems reasonable, because there was little significant change in commercial or recreational harvest regulations until the mid-1990's.

How have changes in harvest regulations affected harvest rates?

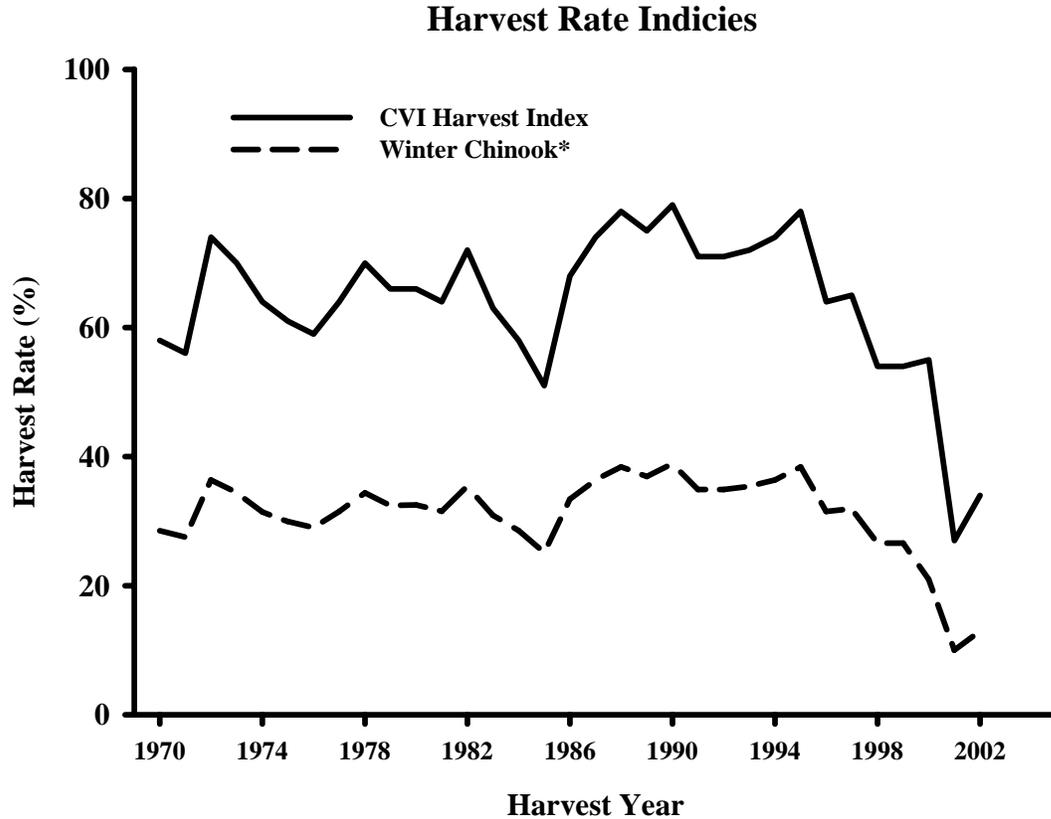
Most of the ocean harvest of winter Chinook is in the recreational fishery. In an effort to protect the endangered winter Chinook, managers began to change recreational harvest regulations in 1995. The recreational harvest season began in mid February before 1995, but was delayed until mid April in 1995 and thereafter. Also, the minimum size limit was increased from 20 inches to 24 inches to reduce retention of winter-run Chinook. These changes impacted the relationship between winter Chinook harvest rates and the CVI harvest index.

How did we model the effects of changes in regulations on winter Chinook harvest rates?

We estimated the effect of these regulatory changes on the harvest rate of winter-run Chinook relative to other runs by using direct estimates of winter-run harvest rates from CWT recoveries of the 1998 brood. This was the first brood since the Hallock and Fisher (1989) studies for which tag recoveries were sufficient to obtain a reliable estimate of harvest rates. NOAA Fisheries has estimated from CWT recoveries in the 2000 ocean fisheries that the harvest rate of age 3 winter-run Chinook was 21%. This



is only slightly less the 27% we would have estimated by taking half of the 54% CVI rate for that year. Based on this new estimate of age 3 harvest rate in 2000, we assumed the winter-run harvest rate at age 3 was 39% of the CVI during 2000 and thereafter. The final harvest rates that we used in the hindcast simulation are listed in Table 1, and shown with the CVI in Figure 2.



*Age 3 Winter Chinook rates used in the hindcast model.

Figure 2. Central Valley Index (CVI) and estimated harvest rates of age 3 winter-run Chinook, 1970-2002.



Table 1. Annual estimates of ocean harvest rates used in the hindcast simulation for winter-run Chinook.

| Year | Ocean Harvest Rate | | |
|------|--------------------|-------|-------|
| | Age 2 | Age 3 | Age 4 |
| 1970 | 0 | 0.29 | 0.44 |
| 1971 | 0 | 0.28 | 0.42 |
| 1972 | 0 | 0.36 | 0.56 |
| 1973 | 0 | 0.34 | 0.53 |
| 1974 | 0 | 0.31 | 0.48 |
| 1975 | 0 | 0.30 | 0.46 |
| 1976 | 0 | 0.29 | 0.45 |
| 1977 | 0 | 0.31 | 0.48 |
| 1978 | 0 | 0.34 | 0.53 |
| 1979 | 0 | 0.32 | 0.50 |
| 1980 | 0 | 0.32 | 0.50 |
| 1981 | 0 | 0.31 | 0.48 |
| 1982 | 0 | 0.35 | 0.55 |
| 1983 | 0 | 0.31 | 0.48 |
| 1984 | 0 | 0.29 | 0.44 |
| 1985 | 0 | 0.25 | 0.39 |
| 1986 | 0 | 0.33 | 0.51 |
| 1987 | 0 | 0.36 | 0.56 |
| 1988 | 0 | 0.38 | 0.59 |
| 1989 | 0 | 0.37 | 0.57 |
| 1990 | 0 | 0.39 | 0.60 |
| 1991 | 0 | 0.35 | 0.54 |
| 1992 | 0 | 0.35 | 0.54 |
| 1993 | 0 | 0.35 | 0.55 |
| 1994 | 0 | 0.36 | 0.56 |
| 1995 | 0 | 0.30 | 0.45 |
| 1996 | 0 | 0.24 | 0.37 |
| 1997 | 0 | 0.24 | 0.38 |
| 1998 | 0 | 0.21 | 0.32 |
| 1999 | 0 | 0.21 | 0.32 |
| 2000 | 0 | 0.21 | 0.32 |
| 2001 | 0 | 0.10 | 0.15 |
| 2002 | 0 | 0.13 | 0.34 |



Freshwater Harvest:

A portion of the winter-run Chinook that return to freshwater are caught by anglers in the Sacramento River, so the model must account for removals of these fish. Current regulations protect winter run Chinook from in-river harvest, but this has not always been the case. In 1990, the California Fish and Game Commission adopted regulations prohibiting the harvest of adult salmon during the period that winter Chinook are in the river. These regulations were thought to virtually have eliminated the impacts of freshwater harvest on winter Chinook returns (NMFS 1997). During the 1968-1975, harvest rates were estimated from angler surveys, and ranged between 4% and 18%, with an average of 10% (Hallock and Fisher 1988). Angler surveys during 1983-1986 indicated that freshwater harvest rate averaged 8.7% in those years (NMFS 1997). Starting in 1987, the angling season was reduced, and harvest rate was estimated at 1.3%, followed by 4.2% in 1988, and 3.1% in 1989 (NMFS 1997).

In years that were not sampled, we assumed harvest rate was 9% prior to 1983 and 5% after 1990 (Figure 3; Table 2). The pre-1983 assumption was based on estimate harvest rates in the late 60's, early 70's, and mid-80's all averaging between 8-10% harvest. The assumed 5% harvest rate after 1990 allows for incidental retention of winter-run Chinook before the season closed January 15. Recoveries of winter-run Chinook CWTs in 2001 revealed the angler take of winter-run Chinook before January 15 accounted for up to 24% of the run (West Coast BRT 2003). This estimate was derived from nine CWTs recovered from the river fishery prior to January 15. Subsequently, the season closed January 1, which would have reduced the observed harvest rate in 2001 to less than 5% (West Coast BRT 2003).

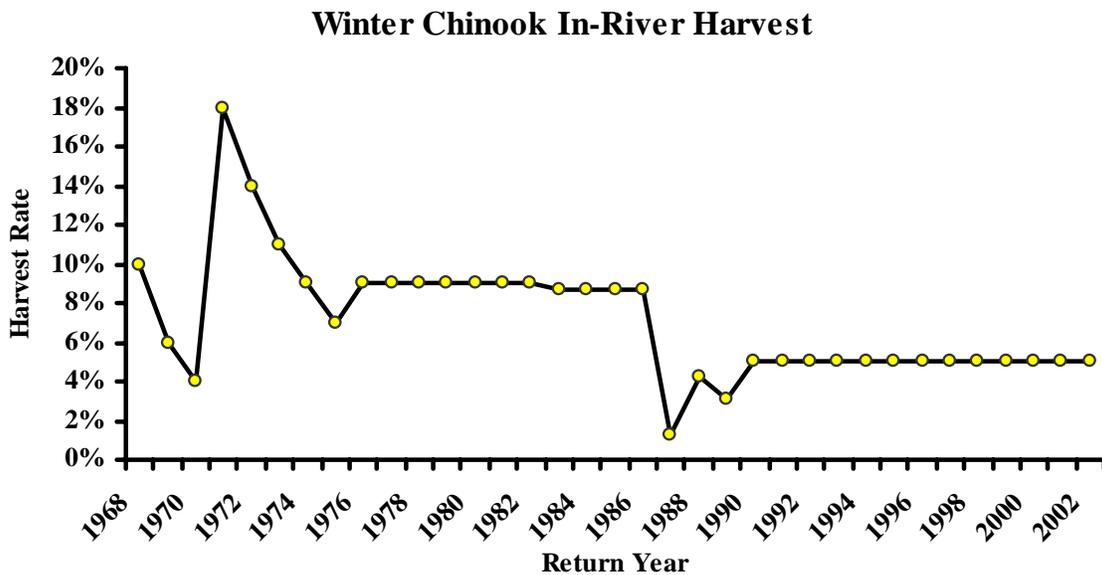


Figure 3. Modeled winter Chinook in-river harvest rates, 1968-2002.



Table 2. Values used to simulate annual in-river harvest of winter Chinook in the Sacramento River.

| Run Year | Freshwater Harvest (%) |
|----------|------------------------|
| 1968 | 10.0 |
| 1969 | 6.0 |
| 1970 | 4.0 |
| 1971 | 18.0 |
| 1972 | 14.0 |
| 1973 | 11.0 |
| 1974 | 9.0 |
| 1975 | 7.0 |
| 1976 | 9.0 |
| 1977 | 9.0 |
| 1978 | 9.0 |
| 1979 | 9.0 |
| 1980 | 9.0 |
| 1981 | 9.0 |
| 1982 | 9.0 |
| 1983 | 8.7 |
| 1984 | 8.7 |
| 1985 | 8.7 |
| 1986 | 8.7 |
| 1987 | 1.3 |
| 1988 | 4.2 |
| 1989 | 3.1 |
| 1990 | 5.0 |
| 1991 | 5.0 |
| 1992 | 5.0 |
| 1993 | 5.0 |
| 1994 | 5.0 |
| 1995 | 5.0 |
| 1996 | 5.0 |
| 1997 | 5.0 |
| 1998 | 5.0 |
| 1999 | 5.0 |
| 2000 | 5.0 |
| 2001 | 5.0 |
| 2002 | 5.0 |



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IMF Technical Memorandum #3

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| From: | <i>Steve Cramer</i> |
| CC: | Pat Brandes; Randy Brown |
| Date: | January 28, 2004 |

Testing the Winter-run Chinook Model:

Smolt Survival Through the Delta

Introduction

This is the third Technical Memorandum to explain how we applied historical data to test how well past trends in spawner abundance of winter-run Chinook could be predicted by the Integrated Modeling Framework (IMF). The first memorandum related to historical spawner abundance and egg survival, and the second related to historical harvest rates. This memorandum describes our derivation of estimates since 1968 for juvenile survival during migration through the Delta. This is an important life stage to model for two reasons: 1) Delta survival is highly variable, and 2) many factors affecting that survival are human caused. Average survival of juvenile winter-run Chinook passing through the Delta has not been directly estimated by sampling in any year, so we needed to develop a means of accounting for variation in this survival when attempting to predict historical population trends. We will discuss the data and methods used, as well as their limitations.

What Factors Affect Survival Through the Delta?

There has been much analysis of factors influencing survival of juvenile fall-run Chinook passing through the Delta, but little on juvenile winter-run Chinook that pass in a different season and at a larger size. Accordingly, we derived our approach from studies with juvenile fall-run Chinook, and assumed they were applicable to winter-run chinook. We corroborated the reasonableness of that assumption by comparing our results against those of Brandes (2003), who used data from tests during late fall and



winter with coded-wire-tagged (CWT) juvenile Chinook near the Delta Cross Channel (DCC; see map in Figure 1).

The most comprehensive analyses of data on factors affecting juvenile Chinook survival through the Delta have been those of Newman and Rice (1997) and Newman (2000). These works were later published as Newman and Rice (2002) and Newman (2003).

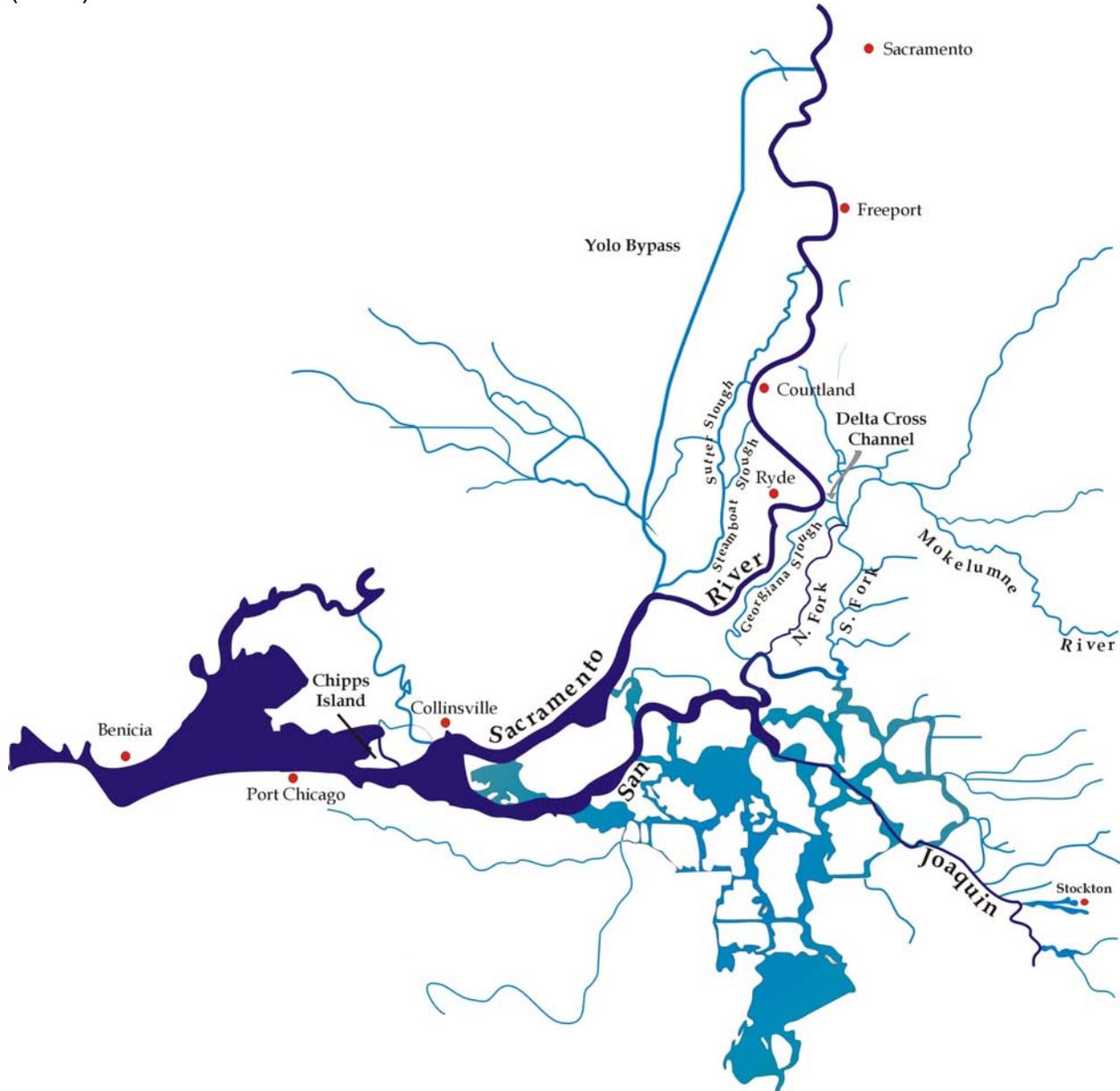


Figure 1. Map of the lower Sacramento River and Delta.

Newman and Rice (1997) analyzed survival estimates from CWT recoveries of fall Chinook released above and below the DCC each spring between 1979 and 1995. They found that temperature was the most influential environmental variable related to survival. Their work also indicated that flow, DCC gate position, and export-to-inflow ratios may also influence Delta migration survival, but those relationships were not statistically significant.

The work of Newman (2000) improved on the work of Newman and Rice (1997) in estimating Delta survival and further isolated factors correlated with survival. Newman and Rice (1997) conducted their analyses on trawl recoveries at Chipps Island of CWT-marked Chinook, and used catch/fish released as an index of survival. Thus, variation in trawl efficiency would have added error to the index. Newman (2000) advanced the analysis by directly estimating Delta survival from recoveries of paired CWT groups: groups released at the entry to the Delta were paired with groups released at the exit to the Delta. The paired analysis of Newman (2000) estimated survival through the Delta as a function of the difference in ocean recovery rates for fish released in the river near Sacramento compared to those released at Port Chicago or Benicia (Figure 1). Newman (2000) found that the majority of cases in which estimated survival was near 100%, flows exceeded 15,000 cfs and in all cases occurred only when release temperatures were less than about 65° Fahrenheit. In further analysis on the effects of covariates on survival Newman (2000) found:

“Flow effect can be seen to have the largest effect: as flow increases from 600 cfs to 15,000 cfs, survival increases from 0.37 to 0.67. The release temperature effect is sizeable as well, with 40% decrease in survival as temperature increase from 58 to 76 degrees Fahrenheit. At a moderate flow of 8,100 cfs, the export effects are also sizeable. As export/inflow increases from zero to 49% (within the historical range of export/inflow values when flow was around 8,100 cfs), survival rate declines 22%. The effect of the cross-channel gate being open is estimated to be roughly 18% decline in survival.”

Newman (2003) compared results of his paired analysis with that of the earlier unpaired analysis (Newman and Rice 1997). He found that the positive or negative effect of each of the variables was similar between the two analyses, but the significance of each relationship was consistently stronger for the paired analysis. Flow had the strongest association with survival in the paired model, whereas temperature had the strongest effect in the unpaired model. Temperature still had a significant negative effect on survival in the paired model, but the magnitude of the effect was less. The effect of the exports was greater in the paired model.

In his final analysis of paired CWT releases, Newman (2003) compared three statistical techniques for estimating environmental effects on survival, and concluded the hierarchical formulation was the most reliable. Thus, we used his hierarchical formulation in our modeling. Newman (2003) estimated coefficients for a number of factors that might affect smolt survival, but we used those factors pertinent to our analysis and that had statistically significant effects on survival. Those factors for which we included coefficients estimated by Newman (2003) were: river inflow, river temperature, exports, DCC gate position, turbidity, and salinity (Table 1). Newman



(2003) also found significant reductions in survival for fish released upstream at Sacramento rather than at Ryde, but we did not include this effect because the juvenile production (JPE) portion of our model already predicted survival to the point of Delta entry (JPE averages survival estimates from Battle Creek to various points representing Delta entry; Sacramento to Ryde). We also did not include the effect of size, because Newman (2003) showed that estimates of that coefficient changed substantially between model formulations.

The equation we used to estimate survival through the Delta, based on coefficients estimated by Newman (2003) is as follows:

$$\text{Survival} = -1.02 + 0.56 \cdot \log_e(\text{Flow}) - 0.56 \cdot \text{River Temp.} - 0.21 \cdot \text{Exports} + 0.04 \cdot \text{Turbidity} + 0.23 \cdot \text{Salinity} - 0.60 \cdot \text{Gate Position}$$

Where:

Flow = Mean flow in cubic feet per second at Freeport.

River Temp. = Mean temperature in Fahrenheit at Freeport

Export flow = Combined export flow to the State and Federal pumps

Turbidity = Turbidity of river in formazine turbidity units near Courtland

Salinity = water salinity measured by conductivity, $\mu\text{mho/cm}$ at Collinsville

Gate Position = Average of daily positions of the Delta Cross channel gates where each day a value of 0 or 1 signaled both gates closed or open, respectively.

Newman (2003) standardized all variables except the DCC position indicator using the following equation:

$$\text{Standardized Value} = (\text{Observation} - \text{Mean}) / \text{Standard Deviation}$$

The mean and standard deviations for each variable were those reported by Newman (2003) from the observations in the dataset for paired CWT releases.



Table 1. Coefficients for environment variables used to estimate winter-run Chinook Delta survival. Relationship presented is the hierarchical formulation in Table 5 of Newman (2003). These coefficients estimate the logistic transform of survival. Coefficients of all variables except the gate indicator are for standardized variables.

| Covariate | β | SE |
|-------------------------|---------------------------|-----------|
| Intercept | -1.02 | 0.10 |
| \log_e (River Flow) | 0.56 | 0.09 |
| River Temperature °F | -0.56 | 0.07 |
| Export Flow | -0.21 | 0.07 |
| Turbidity | 0.04 | 0.10 |
| Salinity | 0.23 | 0.07 |
| Gate Position Indicator | -0.60 | 0.13 |

The equation we used includes salinity, which Newman (2003) reported was highly correlated to flow ($r = -0.79$). Although the two variables are negatively correlated, they both have a positive effect on survival (coefficients are positive). The combination of these effects results in a non-linear relationship between predicted survival and flow, because increasing flow reduces salinity, which decreases the benefit of flow to survival. We determined the relationship between salinity and flow by regressing salinity at Collinsville since 2000, and Sacramento River inflow at Freeport. The data set was limited to observations taken between December and March, because this is the primary time period when winter Chinook pass through the Delta. There was a strong negative exponential decline in salinity as flow increased ($p < 0.0001$, $r^2 = 0.65$) (Figure 2). This relationship is incorporated into IMF so that simulation of future scenarios including different flows will account for changes that flow causes in salinity. In the simulation of historic conditions, we did not link flow and salinity, but rather input the actual observed values of each.



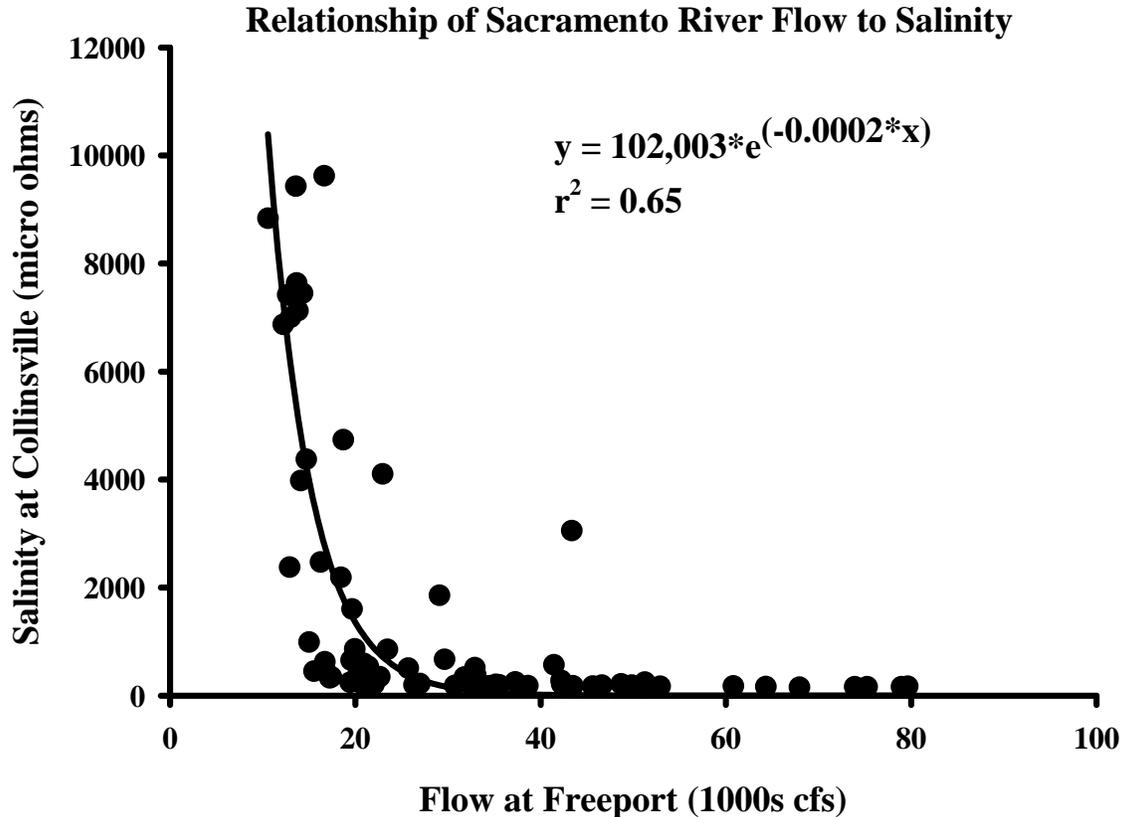


Figure 2. Relationship between Sacramento River flow and salinity in the Delta.

How do the different variables drive the survival estimates?

We analyzed the sensitivity of Delta survival estimates to environmental variables by varying one factor at a time. We examined the ranges for each variable that corresponded to the ranges in the dataset of Newman (2003). When we varied flow in this analysis, we concurrently changed salinity according to the equation presented in Figure 2. The sensitivity of temperature was not examined, because all temperatures in Newman's (2003) data set exceeded the range of temperatures that juvenile winter-run Chinook will encounter when passing through the Delta in December through March. The lowest temperature in the dataset of Newman was 58°F, which is near the upper boundary for optimal growth of juvenile Chinook in a natural setting. Thus, the dataset analyzed by Newman includes temperatures that ranged from the incipient lethal level in the mid 70's F, down to the optimum range for growth. There is little reason to expect that survival would continue to increase as temperature declined below 58°F, given that this is within the optimum range for growth. Therefore, we assumed there was no further benefit to smolt survival as temperature dropped below 58°F (i.e. we assumed the temperature effect was the same as that at 58°F).

The effects of each of the variables on the estimated Delta survival can be seen in Figure 3. The most interesting result was the influence of flow and salinity on survival. As flow increases from a minimum of 6,000 cfs to 15,000 cfs survival

decreases. Though flow has a positive effect on survival, increasing flow results in a decrease in salinity. Reductions in salinity cause decreases in survival. Only up to 15,000 cfs, do the effects of decreasing salinity outweigh the positive effects of increasing flow. Salinity drops to near zero at flows above 20,000 cfs, and survival benefits of increasing flow begin to outweigh the effects of decreasing salinity at approximately 15,000 cfs. The relationships of the other variables to survival, as described by the Newman equation, are linear.

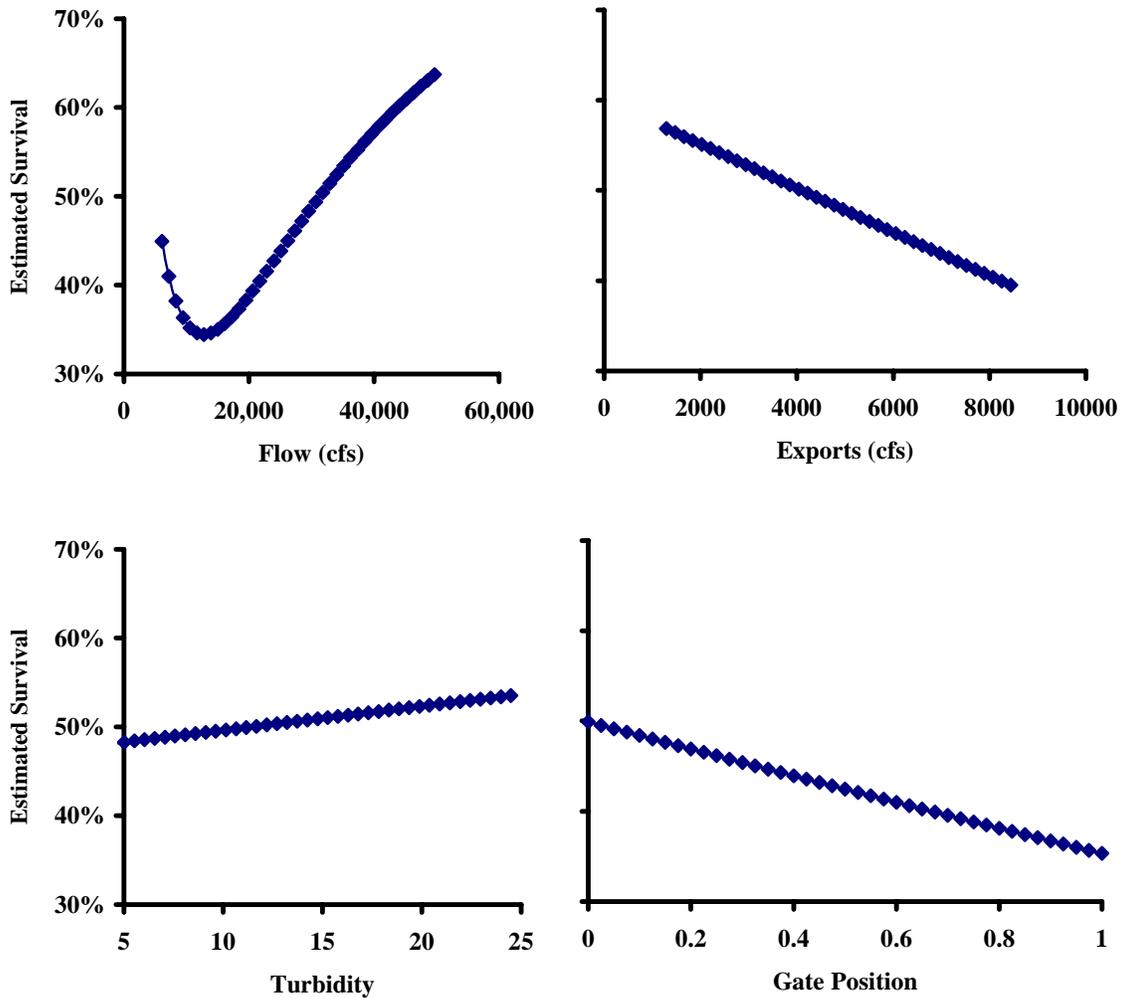


Figure 3. Change in Delta survival predicted by the adapted Newman function used in the IMF. One variable was varied while others were held at their mean value observed during paired releases of CWTs analyzed by Newman (2003). The effect of flow includes a link of flow to salinity according to the equation in Figure 1.

The survival equation just described requires for any simulation that values for environmental variables be supplied for the time frame when juvenile winter-run



Chinook pass through the Delta. Because timing of peak migration varied between years, we next needed to account for differences in timing of winter-run smolt passage through the Delta each year.

When is Peak Migration Through the Delta?

Two peaks in outmigration of winter-run Chinook have generally been apparent each year since 1995-96 from captures of juveniles in the screw traps at Knights Landing, the trawl net at Sacramento, and the trawl net at Chipps Island (Figure 4). In each year, the first significant peak in passage followed the first major increase in flow during late-fall, generally in November or December. Regardless of flow changes, migration also consistently peaked a second time in March or early April, which we assume corresponds to the peak timing of the physiological transition from parr to smolt (seawater adaptation).

How was Survival of Two Migration Groups Modeled?

We accounted for the dual emigration peak in our test simulation of historic conditions by predicting survival for both groups, and averaging the survivals of those two groups. This was equivalent to assuming that half of the smolts passed following the first peak in flow, and the other half passed in March. The true pattern of emigration would have varied substantially from this assumption, but we have yet to develop a more accurate method of predicting smolt migration timing. Timing of passage at Sacramento has only been monitored since 1995-96, so migration timing in prior years was predicted from flows measured at Freeport. We assumed that migration patterns between 1968 and 1994 were similar to those of 1995-2002, in that there would have been a spike in migration following the first peak flow of the season. Passage data during 1995-2002 showed that the initial spike in migration each season lasted between 5 and 18 days following the first peak flow. Consistent with that duration, we predicted survival during the first peak in migration by using the mean values for environmental variables during the 10 days following the first sharp increase in flow. Survival during the second peak in migration that was typically in March [please show the data that make these two emigration periods apparent to everyone] was predicted using means for environmental variables during the full month of March each year.



Although river temperature was a key factor relating to passage survival in the data analyzed by Newman (2003), river temperatures during winter are nearly always lower than the lowest value (58°F) in the data set for fall Chinook used by Newman. Newman (2003) found that passage survival increased as river temperature decreased from 70°F to 58°F. It is doubtful that survival would have increased further as temperature dropped below 58°F, so we assumed the temperature effect at <58°F was the same as that for 58°F. For both migration groups, we assumed temperature was less than 58°F. Sporadic temperature recordings from the Sacramento River at Freeport during November and December of 1968-2002 showed that only 16 of 206 days exceeded 58°F, and the highest was 60.8°F. Of 138 readings in March, only 25 exceeded 58°F, and none exceeded 59.9°F. These data indicate it was reasonable assume average temperature in March was less than 58°F.

Predicted survivals for past years, and the environmental values they were based on, are presented in Figure 5 and Table 2.

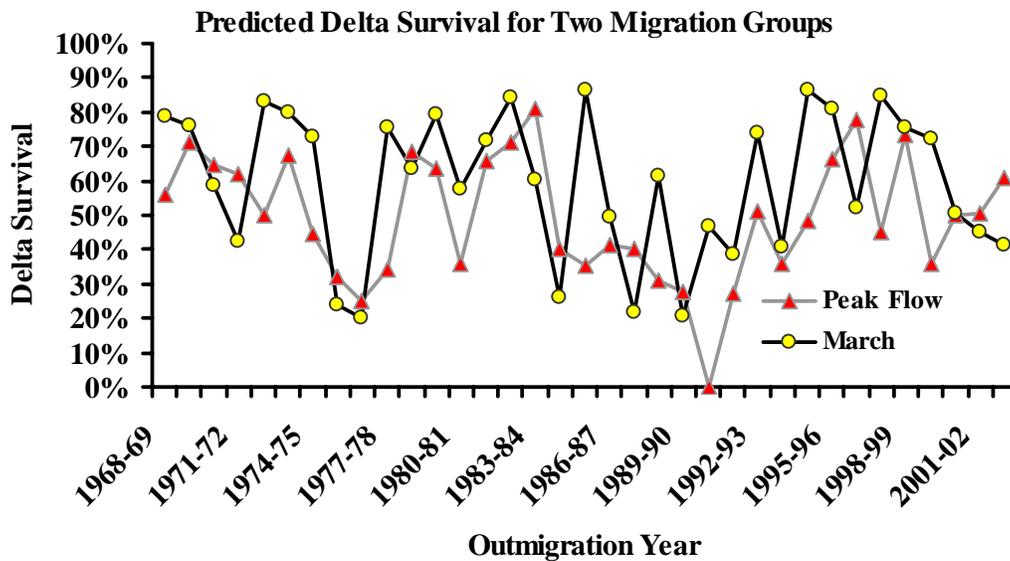


Figure 5. Predicted survival through the Delta during the two peaks in outmigration of winter-run Chinook smolts each year. “Peak flow” refers to the first peak and “March” refers to the second.

Table 2. Values for environmental variables used to predict Delta survival of winter-run Chinook smolts during the first peak (peak flow passage) and second peak (March) in outmigration, 1968-2002. Temperature was assumed to be less than 58°F in all instances. “Peak” and “March” values are 10 and 31-day averages, respectively.

| Run Year | Peak Flow Passage Conditions | | | | | | | | March Conditions | | | | | Total Survival | |
|-------------|------------------------------|---------|---------|-------|----------|-----------|----------|----------|------------------|---------|-------|----------|-----------|-------------------|----------|
| | Start 10 days | Frpt. Q | Exports | Gates | Salinity | Turbidity | Survival | Survival | Frpt. Q | Exports | Gates | Salinity | Turbidity | | Survival |
| 1968-69 | 12-Dec | 25,270 | 2,952 | 0.5 | 517 | 8.2 | 0.25 | 0.56 | 49,730 | 3,403 | 0.0 | 235 | 8.2 | 0.79 | 0.68 |
| 1969-70 | 13-Dec | 29,810 | 1,102 | 0.0 | 221 | 8.2 | 0.92 | 0.71 | 44,210 | 2,265 | 0.2 | 158 | 8.2 | 0.76 | 0.74 |
| 1970-71 | 19-Nov | 24,870 | 2,049 | 0.0 | 167 | 8.2 | 0.59 | 0.64 | 30,480 | 4,702 | 0.4 | 187 | 8.2 | 0.59 | 0.62 |
| 1971-72 | 23-Dec | 27,550 | 1,497 | 0.5 | 212 | 8.2 | 0.48 | 0.62 | 23,900 | 6,601 | 0.7 | 172 | 8.2 | 0.42 | 0.52 |
| 1972-73 | 11-Nov | 22,160 | 3,623 | 0.5 | 275 | 8.2 | 0.00 | 0.50 | 51,640 | 1,331 | 0.0 | 243 | 8.2 | 0.83 | 0.66 |
| 1973-74 | 8-Nov | 44,350 | 5,014 | 0.5 | 327 | 8.2 | 0.73 | 0.68 | 64,680 | 6,200 | 0.0 | 140 | 8.2 | 0.80 | 0.74 |
| 1974-75 | 11-Nov | 20,720 | 1,829 | 1.0 | 161 | 8.2 | -0.21 | 0.45 | 50,940 | 6,061 | 0.2 | 172 | 8.2 | 0.73 | 0.59 |
| 1975-76 | 11-Nov | 21,500 | 7,842 | 1.0 | 190 | 8.2 | -0.75 | 0.32 | 14,570 | 8,410 | 1.0 | 2,224 | 8.2 | 0.24 | 0.28 |
| 1976-77 | 1-Jan | 10,625 | 6,568 | 1.0 | 6,830 | 8.2 | -1.10 | 0.25 | 6,573 | 3,724 | 1.0 | 7,281 | 8.2 | 0.20 | 0.22 |
| 1977-78 | 16-Dec | 17,270 | 8,664 | 1.0 | 7,595 | 8.2 | -0.65 | 0.34 | 55,570 | 5,773 | 0.2 | 194 | 8.2 | 0.75 | 0.55 |
| 1978-79 | 11-Jan | 36,320 | 4,236 | 0.2 | 711 | 8.2 | 0.76 | 0.68 | 29,170 | 4,386 | 0.0 | 199 | 8.2 | 0.63 | 0.66 |
| 1979-80 | 24-Dec | 36,870 | 6,430 | 0.2 | 475 | 8.2 | 0.55 | 0.63 | 55,340 | 4,441 | 0.0 | 203 | 8.2 | 0.80 | 0.72 |
| 1980-81 | 4-Dec | 21,600 | 6,647 | 1.0 | 963 | 8.2 | -0.58 | 0.36 | 24,510 | 4,862 | 0.0 | 254 | 8.2 | 0.58 | 0.47 |
| 1981-82 | 12-Nov | 29,246 | 5,064 | 0.3 | 5,414 | 8.2 | 0.64 | 0.66 | 62,810 | 10,410 | 0.0 | 159 | 8.2 | 0.72 | 0.69 |
| 1982-83 | 18-Nov | 41,510 | 5,231 | 0.0 | 127 | 8.2 | 0.92 | 0.71 | 78,290 | 5,429 | 0.0 | 189 | 8.2 | 0.84 | 0.78 |
| 1983-84 | 11-Nov | 52,120 | 925 | 0.3 | 161 | 8.2 | 1.44 | 0.81 | 31,430 | 6,905 | 0.0 | 202 | 8.2 | 0.60 | 0.71 |
| 1984-85 | 8-Nov | 23,580 | 8,186 | 0.6 | 677 | 8.2 | -0.40 | 0.40 | 14,310 | 8,599 | 0.5 | 575 | 8.2 | 0.26 | 0.33 |
| 1985-86 | 24-Nov | 17,400 | 9,460 | 0.7 | 6,445 | 8.2 | -0.61 | 0.35 | 74,980 | 3,219 | 0.0 | 194 | 8.2 | 0.86 | 0.61 |
| 1986-87 | 4-Jan | 15,200 | 6,290 | 0.0 | 1,523 | 8.2 | -0.35 | 0.41 | 21,580 | 5,596 | 0.2 | 418 | 8.2 | 0.49 | 0.45 |
| 1987-88 | 3-Dec | 19,150 | 7,005 | 1.0 | 6,984 | 8.2 | -0.40 | 0.40 | 11,350 | 8,479 | 1.0 | 5,791 | 8.2 | 0.22 | 0.31 |
| 1988-89 | 24-Nov | 17,240 | 8,795 | 0.9 | 4,580 | 8.2 | -0.79 | 0.31 | 43,370 | 10,288 | 0.2 | 1,881 | 8.2 | 0.61 | 0.46 |
| 1989-90 | 21-Oct | 16,960 | 10,643 | 1.0 | 6,089 | 8.2 | -0.96 | 0.28 | 12,870 | 10,611 | 1.0 | 5,279 | 8.2 | 0.21 | 0.24 |
| 1990-91 | none | -- | -- | -- | -- | -- | -- | -- | 25,760 | 9,794 | 0.3 | 2,975 | 8.2 | 0.47 | 0.47 |
| 1991-92 | 6-Jan | 13,346 | 8,611 | 1.0 | 7,205 | 8.2 | -0.99 | 0.27 | 20,340 | 10,490 | 0.0 | 326 | 8.2 | 0.38 | 0.33 |
| 1992-93 | 9-Dec | 20,340 | 2,890 | 0.9 | 5,364 | 8.2 | 0.04 | 0.51 | 49,340 | 6,117 | 0.0 | 268 | 8.2 | 0.74 | 0.63 |
| 1993-94 | 7-Dec | 23,860 | 10,686 | 1.0 | 5,272 | 8.2 | -0.59 | 0.36 | 13,460 | 4,311 | 0.0 | 459 | 8.2 | 0.41 | 0.38 |
| 1994-95 | 4-Dec | 20,660 | 6,132 | 0.5 | 4,782 | 8.2 | -0.05 | 0.49 | 71,920 | 2,956 | 0.0 | 226 | 8.2 | 0.86 | 0.67 |
| 1995-96 | 18-Dec | 31,820 | 4,360 | 0.0 | 148 | 8.2 | 0.67 | 0.66 | 56,240 | 3,677 | 0.0 | 136 | 8.2 | 0.81 | 0.74 |
| 1996-97 | 10-Dec | 69,000 | 8,320 | 0.0 | 131 | 8.2 | 1.25 | 0.78 | 24,470 | 7,132 | 0.0 | 202 | 8.2 | 0.52 | 0.65 |
| 1997-98 | 24-Nov | 22,400 | 10,785 | 0.2 | 5,493 | 8.2 | -0.19 | 0.45 | 63,830 | 2,507 | 0.0 | 262 | 8.2 | 0.85 | 0.65 |
| 1998-99 | 23-Nov | 33,680 | 1,654 | 0.0 | 134 | 8.2 | 1.01 | 0.73 | 56,840 | 7,223 | 0.0 | 167 | 8.2 | 0.75 | 0.74 |
| 1999-00 | 11-Jan | 18,410 | 9,146 | 0.6 | 4,522 | 8.2 | -0.57 | 0.36 | 58,560 | 9,152 | 0.0 | 171 | 8.2 | 0.72 | 0.54 |
| 2000-01 | 9-Jan | 19,190 | 4,496 | 0.6 | 5,658 | 8.2 | 0.01 | 0.50 | 24,700 | 7,932 | 0.0 | 301 | 8.2 | 0.50 | 0.50 |
| 2001-02 | 24-Nov | 19,690 | 5,291 | 0.5 | 5,563 | 8.2 | 0.02 | 0.50 | 21,320 | 8,276 | 0.0 | 317 | 8.2 | 0.45 | 0.48 |
| 2002-03 | 14-Dec | 41,831 | 10,058 | 0.3 | 2,917 | 8.2 | 0.44 | 0.61 | 22,960 | 10,855 | 0.0 | 289 | 8.2 | 0.41 | 0.51 |



How do conditions during the paired CWT experiments analyzed by Newman compare to those during migration of winter-run smolts?

The current Delta survival function used in the IMF was developed using paired CWT release groups of fall-run Chinook. Though this method uses the best available data on smolt survival through the Delta, environmental conditions during emigration of fall-run Chinook generally differ from those during emigration of winter-run Chinook. Some parameters applied in the winter Chinook model are outside the range of observations used by Newman (2003). Because of our concern for predicting survival when environmental factors were outside the range of values analyzed by Newman, we examined the frequency with which winter conditions fell outside the range of analyzed data. We compared frequency distributions for environmental variables in the dataset analyzed by Newman to those for the period of Delta passage by winter-run Chinook smolts during 1968-2001. These comparisons were precautionary, to help us understand the extent that conditions for which we were predicting survival overlapped with the conditions used to develop the prediction function.

Sacramento River Flow

Sacramento River flow at Freeport during emigration of CWT groups evaluated by Newman (2003) ranged from 6,085 to 50,800 cubic feet per second (cfs). The frequency distribution of flow data indicates that CWT groups were generally released at flows between 5,000 and 15,000 cfs, with most at flows of 12,500 to 15,000 cfs (Figure 6). Few CWT groups were released at flows greater than 35,000 cfs (Figure 6), so the predicted increases in survival related to flows above 35,000 cfs should be accepted with caution. About one third of historic flows during winter-run smolt passage were greater than 35,000 cfs (Figure 4). We regard the survival effects of flow above 35,000 as a critical uncertainty that needs testing.

Frequency Distribution of Flow Values

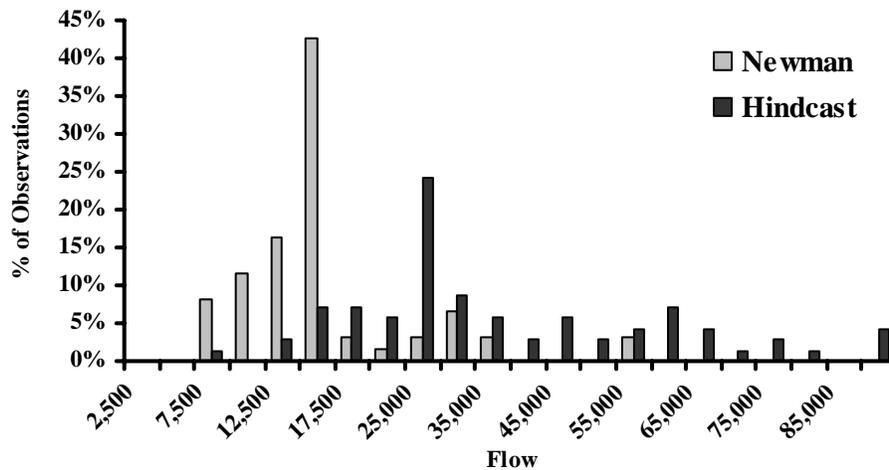


Figure 6. Frequency distributions of Sacramento River flows during the CWT releases analyzed by Newman (2003) compared to those used to predict historic values of Delta survival for winter-run Chinook smolts during 1968-2001.

Water Temperature

Water temperatures during the paired CWT releases analyzed by Newman (2003) ranged from 58°F to 76°F, while water temperatures during winter-run emigration (November through March) were nearly always <58°F. Water temperatures during the paired CWT releases were most often in the 61 - 64°F range, although temperatures in the upper 60's and low to mid 70's were common (Figure 7). The lowest and highest temperatures from the paired CWT data set were often associated with extremes in flow for the data set, i.e. low temperatures were generally associated with relatively high flows, and high temperatures with low flows.

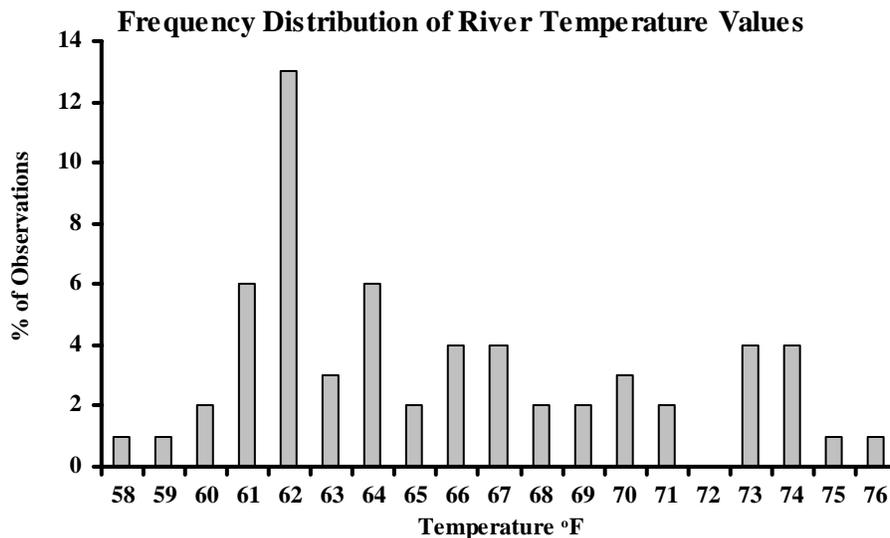


Figure 7. Frequency distribution of temperature observations used by Newman (2003) to estimate Delta survival.

Exports

Delta exports during emigration of CWT groups evaluated by Newman (2003) ranged from 1,289 to 6,821 cubic feet per second (cfs). The frequency distribution of export data indicates that CWT groups were generally released while exports were between 2,000 and 9,000 cfs (Figure 8).

Exports for the historic conditions that were simulated in the hindcast test of the IMF were generally similar to those in the data set analyzed by Newman (2003) (Figure 8). Only the occasional export rates exceeding 10,000 cfs during juvenile winter-run passage were outside the range of the Newman dataset. Thus, the Newman's coefficient for predicting the effect of exports on survival should be reasonable for winter-run Chinook, if there is little interaction of export rate with other environmental variables. The potential for interactive effects of exports and flow is high, so again, studies of survival at higher flows are needed to test the accuracy of predicted export effects on survival.

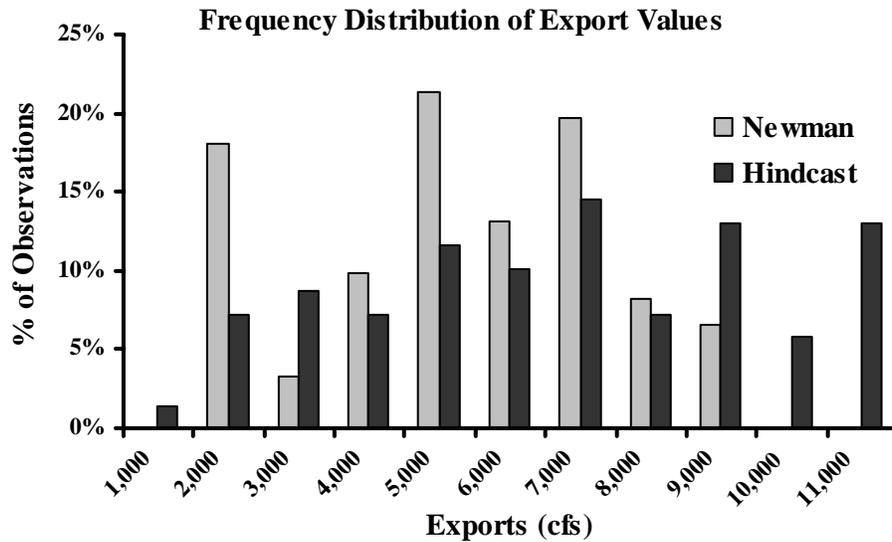


Figure 8. Frequency distribution of observed water export volumes in the dataset used by Newman (2003) and those used to predict historic values of Delta survival for winter-run Chinook smolts during 1968-2001.

Salinity

Salinity during emigration of CWT groups evaluated by Newman (2003) ranged from 160-12,873 μ mhos, and was most often less than 1,000 μ mhos. The same held true for historic values during outmigration of winter-run Chinook smolts. Thus, the coefficient for salinity in Newman’s function (Table 1) should be appropriate for winter-run Chinook.

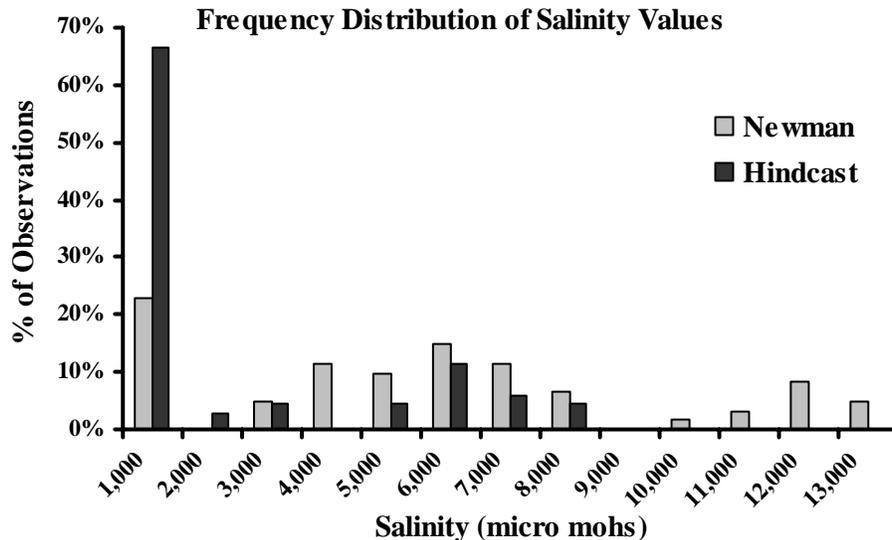


Figure 9. Frequency distribution of observed salinity in the dataset used by Newman (2003) and those used to predict historic values of Delta survival for winter-run Chinook smolts during 1968-2001. X-axis labels give upper bound of interval.



Alternative Evidence for Predicting Delta Survival in the Winter

We checked the reliability of the Newman (2003) function for predicting Delta survival in the winter by comparing its predictions to analyses and modeling of Brandes (personal communication, USFWS, Stockton) that were based on field experiments at the Delta Cross Channel (DCC) with late-fall-run Chinook during November to January. CWT experiments to evaluate effects of the DCC have been conducted in the Delta during November- January each winter since 1995. Data from those experiments provided an opportunity to check how well the observed smolt survivals during winter fit the predictions of the Newman equation, given the actual conditions that existed at the time of the late-fall CWT experiments. The results of this comparison, as will be described, indicate that the Newman equation can be used to predict survival through the Delta in the winter.

Experimental releases of late-fall Chinook near the DCC in November through January were not conducted so as to directly estimate overall of juvenile salmon survival through the Delta from Sacramento to Chipps Island (as the Newman equation does), but rather they provided ratios for expanded recovery rates in the Chipps Island trawl of fish passing through Georgiana Slough versus those passing down the main Sacramento River to Chipps Island. By making some simplifying assumptions, Pat Brandes (USFWS) was able to use the GS/Ryde recovery ratio in a five-step model to estimate survival from Sacramento to Chipps Island. Her model was based on the assumptions that (a) the proportion of juveniles following migration routes through the central Delta is equal to the proportion of Sacramento flow entering the central Delta, and that (b) Delta survival of juveniles continuing down the main stem Sacramento River to Chipps Island is constant at 80%. We compared the estimates from her model to predictions from the Newman equation to see if the results corroborated each other.

The model by Brandes to estimate survival of juvenile Chinook migrating through the Delta in winter used the following steps:

1. Because there was a limited number of tests performed with CWT groups, each at a discrete flow, Brandes needed first to quantify how survival varied across the continuous range of flows tested. To do this she regressed the GS/Ryde survival ratio from late-fall experiments on the export rates averaged for three days after release of each CWT group.
2. The regression in step 1 was then used to estimate the average GS/Ryde survival ratio for a given winter based on the mean export level between December 1 and April 15 that winter.
3. The proportion of smolts continuing down the main stem versus entering the Central Delta was assumed equal to the proportions of flow passing those two routes during the month of December.
4. The actual survival from Ryde to Chipps Island was assumed to be 80%, which is in the range of direct estimates in the spring, as calculated by Newman (2003).
5. Given the values calculated in steps 1-4, the survivals for the Interior Delta route



could be calculated and survivals from the two routes could be combined to estimate average survival through the Delta.

The equations and data used to complete the preceding five steps are described in more detail here. Experiments using late fall hatchery fish from Coleman National Fish Hatchery were used to estimate survival index ratios between fish migrating from Ryde and through the mainstem Sacramento and Georgiana Slough migration through the interior Delta. Brandes found that GS:Ryde survival index ratios were negatively correlated to average exports three days after release of the experimental groups, as defined by the equation:

$$\text{GS:R} = (3 \times 10^{-5}) * \text{Exports} + 0.4583$$

Where:

GS:R = Georgian Slough to Ryde survival index ratio

This relationship was subsequently used in the Brandes model to estimate Delta migration survival via the equation:

$$S = (S_M(P_M) + S_I(P_I))/100$$

and

$$S_I = (G:R) * S_M$$

Where:

S = Survival index of all migrants

S_M = Survival index of fish migrating through the mainstem (assumed to be 0.8)

S_I = Survival index of fish migrating through the interior Delta

P_M = Proportion of outmigrants migrating through the mainstem; assumed equal to the

proportion of flow not diverted from the mainstem in December.

P_I = Proportion of outmigrants migrating through the interior Delta; assumed equal to the

proportion of flow diverted from the mainstem in December.

Brandes estimated Delta survival of late fall Chinook via this model using the percent of water diverted in December and the mean exports between December 1 and April 15 for the migration years of 1995-96 to 2002-03. We compared the survival estimates of Brandes to Delta survival as estimated via the Newman equation under the same environmental conditions.

Survival estimates of the two methods were strongly and significantly correlated ($p < 0.001$; $r^2 = 0.80$) (Figure 10). This correlation of estimates from models developed with independent data indicates that both models capture similar variation due to the factors affecting late-fall run survival through the Delta. Although the Newman model predicts that survivals will reach higher highs and lower lows than the Brandes model, the two models correspond in predicting which conditions will produce high or low survival. The Brandes model is driven primarily by the assumptions that the proportion of outmigrants entering the interior Delta is equal to the proportion of flow diverted to the interior Delta, and that variation in the GS/Ryde recovery ratio during



winter is driven by variation in survival only through the interior Delta (GS release groups). The Newman equation does not distinguish which fish take which route, and is driven primarily by total flow, export flow, and DCC gate position. The corroboration of the two models lends support to assumptions made and relationships used within each model, and gives added credence to their respective results.

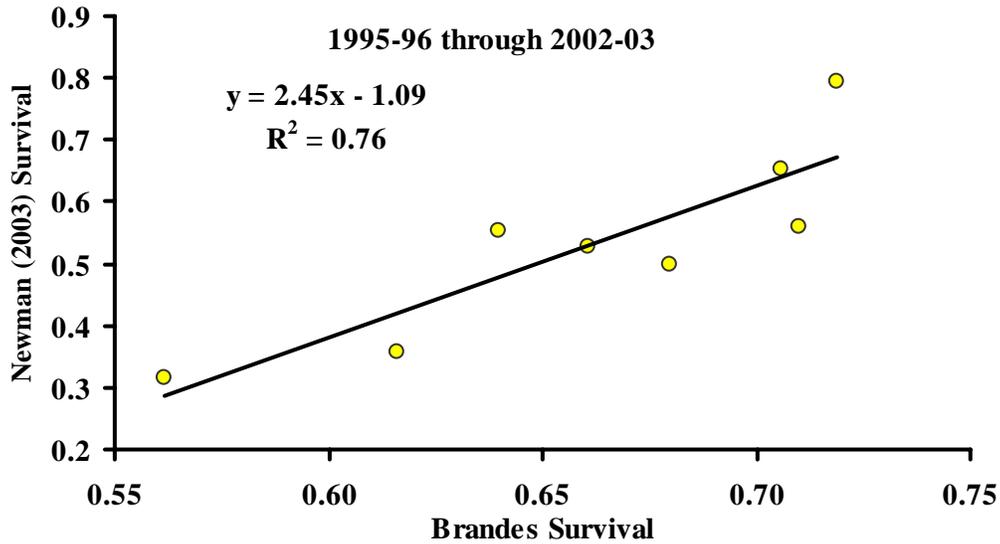


Figure 10. Relationship between survival predictions by the methods of Brandes vs those of Newman for winter-run Chinook smolts passing through the Delta during the winters of 1995-96 through 2002-03.

Table 3. Environmental values used in the Brandes and Newman models, and the associated estimates of survival for winter-run Chinook smolts passing through the Delta.

| Year | Brandes | | Newman | | | | | | |
|---------|------------|----------|------------|----------|---------|-----------|----------|-----------|----------|
| | % Diverted | Survival | Flow (cfs) | Temp (F) | Exports | Gate Pos. | Salinity | Turbidity | Survival |
| 1995-96 | 26 | 0.66 | 24,570 | <58 | 5,143 | 0 | 853 | 8.2 | 0.82 |
| 1996-97 | 15 | 0.72 | 58,420 | <58 | 5,418 | 0 | 469 | 8.2 | 0.95 |
| 1997-98 | 17 | 0.71 | 22,010 | <58 | 4,858 | 0 | 1,398 | 8.2 | 0.75 |
| 1998-99 | 15 | 0.71 | 44,370 | <58 | 9,000 | 0 | 108 | 8.2 | 0.95 |
| 1999-00 | 31 | 0.62 | 16,550 | <58 | 7,550 | 1 | 3,716 | 8.2 | 0.62 |
| 2000-01 | 40 | 0.56 | 13,669 | <58 | 7,687 | 1 | 7,893 | 8.2 | 0.41 |
| 2001-02 | 19 | 0.68 | 27,380 | <58 | 9,234 | 0 | 930 | 8.2 | 0.83 |
| 2002-03 | 25 | 0.64 | 29189 | <58 | 9,516 | 0 | 4,320 | 8.2 | 0.55 |

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APPENDIX 2. INPUT VALUES USED TO RECONSTRUCT HISTORICAL ESTIMATES OF FRY PRODUCTION. ESTIMATES OF FRY ABUNDANCE WERE USED ALONG WITH RECONSTRUCTED ESTIMATES OF SMOLT PRODUCTION TO DEVELOP THE BEVERTON-HOLT FUNCTION FOR FRY-TO-SMOLT SURVIVAL.

| Return/Brood Year | Escapement | | | | | |
|-------------------|------------------------------|------------------------------------|-------------------------|--------------------------------|------------------------------|---------------|
| | Total Spawners above RBDD | Prespawning Adult Survival Rate | Female Spawner Ratio | No. Eggs per Female Spawner | Egg Survival from Hi Temp | Number of Fry |
| 1968 | 84,414 | 0.95 | 0.65 | 3800 | 1 | 49,519,363 |
| 1969 | 117,808 | 0.95 | 0.65 | 3800 | 1 | 69,109,118 |
| 1970 | 45673 | 0.95 | 0.65 | 3800 | 1 | 26,792,924 |
| 1971 | 53089 | 0.95 | 0.65 | 3800 | 1 | 31,143,335 |
| 1972 | 35929 | 0.95 | 0.65 | 3800 | 1 | 21,076,850 |
| 1973 | 22651 | 0.95 | 0.65 | 3800 | 1 | 13,287,643 |
| 1974 | 18536 | 0.95 | 0.65 | 3800 | 1 | 10,873,681 |
| 1975 | 22579 | 0.95 | 0.65 | 3800 | 1 | 13,245,406 |
| 1976 | 33029 | 0.95 | 0.65 | 3800 | 0.61 | 11,819,139 |
| 1977 | 16470 | 0.95 | 0.65 | 3800 | 0.2 | 1,932,343 |
| 1978 | 24735 | 0.95 | 0.65 | 3800 | 1 | 14,510,169 |
| 1979 | 2339 | 0.95 | 0.65 | 3800 | 1 | 1,372,116 |
| 1980 | 1142 | 0.95 | 0.65 | 3800 | 1 | 669,926 |
| 1981 | 19795 | 0.95 | 0.65 | 3800 | 1 | 11,612,242 |
| 1982 | 1233 | 0.95 | 0.65 | 3800 | 1 | 723,309 |
| 1983 | 1827 | 0.95 | 0.65 | 3800 | 1 | 1,071,764 |
| 1984 | 2662 | 0.95 | 0.65 | 3800 | 1 | 1,561,596 |
| 1985 | 3684 | 0.95 | 0.65 | 3800 | 0.88 | 1,901,791 |
| 1986 | 2596 | 0.95 | 0.65 | 3800 | 1 | 1,522,879 |
| 1987 | 2088 | 0.95 | 0.65 | 3800 | 0.92 | 1,126,883 |
| 1988 | 2150 | 0.95 | 0.65 | 3800 | 0.84 | 1,059,445 |
| 1989 | 640 | 0.95 | 0.65 | 3800 | 0.94 | 352,914 |
| 1990 | 388 | 0.95 | 0.65 | 3800 | 0.75 | 170,708 |
| 1991 | 178 | 0.95 | 0.65 | 3800 | 0.925 | 96,588 |
| 1992 | 1162 | 0.95 | 0.65 | 3800 | 0.959 | 653,710 |
| 1993 | 378 | 0.95 | 0.65 | 3800 | 1 | 221,744 |
| 1994 | 144 | 0.95 | 0.65 | 3800 | 1 | 84,474 |



| Return/Brood Year | Escapement | | | | | |
|-------------------|------------------------------|------------------------------------|-------------------------|--------------------------------|------------------------------|---------------|
| | Total Spawners above RBDD | Prespawning Adult Survival Rate | Female Spawner Ratio | No. Eggs per Female Spawner | Egg Survival from Hi Temp | Number of Fry |
| 1995 | 1159 | 0.95 | 0.65 | 3800 | 1 | 679,898 |
| 1996 | 1012 | 1 | 0.65 | 3800 | 1 | 624,910 |
| 1997 | 836 | 1 | 0.65 | 3800 | 1 | 516,230 |
| 1998 | 2831 | 1 | 0.65 | 3800 | 1 | 1,748,143 |
| 1999 | 3264 | 1 | 0.65 | 3800 | 1 | 2,015,520 |
| 2000 | 1263 | 1 | 0.65 | 3800 | 1 | 779,903 |
| 2001 | 8085 | 1 | 0.65 | 3800 | 1 | 4,992,488 |
| 2002 | 7325 | 1 | 0.65 | 3800 | 1 | 4,523,188 |
| 2003 | 8,105 | 1 | 0.65 | 3800 | 1 | 5,004,838 |



APPENDIX 3. INPUT VALUES USED TO RECONSTRUCT HISTORICAL ESTIMATES OF SMOLT PRODUCTION. ESTIMATES OF SMOLT ABUNDANCE WERE USED ALONG WITH RECONSTRUCTED ESTIMATES OF SMOLT PRODUCTION TO DEVELOP THE BEVERTON-HOLT FUNCTION FOR FRY-TO-SMOLT SURVIVAL.

| Run Year | Escapement Total Spawners above RBDD | Percent Hatchery Fish | % of Run Blocked | Age Composition | | | Freshwater Harvest Rate by Age | Age specific ocean harvest rate | | Ocean Entry Survival | Delta Survival | Smolts In- river |
|----------|---|-----------------------------|------------------------|-----------------|-------|------|---|------------------------------------|------|----------------------------|-------------------|---------------------|
| | | | | 2 | 3 | 4 | 3/4 | 3 | 4 | | | |
| 1966 | | | | | | | | | | | | |
| 1967 | | | | | | | | | | | | |
| 1968 | 84,414 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.1 | 0.29 | 0.44 | | | |
| 1969 | 117,808 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.06 | 0.28 | 0.42 | | | |
| 1970 | 45,673 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.04 | 0.36 | 0.56 | 0.04 | 0.95 | 10,178,511 |
| 1971 | 53,089 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.18 | 0.34 | 0.53 | 0.04 | 0.95 | 6,502,965 |
| 1972 | 35,929 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.14 | 0.31 | 0.48 | 0.04 | 0.96 | 5,915,042 |
| 1973 | 22,651 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.11 | 0.3 | 0.46 | 0.04 | 0.98 | 3,867,310 |
| 1974 | 18,536 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.09 | 0.29 | 0.45 | 0.04 | 0.95 | 2,531,436 |
| 1975 | 22,579 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.07 | 0.31 | 0.48 | 0.04 | 0.90 | 2,185,758 |
| 1976 | 33,029 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.09 | 0.34 | 0.53 | 0.04 | 0.95 | 2,647,370 |
| 1977 | 16,470 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.09 | 0.32 | 0.5 | 0.04 | 0.98 | 3,124,683 |
| 1978 | 24,735 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.09 | 0.32 | 0.5 | 0.04 | 0.93 | 2,277,031 |
| 1979 | 2,339 | 0 | 0.4 | 0.25 | 0.67 | 0.08 | 0.09 | 0.31 | 0.48 | 0.04 | 0.69 | 2,892,153 |
| 1980 | 1,142 | 0.25 | 0.4 | 0.175 | 0.785 | 0.04 | 0.09 | 0.35 | 0.55 | 0.04 | 0.60 | 830,293 |
| 1981 | 19,795 | 0 | 0.4 | 0.175 | 0.785 | 0.04 | 0.09 | 0.31 | 0.48 | 0.04 | 0.88 | 355,472 |
| 1982 | 1,233 | 0 | 0.4 | 0.175 | 0.785 | 0.04 | 0.09 | 0.29 | 0.44 | 0.04 | 0.96 | 1,700,317 |
| 1983 | 1,827 | 0 | 0.4 | 0.175 | 0.785 | 0.04 | 0.087 | 0.25 | 0.39 | 0.04 | 0.97 | 302,173 |
| 1984 | 2,662 | 0.1 | 0.4 | 0.175 | 0.785 | 0.04 | 0.087 | 0.33 | 0.51 | 0.04 | 0.87 | 196,829 |
| 1985 | 3,684 | 0 | 0.4 | 0.175 | 0.785 | 0.04 | 0.087 | 0.36 | 0.56 | 0.04 | 0.97 | 270,522 |
| 1986 | 2,596 | 0 | 0.4 | 0.175 | 0.785 | 0.04 | 0.087 | 0.38 | 0.59 | 0.04 | 0.98 | 386,406 |
| 1987 | 2,088 | 0 | 0.044 | 0.175 | 0.785 | 0.04 | 0.013 | 0.37 | 0.57 | 0.04 | 0.96 | 294,606 |
| 1988 | 2,150 | 0 | 0.257 | 0.175 | 0.785 | 0.04 | 0.042 | 0.39 | 0.6 | 0.04 | 0.75 | 207,746 |
| 1989 | 682 | 0 | 0.022 | 0.175 | 0.785 | 0.04 | 0.031 | 0.35 | 0.54 | 0.04 | 0.89 | 189,447 |
| 1990 | 402 | 0 | 0.072 | 0.175 | 0.785 | 0.04 | 0.05 | 0.35 | 0.54 | 0.04 | 0.86 | 61,157 |



| Run Year | Escapement Total Spawners above RBDD | Percent Hatchery Fish | % of Run Blocked | Age Composition | | | Freshwater Harvest Rate by Age | Age specific ocean harvest rate | | Ocean Entry Survival | Delta Survival | Smolts In- river |
|----------|---|-----------------------------|------------------------|-----------------|-------|------|---|------------------------------------|------|----------------------------|-------------------|---------------------|
| | | | | 2 | 3 | 4 | 3/4 | 3 | 4 | | | |
| 1991 | 211 | 0.5 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.35 | 0.55 | 0.04 | 0.72 | 36,360 |
| 1992 | 1,196 | 0.07 | 0.037 | 0.175 | 0.785 | 0.04 | 0.05 | 0.36 | 0.56 | 0.04 | 0.85 | 18,794 |
| 1993 | 378 | 0.09 | 0.008 | 0.175 | 0.785 | 0.04 | 0.05 | 0.38 | 0.59 | 0.04 | 0.63 | 98,047 |
| 1994 | 186 | 0.25 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.31 | 0.48 | 0.04 | 0.88 | 28,671 |
| 1995 | 1,202 | 0.03 | 0.005 | 0.175 | 0.785 | 0.04 | 0.05 | 0.32 | 0.49 | 0.04 | 0.75 | 20,479 |
| 1996 | 1,012 | 0.31 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.27 | 0.41 | 0.04 | 0.94 | 63,655 |
| 1997 | 836 | 0.05 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.27 | 0.41 | 0.04 | 0.81 | 52,652 |
| 1998 | 2,930 | 0.02 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.21 | 0.32 | 0.04 | 0.94 | 56,691 |
| 1999 | 3,288 | 0.01 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.23 | 0.15 | 0.04 | 0.97 | 142,315 |
| 2000 | 1,352 | 0.12 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.2 | 0.57 | 0.04 | 0.94 | 177,847 |
| 2001 | 8,189 | 0.05 | 0.004 | 0.175 | 0.785 | 0.04 | 0.05 | 0.21 | 0.74 | 0.04 | 0.93 | 161,833 |
| 2002 | 7,429 | 0.1 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.21 | 0.65 | 0.04 | 0.98 | 404,254 |
| 2003 | 8,190 | 0.1 | 0 | 0.175 | 0.785 | 0.04 | 0.05 | 0.21 | 0.65 | 0.04 | 0.89 | 440,653 |

