A Revised Sacramento River Winter Chinook Salmon Juvenile Production Model

Prepared by:
Kristopher Jones
Paul Bergman

Prepared for:
The National Oceanic and Atmospheric Administration (NOAA)
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INTRODUCTION

There are four runs (or “races”) of chinook salmon (*Oncorhynchus tshawytscha*) present in the upper Sacramento River California, which can be distinguished by the season adults return to spawn. Over the past 25 years, all four runs of chinook have experienced declining numbers. Winter chinook salmon abundance was estimated as high as 53,089 in 1970, but abundance estimates for the most recent years (2007-2009) were between 2,542 and 4,658 (CDFG 2010).

Historically, winter chinook spawned in spring-fed streams which provided cool summertime habitat for spawning, incubation and rearing (Yoshiyama et al. 1998). The upper Sacramento River drainage once provided ideal conditions for winter chinook due to the cool water, which would last year round from glacier and snow melt from Mount Shasta and Mount Lassen. However, following the construction of numerous small dams in the upper Sacramento River and its tributaries during the early part of the 20th Century, the reproductive potential of winter chinook were greatly reduced (e.g., after the dams prevented them from reaching their historic spawning grounds; Yoshiyama et al. 1998). Moreover, fluctuating water temperatures from dam operations have also reduced reproductive success of winter-chinook, by resulting in poor conditions for incubating eggs (NMFS 1997).

Since receiving endangered status in 1994, a number of measures have been taken to assist in the recovery of winter-run chinook. For example, in order to limit entrainment of juvenile winter-run chinook during their outmigration through the Delta, water exports are being adaptively managed from the Central Valley Project’s Tracy Pumping Plant and the State Water Project’s Harvey Banks Delta Pumping Plant in the Sacramento-San Joaquin Delta. In order to make quantitative assessments for entrainment of winter-chinook, the National Oceanic and Atmospheric Administration’s National Marine Fisheries Service (NOAA Fisheries) has annually estimated the abundance of juvenile winter-chinook entering the Delta. However, there are limitations to the methods used to derive these estimates. For example, the methods used previously to obtain juvenile production estimates (JPEs) did not account for environmental factors which are known to be important for the development and survival of juvenile salmonids. Although the JPE calculations did account for egg loss due to temperature effects, these estimates did not account for daily fluctuations that affect individual cohorts of fish developing through the season. Moreover, previous work has demonstrated that flow is a key predictor of juvenile survival during their outmigration in the Snake River (Williams and Mathews 1995) and Sacramento River (Brandes & McLain 2001). Yet, differences in survival associated with flow conditions were not accounted for in the original JPE calculations.

Lastly, uncertainty in juvenile production estimates was not included in the previous JPE models. For a model to be useful, predicted values need to be accompanied by measures of precision.
(McCullagh and Nelder 1999). Three major categories of uncertainty exist in fisheries data: random fluctuations (‘noise’), uncertainty in parameter estimates, and structural uncertainty (Charles 1998). Error associated with random fluctuations of observed data and parameter estimation error can be incorporated into predictive models to inform the precision of predicted values. Structural uncertainty, or uncertainty in the basic nature of the fishery system, its dynamics and internal interactions, can have a considerable effect on fisheries models (Charles 1998). Instances of structural uncertainty include: uncertainty in fish migration patterns, predator-prey effects, effects of environmental conditions (Charles 1998). Because structural uncertainties reflect a fundamental lack of knowledge about the fishery system (Charles 1998), their associated error is usually unknown. The best that modelers can do is hope to reduce the level of structural uncertainty by using the best available information from literature to inform model function and form.

The goals of this study were to develop an improved JPE model, which would (1) develop a more robust production model by incorporating the best available information on juvenile chinook salmon production and incorporating model error wherever data on uncertainty was available (2) enable NMFS to derive JPE values with associated error; and (3) allow flexibility for making calculations sequentially as updated data becomes available. At the end of this document we provide a user manual which details directions for use of the revised JPE model.

METHODS

The JPE model uses a systems dynamics computer simulation modeling framework, a technique that is used for framing and understanding the behavior of complex systems over time. System dynamics models are made up of stocks (e.g. number of fish) and flows (e.g. sources of mortality) that influence the stocks and are informed by mathematical equations (Ford 1999). The JPE model was implemented in the software GoldSim, which enables the simulation of complex processes through creation of simple object relationships, incorporates Monte Carlo stochastic methods, and includes interactive, user-friendly interfaces (Rizzo et al. 2006). The model is composed of three submodels: Spawning, Development, and Downstream Migration (Figure 1).
The model is first seeded with the number of female spawners for the current spawning year. In order to ensure that developing fish experience the correct environmental conditions, spawn timing mimics the observed spawning distribution during carcass surveys (Step 1). Eggs deposited on a particular date are treated as cohorts which experience environmental conditions on a daily time step in the model. A stock-recruitment function is applied in Step 2 to predict the number of emergent fry from the number of female spawners. Even though the stock-recruitment relationship already accounts for temperature effects on egg mortality, in Step 3 additional daily temperature-induced mortality is imposed on incubating eggs for temperatures that go beyond those experienced during the years used to develop the stock-recruitment model (1996-1999, 2002-2007). Each day the proportional maturation of the incubating eggs is predicted from the daily temperature, and eggs continue to mature until 100% maturation is
reached (Step 4). The affect of temperature on fry to smolt mortality during rearing is also accounted for in the model (Step 5). In addition, to account for the effects of flow on the survival of outmigrating juveniles, mean downstream migration survival of smolts to Chipps Island (entrance to bay) is scaled by the average Sacramento River flow experienced during each individual cohort’s migration period (Step 6).

**Spawning**

*Spawning Distribution*

Model timing is initiated with the distribution of female spawners corresponding with observed spawn timing during carcass surveys (Figure 2). The daily number of female spawners was calculated by multiplying the daily proportion of the total carcasses observed from April-September for the main-stem Sacramento River (Doug Killam, personal communication) by the total Jolly Seber estimate of female spawners (Poytress and Carillo 2007). In order to better match the timing of carcass observations to the deposition of eggs, the date of egg deposition was shifted 14 days before the carcasses were observed (Kevin Niemela, personal communication).

![Figure 2](image)

Figure 2. Spawning distribution of winter-run Chinook on the main-stem Sacramento River. Values shown are the proportion of the total female spawners observed on particular dates in brood year 2009. Dates shown are shifted 14 days before carcasses were observed.
Stock-Recruitment Relationship

A Ricker stock-recruitment curve (Ricker 1975) was fit to estimate the total number of winter chinook salmon emergent fry produced each year ($R$) from the number of female spawners ($S$):

$$ R = \alpha S e^{-\beta S} + \varepsilon; $$

where $\alpha$ is a parameter that describes recruitment rate at low spawner abundance, and $\beta$ is a parameter that measures the level of density dependence. Estimates of female spawners are from carcass surveys from the mainstem Sacramento River and estimates of fry production are from juvenile production index (JPI) values calculated from rotary-screw trap catches at Red Bluff Diversion Dam (RBDD) (Poytress and Carillo 2007). All years with available data were included in the analysis (1996-1999 and 2002-2007). Model coefficients were estimated from the log-e-transformed version of the stock-recruitment model:

$$ \log_e \left( \frac{R}{S} \right) = \log_e \alpha - \beta S + \varepsilon. $$

The log-e-transformed model describes the per capita recruitment rate ($\log_e(R/S)$) as a function of the number of female spawners ($S$). The number of female spawners explained less than 0.01% of the variation in winter chinook salmon recruitment rate ($\log_e(R/S)$) in the Sacramento River ($F = 0.03; \text{df} = 1.8; p = 0.866$):

$$ \log_e \left( \frac{R}{S} \right) = \log_e 1089 - 4.47 \times 10^{-6} S + \varepsilon. $$

The density-dependent parameter ($\beta$) did not differ significantly from zero (95% CI = $-6.3 \times 10^{-6} - 5.5 \times 10^{-6}$), indicating that the relationships between emergent fry and female spawners is linear (density independent). Therefore, $\beta$ was removed from the equation and a linear version of the model was estimated:

$$ R = \alpha S. $$

The number of female spawners explained 86% of the residual variation in fry production ($F = 268; \text{df} = 1.9; p < 0.001$)(Figure 3):

$$ R = 1043 \times S. $$
Figure 3. Fry production of winter Chinook salmon as a function of female spawners in the Sacramento River, 1996-1999 and 2002-2007. The observed values are dots, the solid line is the model: \( \text{Recruits} = 1043 \times \text{Spawners} \), and the dashed lines depict the 95% confidence bounds of the predicted values.

In the JPE model, the mean fry production is predicted from the number of female spawners using the stock-recruitment relationship; the predicted mean fry production along with the confidence intervals for the predicted values were used to define a normal probability distribution, which was then randomly sampled to determine the annual fry production (Figure 3).

**Juvenile Development**

In reviewing available literature, temperature emerged as one of the most important environmental factors affecting maturation and survival of developing fishes (Embody 1934; Bailey and Evans 1971; Tang et al. 1987). In addition, temperature is an environmental factor for which there is ample data to associate with cohorts of fish developing in the mainstem Sacramento River. We used data from three experimental studies which explored the relationship between temperature and the survival and maturation time for developing chinook (fall-run: Murray and McPhail 1988, Beacham and Murray 1989; winter-run: USFWS 1999). Mean daily temperatures from Bend Bridge, CA were used in the JPE model (California Department of Water Resources CDEC website) to inform these relationships.
**Temperature-induced mortality**

The stock-recruitment relationship described above already accounts for temperature effects on mortality. In order to account for extreme temperatures, analyses were performed to account for temperatures that go beyond those experienced during the years used in the stock-recruitment model. We used data from the experimental work of the USFWS (1999), which explored the relationship between temperature and the mortality of developing winter-run chinook (from fertilization to emergence). In order to apply these temperature effects to the JPE model, we needed to convert the predicted proportional mortality over the entire incubation period to a daily mortality rate. This conversion allowed us to apply the temperature-mortality relationship on a daily time step in the JPE model. Daily mortality was calculated using methods described in Bartholow and Heasley (2006) as follows:

\[ \text{mortality} = 1 - (1 - \text{total mortality})^{(1/d\text{evelopment time})} \]

Where *total mortality* is the predicted mortality over the entire incubation period observed for a particular water temperature and *development time* was the time to develop from fertilization to emergence.

Due to limited sample size from the study by the USFWS (1999), we were unable to run the appropriate statistical analyses to test for the effects of temperature on mortality (e.g., a general additive model). However, in order to acquire predicted values for the model, the following exponential relationship was fitted between daily mortality and temperatures at Bend Bridge:

\[ \text{daily mortality} = 1.38 \times 10^{-15} e^{(0.503 \times \text{Temp})} \]

The intercept of the daily mortality function was adjusted from the original laboratory data to have temperature-induced mortality only occur at temperatures outside the range observed during the period used to develop the stock-recruitment model (1996-1999, 2002-2007); the 95\(^{\text{th}}\) percentile of the mean daily temperatures observed during the incubation period (May-August) was 57\(^{\circ}\)F for the years used to construct the stock-recruitment model. Therefore, we adjusted the intercept of the daily mortality function so that daily mortality begins at water temperatures above 57\(^{\circ}\)F (Figure 4).
In the JPE model, each day the mean proportional mortality of the incubating eggs is predicted from the daily water temperature using the above polynomial relationship; as described previously, the predicted mean mortality along with the confidence intervals from the predicted values were used to define a normal probability distribution, which was then randomly sampled to determine the daily egg mortality (Figure 4).

Temperature effects on maturation time

In many previous studies salmon egg maturation time has been found to be negatively related to water temperatures (Murray and McPhail 1988; Beacham and Murray 1989; Crisp 1988; Geist et al. 2006). Using data from the aforementioned experiments looking at temperature effects on development (Murray and McPhail 1988; Beacham and Murray 1989) we examined the relationship between maturation time and water temperature. First we converted maturation time (days) to daily maturation rate (1/day):

\[
\text{daily maturation rate} = \frac{1}{\text{maturation time}}
\]
Next, we tested for a significant linear relationship between maturation rate and water temperature. Daily water temperature (Temp) explained 99% of the residual variation in daily maturation rate (\(F = 2188; \text{df} = 1,15; p < 0.001\)) (Figure 6):

\[
daily \text{ maturation rate} = 0.00058 \times \text{Temp} - 0.018
\]

In the JPE model, each day the mean maturation rate of the incubating eggs is predicted from the daily temperature using the above linear function; the predicted mean maturation rate along with the confidence intervals of the predicted values were used to define a normal probability distribution, which was then randomly sampled to determine the daily maturation rate (Figure 5).

![Figure 5](image)

Figure 5. Relationship between daily proportional maturation and mean daily water temperature (°F) and. The observed values are dots, the solid line is the linear model, and the dashed lines depict the 95% confidence bounds of the predicted values.

**Temperature induced rearing mortality**

Using data from the study by USFWS (1999), we were able to incorporate information regarding the effects of temperature on mortality during the fry-smolt rearing period. In their study, fish were reared under three temperature regimes (temperatures were kept constant over the treatment period), and the rearing phase was ended when 100% mortality occurred or fish reached a mean fork length of 85-90 mm. Juvenile chinook >75 mm are generally considered smolts (see Miller et al. 2010), therefore fish were reared for 113 days in the model, as this was the amount of time it took for fish in the experiment to reach ~75 mm. As described above, we needed to convert the predicted proportional mortality over the entire rearing period to a daily mortality rate; we
used the result from the temperature-mortality relationship (USFWS 1999) to calculate a daily mortality (see Bartholow and Heasley 2006). This conversion allowed us to apply the temperature-mortality relationship on a daily time step in the JPE model.

Again, due to limited sample size from the study by the USFWS (1999), we were unable to run statistical analyses to test for the effects of temperature on rearing mortality. However, to acquire predicted values for the model, the following exponential relationship was fitted between daily mortality and temperatures at Bend Bridge:

\[
daily \_mortality = 3.92 \times 10^{-12} e^{(0.349\times Temp)}
\]

In the model, each day the mean proportional mortality of the rearing fish is predicted from the daily temperature using the above exponential relationship; as described above, the predicted mean mortality along with the confidence intervals of the predicted values were used to define a normal probability distribution, which was then randomly sampled to determine the daily mortality of the rearing fish (Figure 6).

![Figure 6. Relationship between daily proportional mortality and mean daily water temperature (°F) at Bend Bridge. The observed values are dots and the solid line is the exponential model. The confidence bounds of the predicted values are too small to be seen on figure.](image-url)
Survival to Chipps Island

Previous studies have found flow during the migration period to be a significant predictor of smolt migration survival (Kjelson and Brandes 1989; Williams and Mathews 1995; Brandes & McLain 2001). Although the shapes of the relationships were not tested, a logarithmic relationship appears evident for fall-run Chinook hatchery smolts released in the north Sacramento-San Joaquin Delta (Kjelson and Brandes 1989; Brandes & McLain 2001) and for spring and summer-run Chinook smolts in the Snake River Basin (Williams and Mathews 1995). Therefore, in the JPE, model mean downstream migration survival of smolts to Chipps Island (entrance to bay) is scaled by the mean Sacramento River flow experienced during each individual cohort’s migration period.

In order to model the downstream migration of smolts in the Sacramento River, we used data from release experiments of coded-wire tagged (CWT) late-fall hatchery Chinook salmon smolts released at Battle Creek, CA (released to mimic wild winter chinook), which were recovered in the Chipps Island Trawl (1994-2006). We applied a delay of 59 days, which was the average travel time of the CWT chinook smolts between their release and capture in the Chipps Island Trawl. Mean daily flow at Freeport (California Department of Water Resources CDEC website) was used in the model to represent flow conditions during the smolt outmigration.

We examined the relationship between the USFWS smolt survival index (SSI) and mean Sacramento River Flow at Freeport, CA during the migration period for CWT surrogate winter Chinook hatchery smolts released at Battle Creek, CA. The SSI is calculated by expanding the number of smolts captured by the Chipps Island mid-water trawl to account for time spent sampling and the ratio of the net width to channel width to form an estimate of absolute abundance (Baker and Morhardt 2001). The expanded recovery is then divided by the number of smolts originally released and reported as the SSI (Baker and Morhardt 2001). Although not significant at an alpha of 0.05 ($F = 2.86; \text{df} = 1,126; p = 0.093$), winter chinook SSI exhibited a positive relationship with log-transformed mean flow ($\text{flow}$) (Figure 7):

$$SSI = 0.0913 \times \text{flow} - 0.4829$$
Each day the mean SSI of migrating smolts is predicted from the log-transformed mean flow during the future 59 day migration period using the above linear function. The predicted mean SSI along with the confidence intervals of the predicted values for SSI were used to define a normal probability distribution, which was then randomly sampled to determine the daily SSI (Figure 7).

Next, the predicted SSI is converted into a scalar that adjusts the default mean survival of migrating smolts (53%; USFWS, unpublished data). The predicted values from the SSI-flow relationship described above is divided by the mean predicted survival to calculate a daily scalar on migration survival (Figure 8). The scalar is then multiplied by 53% (default migration survival) to calculate the survival of the current day’s cohort of migrating smolts.

Figure 7. Coded-wire tagged winter Chinook surrogate SSI as a function of log-transformed mean Sacramento River flow during the migration period. Dots are observed values, solid line is best-fit linear regression, dashed lines depict the 95% confidence bounds of the predicted values.
Model Sensitivity to Environmental Inputs

Methods

We examined model sensitivity to changes in water temperature and flow by running the model under differing annual water temperature and flow regimes that represent the range of recent historical conditions. Input values were held at 2008-2009 values during sensitivity analyses. For both sensitivity analyses, we only included results that were affected by changes in the environmental variable examined.

We examined the sensitivity of model results to changes in annual flow regime. Historical flow data was used to examine the response in downstream migration survival, overall survival (Eggs to smolts entering the bay) and the juvenile production estimate under three different water year types (Critically Dry, Below Normal, and Wet). Water temperatures and spawning number inputs were held at 2008-2009 levels. The number of spawning females was set to 1,462 from the 2008 USFWS carcass survey estimate (Killam 2009). The total and daily number of observed carcasses, used in the model to determine time of egg deposition, was set to 2008 USFWS carcass survey values (USFWS, unpublished data). We conducted 100 Monte Carlo simulations to examine uncertainty in our estimates of survival.
We examined model sensitivity to changes in water temperature regime. First, we examined historical water temperature data at Bend Bridge to select 3 years that represent the range of annual temperature regimes experienced in the Sacramento River. We chose a warm (2008), moderate (2007), and cool (2006) temperature regime to examine model sensitivity (Figure 9). Flows and spawning number inputs were held at 2008-2009 levels. The number of spawning females was set to 1,462 from the 2008 USFWS carcass survey estimate (Killam 2009). The total and daily number of observed carcasses, used in the model to determine time of egg deposition, was set to 2008 USFWS carcass survey values (USFWS, unpublished data). As with the flow analyses, we conducted 100 Monte Carlo simulations to incorporate uncertainty in our estimates of survival.

![Figure 9. Three water temperature regimes used to examine model sensitivity.](image)

**Results**

As the water year type was changed from critically dry to below normal to wet, mean downstream migration survival increased 10.6%, from 47.7% to 58.3%. This increase in migration survival resulted in an increase in overall survival (egg to Bay entry) of 1.3%. The number of juveniles produced increased by 22%, from 427,000 to 522,000.
Figure 10. Sensitivity of model results to changes in annual flow regime. Historical flow data was used to examine the response in downstream migration survival, overall survival (Eggs to smolts entering the bay) and the juvenile production estimate under three different water year types (Critically Dry, Below Normal, and Wet). All other input values were set to 2008-2009 values. The boxes depict the median, 25th percentile, and 75 percentile, the whiskers are the 5th and 95th percentile, and the asterix are the minimum and maximum values. The mean values are highlighted in red.

As the water temperature regime was changed from a cool to moderate to warm year, mean temperature-related egg mortality increased from 0% to 3.2% to 25.1%. This increase in egg mortality resulted in a decrease in overall egg-fry survival of 5.3%. Fry-smolt survival decreased from 93.4% to 78.4% as temperatures were increased. Overall survival (egg to Bay entry) decreased 3.6%, from 9.6% to 6.0%. The number of juveniles produced decreased by 38% as temperatures increased, from 689,000 to 427,000.
Figure 11. Sensitivity of model results to changes in annual water temperature regime. Historical water temperature data was used to examine the response in temperature-related egg mortality, overall egg-fry survival, fry-smolt survival, overall survival (Eggs to smolts entering the bay), and the juvenile production estimate under three different temperature types (Cool: 2006, Moderate: 2007, Warm: 2008). All other input values were set to 2008-2009 values. The boxes depict the median, 25th percentile, and 75th percentile, the whiskers are the 5th and 95th percentile, and the asterix are the minimum and maximum values. The mean values are highlighted in red.
Example Model Run

Methods
To demonstrate an example run of the model, we ran the model under 2008-2009 flow and temperature conditions and set spawner number inputs to 2008 carcass survey estimates (see sensitivity analyses). Therefore, model results depict the predicted JPE and associated survivals for the 2008 brood year. We conducted 100 Monte Carlo simulations to examine uncertainty in our estimates of survival.

Results
The 2008-2009 example run of the JPE model resulted in a mean predicted juvenile production estimate of 427,265 (Figure 12). Predicted juvenile production ranged from 185,540 to 694,910, with a standard deviation of 95,425. Mean egg to fry survival was 15.83%, mean fry to smolt survival was 78.36%, and mean downstream migration survival was 47.70% (Figure 13). Mean overall survival from egg to Bay entry was 5.95%, ranging from 2.58% to 9.67% (Figure 13).

Figure 12. Range of Juvenile Production Estimates predicted under 2008-2009 conditions for 100 Monte Carlo Simulations.
DISCUSSION AND CONCLUSIONS

The revised winter run juvenile production (JPE) model provides a tool to derive estimates of winter run production with associated error. Individual life stages are modeled using functional relationships, whose form and parameters values are informed by the best available information from literature. Uncertainty is explicitly modeled in the JPE model by incorporating environmental stochasticity and estimation error where data is available. The model also allows the user the flexibility to make production estimates at different points during the season, using the appropriate ‘dummy’ datasets (e.g., depending on water year type and conditions).

While it is normal for many modeling papers to provide some sort of validation to demonstrate the accuracy of their models, this was not possible for the JPE model, as no validation dataset is available; the only datasets that would be available would be to compare to the original JPE values from previous years. However, comparing the revised model’s estimates to the previous model would be inappropriate since the uncertainty in the previous models’ estimates are unknown. Instead, we conducted sensitivity analyses to demonstrate the functionality of the model in relation to the various factors which informed the statistical relationships (e.g., temperature and flow effects). Through these analyses we were able to demonstrate the relative performance of the model under different conditions.
influence of these factors on the survival at various portions of the winter-run life cycle, as well as the resulting JPE values.

Sensitivity analyses and example model run

The sensitivity analyses demonstrate how the model components (e.g., temperature and flow effects) influence the survival and resulting JPE values. With regards to the flow effects, these analyses showed that migration survival increased with increasing flow, with JPE values differing by 95,000 in wet years when compared to critically dry years (see Figure 10). While the flow-survival relationship appears relatively weak (e.g., from CWT data; see Figure 7), these analyses demonstrate that natural variation in flow conditions can still have a significant impact on the JPE. Increased temperatures showed similarly significant effects on survival and resulting JPE values (e.g., increased temperature resulted in a decrease in survival). For the warm year of 2008, egg and fry mortality were severe, with 25% temperature-related mortality for eggs and 22% for fry. This large increase in temperature-related mortality from the moderate year to the warm year was a result of temperatures consistently exceeding 57°F during 2008, which was the temperature above which the model applied temperature-mortality effects (as observed in USFWS 1999).

The example run of the model was to demonstrate the model’s functionality for the most recent year where data was available (in this case brood year 2008). It should be noted that 2008-2009 was a critically dry year, warm, and a year with low escapement returns. The combination of these factors was most likely the reason for the low JPE values reported from this example run (427,265). Therefore, this low JPE result should not be viewed as representative of the JPE model (e.g., showing lower than expected JPE values).

Model uncertainty and limitations

As discussed previously, the JPE model is composed of a series of statistical models which are connected within the model framework. The error that is associated with each of the model’s statistical relationships is then incorporated in the final JPE value. Although error is incorporated in the model wherever data on uncertainty was available, some parameter values were informed by limited data from the literature. In addition, portions of the model rely on scientific inference where information to inform uncertainty was lacking (e.g. 53% downstream migration survival).
To reduce model uncertainty and improve the accuracy of the model, it is important to conduct experiments which specifically target portions of the winter-run life cycle where little is known about the factors that influence their development and survival. Experiments such as the USFWS (1999) study, looking at the effects of temperature on winter-run development and survival were particularly useful in the model, as we were able to use data from controlled experiments to adjust the fishes survival depending on the environmental conditions they experience. Temperature effects are known to greatly influence the survival and development of juvenile salmonids. By incorporating the data and the statistical relationship from such studies in the JPE model (along with their associated error), we were able to incorporate these environmental effects and derive more accurate JPE values.

While the portions of the model pertaining to temperature effects on development and survival are particularly robust, we are less confident with the portion relating to downstream survival. This is due in large part to the limitations of using CWT data and the recovery method of the Chipps Trawl used for survival index calculations. Unlike other tagging methods like passive integrated transponders (PIT tags) and acoustic tags which allow recovery events without recapture (and can have relatively high detection probabilities), coded-wire tags require physical recapture of the tag which results in a much lower rate of detection. Likewise, the low efficiency of the Chipps Island trawl contributed to extremely low recovery rates (mean = 0.03%) and resulted in high uncertainty and noise associated with smolt survival indices. The considerable noise in the relationship between flow and survival limited our ability to understand the underlying nature of the relationship and resulted in the implementation of a simple linear model. Another limitation with CWT data is that the only data available which could be used to look at the downstream survival portion of the winter-run life cycle were fall-run CWT studies; fall-run chinook are known to exhibit differences in their behavior during their outmigration (Kevin Niemela, personal communication).

The JPE model should not be viewed as a static or definitive product, but a framework that can be modified or expanded upon as new information becomes available. More studies are needed to fill in additional ‘knowledge gaps’, if we hope to improve model accuracy and reduce the uncertainty in the JPE estimates. Acoustic studies would be an ideal way to explore the effect of environmental factors (e.g., flow) on downstream survival. The benefit of acoustic studies versus those using CWT fish is that acoustically tagged fish have much higher detection probabilities, and do not require fish to be captured. In the future, we also plan on improving model functionality by applying recent predator-prey logic to the model (e.g. Anderson et al. 2005), which will further reduce the variability in the data. By conducting controlled
experiments, we would be able learn more about specific factors influencing the development and survival of winter-run chinook at different points in their life cycle, which in turn provides valuable data which can be used to improve the JPE model.
REFERENCES


USER MANUAL

Goldsim Player Download

In order to update and run the JPE model, the user must first download the player version of GoldSim. To download this software, go to the following link:

http://www.goldsim.com/content.asp?pageid=44

The GoldSim player will allow you to view, navigate and run the JPE model. Using the player version you will also be able to modify the components of the model as described in the sections below.

Updating the Model

On the model dashboard, there is a brief description of the model detailing the time frame during which the model operates along with details regarding its use. Each tab also has a brief description, which provides relevant information for the user.

Under the ‘Input Data’ section, the user is able to update the model with the current year’s temperature and flow data, as well as information about the total estimated number of female spawners and observed carcasses. These data will be used to inform the model, as described in the previous section. When the ‘modify data’ button is selected, this will open a window to the time series data where the daily average temperatures for Bend Bridge (CDEC) can be entered; as described in the window description, Day 0 = April 1. Similarly, data for flow can also be modified using the mean daily flow at Freeport (CDEC). Alternatively, the user can select ‘dummy’ data based on water year type (listed by water year type and the year from which the data were derived).
Under the ‘Female Spawners’ section, the user can enter the estimated total number of female spawners derived from the Jolly-Seber estimates, as well as the observed carcasses during the survey. It is important to note that the sum of all daily values (used for the spawning distribution) must equal the total carcasses observed during the carcass surveys.

In the “Downstream Survival” box the mean smolt migration survival proportion can be entered. The default value is 53%. Once this data is entered, the model can be run to obtain the current year’s JPE.

**Model Use and Results**

On the dashboard, you will see the ‘GoldSim Run Controller’. Once the data has been updated, select ‘run’ on the controller. The model will take a few minutes to run through the 100 Monte Carlo simulations used to get the results. Once it is finished, the user can get the JPE results by selecting the ‘Show Chart’ button under Juvenile Production Estimate header. The following window will appear:

The value circled in red (above) is the juvenile production estimate, with the associated error circled in blue. To obtain the JPE results from the 100 Monte Carlo simulations, click on the
‘table view’ button (circled in orange above). The following window will open, which provides those results:

![Distribution Result: Juvenile_Production_Estimate](image)

These 100 Monte Carlo simulations are the values that were used to come up with the mean JPE value (as well as the associated error). These data can be copied into Excel in order to keep a copy of the results from each model run (Note: the player version of GoldSim will not allow you to save model runs). If necessary, these data can also be used to run further analyses.

Also under the results section of the Dashboard, results are provided for the temperature induced egg mortality, egg to fry survival, fry to smolt survival, survival of smolts to the delta and overall survival.