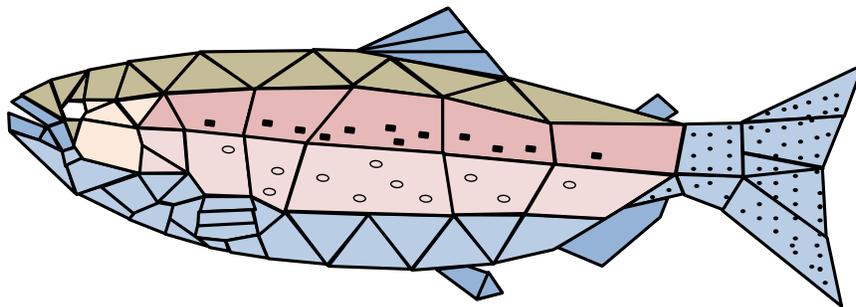


# Calibration and Validation of inSALMO for Fall Chinook Salmon in Lower Clear Creek, California

Task 1, inSALMO Salmon Model Project

Conducted by:  
Lang, Railsback & Associates, Arcata CA

For:  
US Fish and Wildlife Service, Bay Delta Fish and Wildlife Office  
Sacramento CA



Prepared by:  
Steven F. Railsback  
Lang, Railsback & Associates  
Bret C. Harvey, Jason L. White  
USDA Forest Service  
Pacific Southwest Research Station  
Report dated: May 28, 2013

## Contents

|  |    |
|--|----|
| Figures.....   | iv |
| Tables.....  | vi |
| 1 Introduction.....  | 1  |
| 2 Validation of Spawning Habitat Selection.....                      | 3  |
| 2.1 Methods.....   | 3  |
| 2.1.1 Analysis of simulated redd hydraulic habitat.....              | 3  |
| 2.1.2 Comparison of simulated and observed spawning areas .....      | 3  |
| 2.1.2.1 Field observations.....                                      | 3  |
| 2.1.2.2 Simulation experiments and validation analysis .....         | 3  |
| 2.2 Results.....   | 5  |
| 2.2.1 Redd hydraulic habitat .....                                   | 5  |
| 2.2.2 Spawning locations .....                                       | 5  |
| 2.3 Conclusions and model revisions.....                             | 17 |
| 3 Calibration of Outmigrant Abundance, Size, and Timing .....        | 19 |
| 3.1 Methods.....   | 19 |
| 3.1.1 Reproduction of general patterns in RST data.....              | 19 |
| 3.1.2 Parameter calibration of outmigrant abundance and length ..... | 19 |
| 3.2 Results and model revisions.....                                 | 22 |
| 3.2.1 General patterns .....   | 22 |
| 3.2.2 Parameter calibration .....                                    | 26 |
| 3.3 Conclusions and model revisions.....                             | 31 |
| 4 Juvenile Abundance and Mesohabitat Use .....                       | 34 |
| 4.1 Methods.....   | 34 |
| 4.1.1 Analysis of simulated habitat selection.....                   | 34 |
| 4.1.2 Comparison of mesohabitat use to observations.....             | 34 |
| 4.1.3 Comparison of juvenile abundance to observations .....         | 35 |
| 4.2 Results .....  | 35 |
| 4.2.1 Simulated habitat selection .....                              | 35 |
| 4.2.2 Mesohabitat use .....  | 36 |
| 4.2.3 Juvenile abundance .....                                       | 39 |
| 4.3 Conclusions .....  | 40 |
| 5 Validation of Interannual Variation in Outmigrant Numbers.....     | 42 |
| 5.1 Methods.....   | 42 |

|     |   |    |
|-----|---|----|
| 5.2 | Results .....   | 42 |
| 5.3 | Conclusions .....                                       | 44 |
| 6   | Summary and Conclusions .....                           | 46 |
| 6.1 | Summary of calibration and validation results.....      | 46 |
| 6.2 | Conclusions for future applications and validation..... | 46 |
| 6.3 | Conclusions about inSALMO's validity .....              | 48 |
| 7   | Literature Cited .....                                  | 50 |

## Figures

|   |    |
|---|----|
| Figure 1. Map of Lower Clear Creek showing the 12 sites modeled in inSALMO. ....  | 2  |
| Figure 2. Depths (top left) and velocities (lower left) experienced by simulated redds in water years 2008-2010; bars represent the percentage of redd-days (one observation per redd for each day it exists) within a depth or velocity range. For comparison, the right graphs display the depth and velocity suitability functions (USFWS 2011) used by simulated spawners to select cells for redds. .... | 5  |
| Figure 3. Cells used for spawning in inSALMO simulations, ACID Glide site. Blue cells contained redds in all 10 replicate model runs; red cells were used in at least one replicate. Yellow-shaded areas depict spawning areas observed in the field. Upper: brood year 2007 (low spawner abundance); lower: brood year 2008 (average spawner abundance). ....  | 6  |
| Figure 4. Comparison of simulated and observed spawning habitat at Tarzan Pool site. Format as in Figure 2. ....  | 7  |
| Figure 5. Simulated and observed spawning habitat use at site Restoration 3C. Format as in Figure 3. ....   | 8  |
| Figure 6. Simulated and observed spawning habitat use at site Restoration 3B. Format as in Figure 3. ....   | 9  |
| Figure 7. Simulated and observed spawning habitat use at site Restoration 3A. Format as in Figure 3. ....   | 10 |
| Figure 8. Simulated and observed spawning habitat use at site North State Riffle. Format as in Figure 3. ....   | 11 |
| Figure 9. Simulated and observed spawning habitat use at site Upper Isolation. Format as in Figure 3. ....  | 12 |
| Figure 10. Simulated and observed spawning habitat use at site Lower Renshaw. Format as in Figure 3. ....   | 13 |
| Figure 11. Simulated and observed spawning habitat use at site Upper Renshaw. Format as in Figure 3. ....   | 13 |
| Figure 12. Simulated and observed spawning habitat use at site Lower Gorge. Format as in Figure 3. ....   | 14 |
| Figure 13. Simulated spawning habitat use at site Side Channel Run Pool. Format as in Figure 3. ....  | 15 |
| Figure 14. Simulated and observed spawning habitat use at site Shooting Gallery. Format as in Figure 3. ....  | 15 |
| Figure 15. Simulated and observed spawning habitat use with spawners allowed to move to adjacent reaches, at sites Restoration 3C (upper) and Lower Renshaw (lower). Format as in Figure 3. Compare to Figure 4 and Figure 9. ....  | 17 |
| Figure 16. Simulated and observed spawning habitat use with revised spawner density input, at site Restoration 3C. Compare to Figure 4. ....  | 18 |
| Figure 17. Simulated and observed outmigrant numbers (left) and mean length (right), for 2008-2010, after preliminary calibration. “Week” on the X axis is the calendar-year week, with Week 1 the week that includes January 1. ....   | 23 |
| Figure 18. Comparison of observed and simulated spawn timing. Bars represent the number of redds created in the week ending on the label date. Left: spawn dates inferred from CDF&G carcass surveys (equal to the number of new carcasses found on the label date). Right: simulated spawn dates in inSALMO, with <i>fishSpawnProb</i> = 0.1. ....   | 26 |

|  |    |
|--|----|
| Figure 19. Calibration results for drift food concentration. ....  | 27 |
| Figure 20. Calibration results for aquatic predation risk and outmigration length. Left: SSE in weekly number of outmigrants. Right: SSE in weekly mean outmigrant length.....   | 27 |
| Figure 21. inSALMO results with calibrated parameters. Format as in Figure 16.....   | 29 |
| Figure 22. inSALMO results with calibrated parameters and simulated stream length tripled. Format as in Figure 16. ....  | 31 |
| Figure 23. Simulated juvenile habitat selection during March-April of 2008 and 2010, site Restoration 3B. Contoured values of mean density (fish per m <sup>2</sup> of cell area). Top row: juveniles < 5 cm length; bottom row: juveniles > 5 cm length. Left panels: juveniles in cells lacking velocity shelter; right: juveniles in cells with velocity shelter. Plots are limited to depth and velocity values < 50, where densities are highest. ....                          | 36 |
| Figure 24. Observed and simulated juvenile distributions, for site Restoration 3A, April 23, 2008. Red polygons denote areas dive-sampled by USFWS; red numbers indicate the number of juveniles counted in each polygon. Blue numbers are how many simulated large juveniles were in inSALMO cells, including all cells containing any fish (not just cells in or near the dive polygons). Left: small juveniles (fork length < 5 cm); right: large juveniles (length > 5 cm). .... | 38 |
| Figure 25. Observed and simulated juvenile distributions, for site Restoration 3A, May 8, 2008. Format as in Figure 23. ....   | 39 |
| Figure 26. Time series of simulated and observed juvenile abundance at Restoration 3A. Field surveys did not include the entire site, so magnitude of observed values are not comparable to model results. Top: 2008; bottom: 2010. Left: large juveniles; right: total of all juveniles. ....   | 40 |
| Figure 27. Comparison of model-predicted and RST-observed total number of outmigrants by year. The diagonal line represents 1:1 correspondence of model and data. ....   | 43 |
| Figure 28. Comparison of model-predicted and RST-observed number of large outmigrants by year. Note the different scales on X and Y axes. ....   | 43 |
| Figure 29. Relations between the number of spawners (adult females) and outmigrants in (top) inSALMO results and (bottom) RST data. ....   | 44 |
| Figure 30. Relation between total number of outmigrants and number of large outmigrants in the same year, in (top) inSALMO results and (bottom) RST data. Each point represents one year; model results include five replicates of each year. ....   | 45 |

## Tables

|   |    |
|---|----|
| Table 1. Spawner population characteristics for 2005-2011. .... | 4  |
| Table 2. Calibration data for outmigrant number and length..... | 21 |
| Table 3. Updated parameter values.....                          | 32 |

## 1 Introduction

This report is the product of Task 1 of the project *inSALMO – Individual-based Salmon Life-cycle Framework Model*, conducted by Lang, Railsback & Associates and Pacific Southwest Research Station, US Forest Service, for the US Fish and Wildlife Service. Task 1 is model validation and calibration. The scope of work for this task is:

Contractor shall acquire data as needed to test, improve and document the reliability of inSALMO's major results. In particular, model validation and calibration shall address: (a) total outmigrant numbers and contributions by size class; (b) spawning locations and how differences in gravel availability affect spawning densities among reaches; (c) habitat selection and growth of juvenile salmon; and (d) densities of rearing juveniles and how density varies with habitat, at the habitat unit or reach scale.

The inSALMO model is an individual-based representation of salmon life stages that take place in stream spawning and rearing habitat. The model is described in detail by Railsback et al. (2011).

This project addresses the application of inSALMO to fall Chinook salmon in lower Clear Creek (LCC), Shasta County, California. The stream is represented in inSALMO via 12 model "reaches", totaling 4000 m of stream length (Figure 1). The model thus includes 29% of LCC's actual length of 14 km from Clear Creek Road Bridge to the creek's confluence with the Sacramento River. The study sites and development of input for them (from US Fish and Wildlife Service instream flow study data) are described in the Task 2 product of this project (Railsback et al. in prep.).

Calibration and validation of inSALMO to lower Clear Creek was a sequential process, with processes representing earlier phases of the life cycle (spawning–incubation–rearing–outmigration) calibrated before later phases. To make it easier to understand this sequential process, we present methods and results of each calibration or validation phase together in separate sections. The final section summarizes important results and discusses conclusions from the whole process.

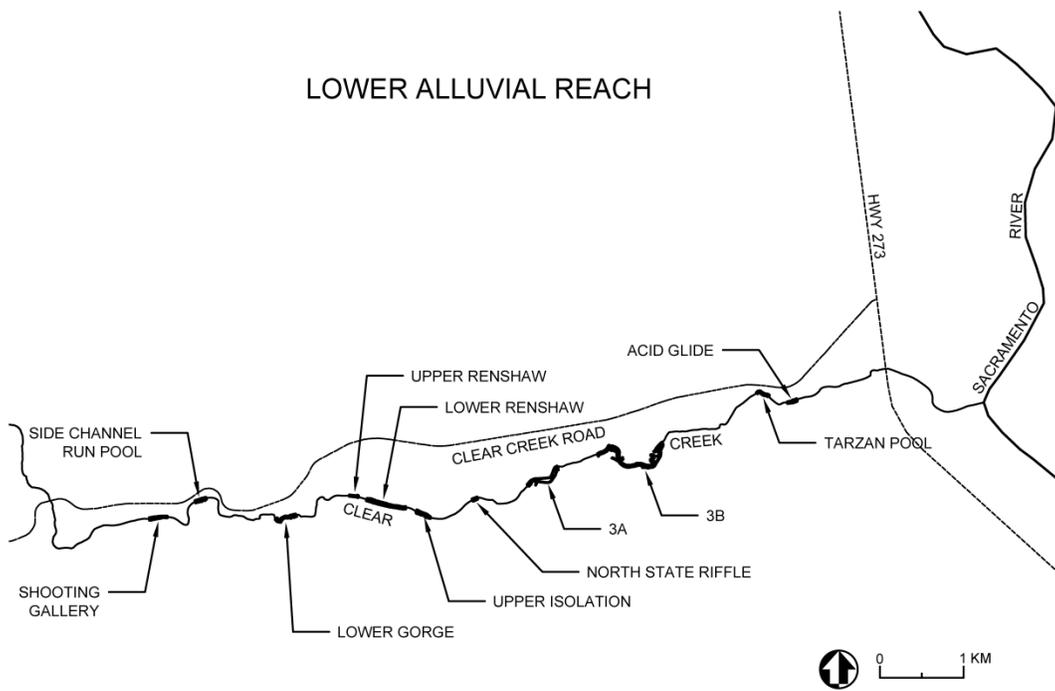


Figure 1. Map of Lower Clear Creek showing the 12 sites modeled in inSALMO.

## **2 Validation of Spawning Habitat Selection**

This section describes validation and improvement of inSALMO's ability to predict where salmon place redds.

### **2.1 Methods**

#### **2.1.1 Analysis of simulated redd hydraulic habitat**

The first method used to validate inSALMO's spawning habitat selection is a simple examination of the habitat characteristics of cells where redds occur. This analysis addresses depth and velocity, the two hydraulic variables believed to most affect redd survival. In inSALMO, female spawners use depth and velocity suitability functions (plus the area of unguarded spawning gravel) to rank cells for redd placement. This ranking is based on depths and velocities available on the day of spawning.

We output from inSALMO a daily histogram reporting the number of redds in each of 10 depth "bins": 0-20 cm, 20-40 cm, etc. up to 200 cm. Identical information is output for the cell velocities that redds are exposed to each day. We summed these histograms over all redds on each day to develop total depth and velocity use histograms for a simulation of the entire water year 2008-2010 period used for other calibration and validation analyses.

(These histograms are *not* habitat selection or "suitability" functions because they do not consider habitat availability. They simply report the conditions that simulated redds were exposed to.)

#### **2.1.2 Comparison of simulated and observed spawning areas**

This analysis compared redd locations in inSALMO simulations to observed spawning locations in Clear Creek.

##### ***2.1.2.1 Field observations***

The U.S. Fish and Wildlife Service (USFWS) collects data on where adult fall Chinook spawn (e.g., Giovannetti et al. 2008). These Spawning Area Mapping (SAM) observations are intended to define the locations where fall Chinook spawn and define the streambed area disturbed by spawning activity. Hence, the SAM data are useful for validating inSALMO's simulations of where adults spawn.

The SAM observations are made once per year, usually in the first week of December, throughout the entire LCC. The stream area disturbed by spawning salmon is delineated by hand on maps and later digitized to real coordinates via geographic information system (GIS). Above the cascade at river kilometer (RK) 10.5, individual redds are delineated because they are scarcer. These data are available for all the inSALMO sites.

##### ***2.1.2.2 Simulation experiments and validation analysis***

While the SAM data identify areas used for spawning, inSALMO identifies redd locations by which cell they are in. Therefore, the field data are not directly comparable with model results for statistical analysis, but they are useful for examining whether simulated spawning is generally in the same areas as actual spawning and whether areas avoided by real spawners also

have few simulated redds. We compared simulated and observed spawning areas by simply developing maps of each study site that show both observed spawning areas and the inSALMO cells that contained redds.

The inSALMO simulations used standard input for all 12 sites, including our standard spawner population characteristics (Table 1). The spawner population characteristics were developed from estimates of spawning population generated by the California Department of Fish and Game (CDF&G) for an approximately 6.75 km section of lower Clear Creek (source: Data query from CalFish.org website, and unpublished data provided by CDF&G, Red Bluff, CA). Estimates of adult sizes and sex ratio (percent female in Table 1) were generated from unpublished carcass data provided by CDF&G.

There are important uncertainties and limitations of the spawner input to inSALMO. Spawner surveys are generally considered relatively uncertain, and we applied results from 6.75 km to the entire 14 km of LCC. In addition, the CDF&G data provide a single estimate of spawner escapement for the lower half of LCC, not estimates of spawner density at a finer resolution. Hence, we simply assumed that the overall spawner density (number of adult spawners per unit stream length) estimated by CDF&G applied to all our reaches. This assumption makes it impossible for inSALMO to reproduce strong patterns in spawning site selection among (instead of within) reaches.

Table 1. Spawner population characteristics for 2005-2011.

| Brood year | Spawner density<br>(adults per km stream length) | Percent female |
|------------|--|----------------|
| 2005       | 2120   | 65%            |
| 2006       | 1210   | 57%            |
| 2007       | 590  | 64%            |
| 2008       | 1100   | 65%            |
| 2009       | 460  | 57%            |
| 2010       | 1060   | 51%            |
| 2011       | 670  | 68%            |

We compared simulated to observed spawning locations at all 12 model reaches, for two years: 2007 and 2008. (Here, “year” is the “brood year”, which is the calendar year during the October-November period of simulated spawning.) These two years were chosen because they are within the years (2007-9) when the habitat data used to develop inSALMO input were collected, and because they provide contrasting spawner densities. In 2008, the number of spawners (4380) was close to the 1998-2009 mean of 4820 adults. In 2007, the number of spawners (2350) was among the lowest of this period. Analysis of a low spawner density year is expected to provide a better test of the model’s ability to predict the best spawning locations because fewer spawners will be forced to use marginal habitat.

We analyzed model output from 10 replicate simulations of the entire 12-site system. The main redd output file of inSALMO was used to identify simulated redd locations (the habitat cell each redd was in). These results were used to count the number of redds in each cell over each simulated year. We distinguished three categories of habitat cell: those never used for spawning,

those used in all 10 replicate simulations (strongly selected by spawners), and those used in some but not all of the replicates.

## 2.2 Results

### 2.2.1 Redd hydraulic habitat

Simulated redds experienced moderate depths and velocities the vast majority of days (Figure 2). This result reflects (a) the suitability functions used by simulated females to select spawning cells (also shown in Figure 2; source: USFWS 2011) and (b) the generally stable flows that redds are exposed to in Clear Creek.

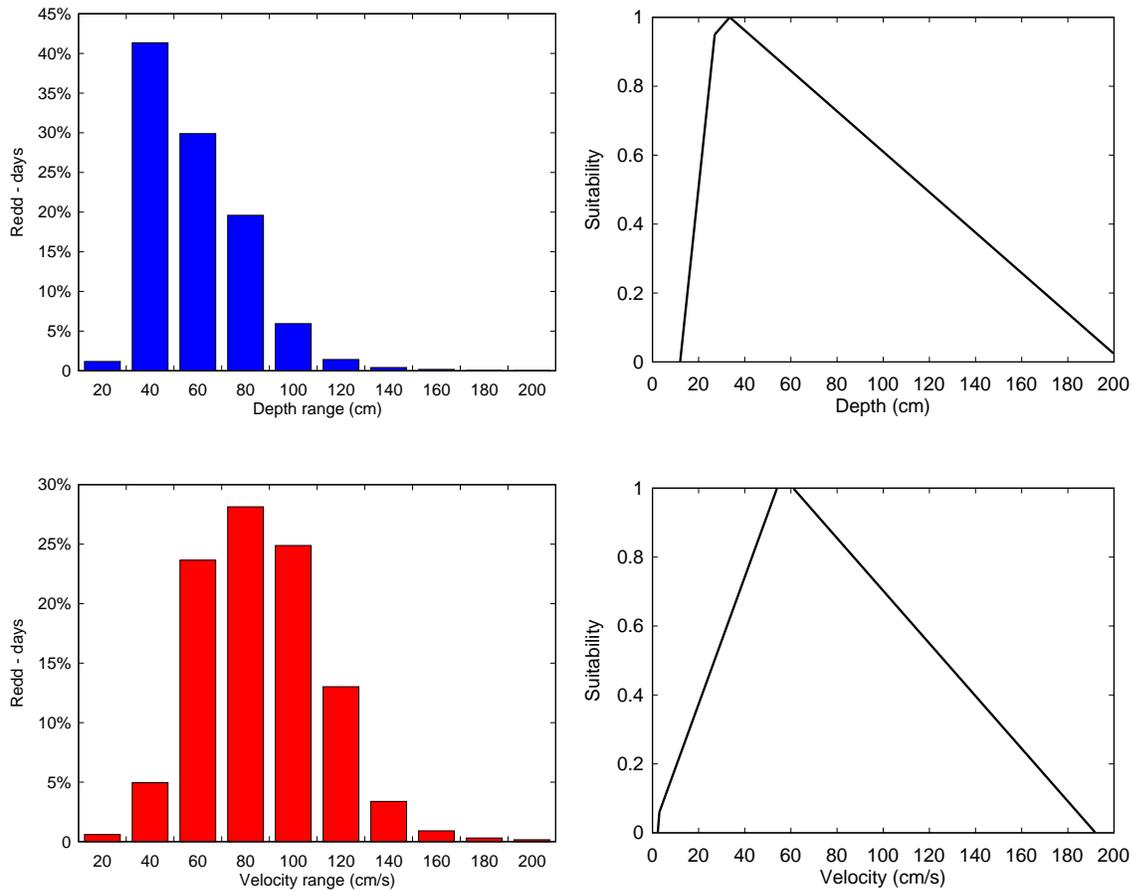


Figure 2. Depths (top left) and velocities (lower left) experienced by simulated redds in water years 2008-2010; bars represent the percentage of redd-days (one observation per redd for each day it exists) within a depth or velocity range. For comparison, the right graphs display the depth and velocity suitability functions (USFWS 2011) used by simulated spawners to select cells for redds.

### 2.2.2 Spawning locations

The simulated and observed spawning areas are compared in Figure 3 through Figure 14, which represent each site, from downstream to upstream. In general (but with exceptions discussed below) these figures show good correspondence between the cells where simulated spawners placed redds and the areas where redds were observed.

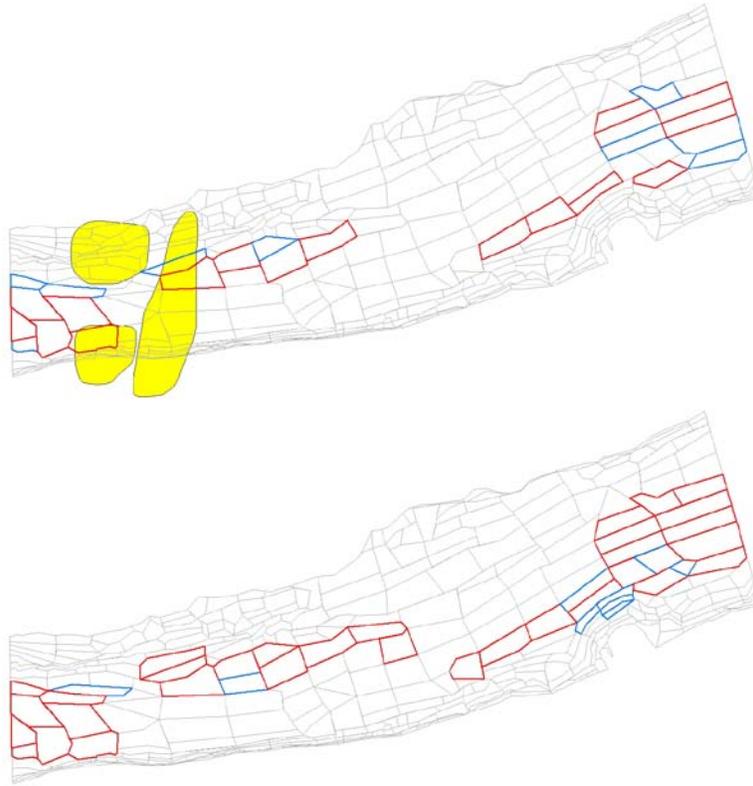


Figure 3. Cells used for spawning in inSALMO simulations, ACID Glide site. Blue-outlined cells contained redds in all 10 replicate model runs; red-outlined cells were used in at least one replicate. Yellow-shaded areas depict spawning areas observed in the field. Upper: brood year 2007 (low spawner abundance); lower: brood year 2008 (average spawner abundance).

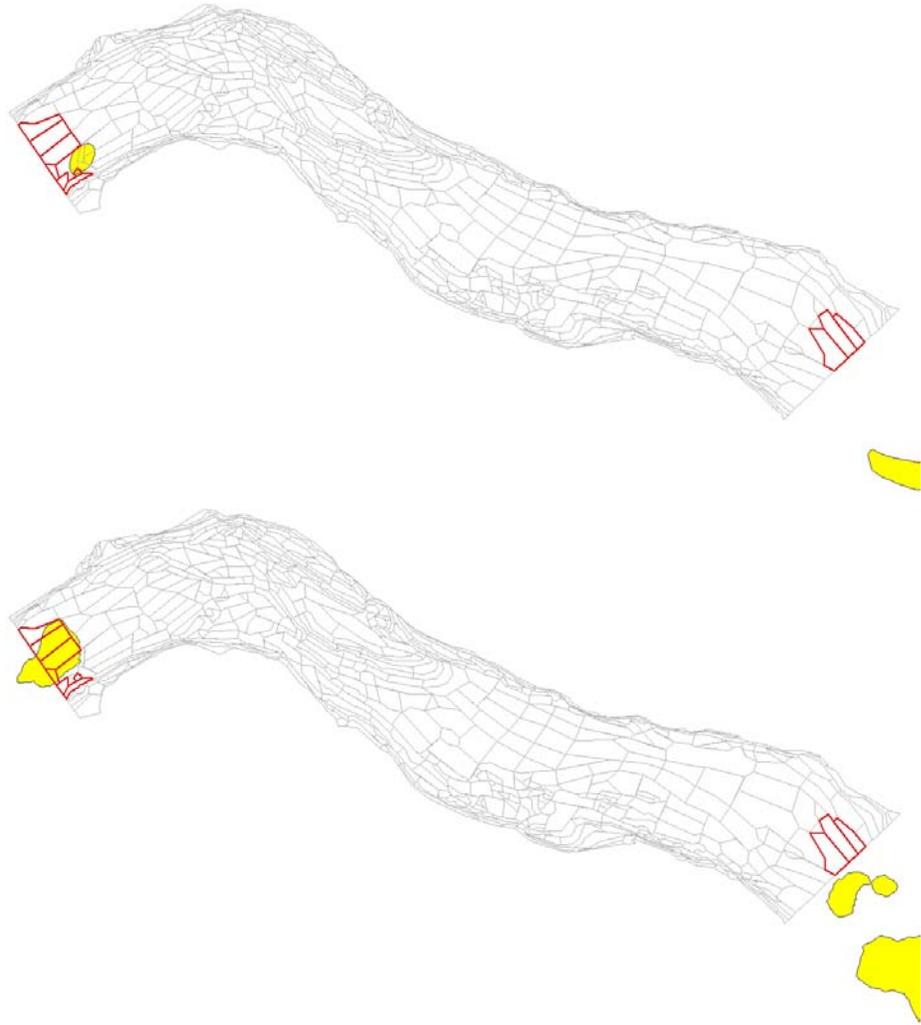


Figure 4. Comparison of simulated and observed spawning habitat at Tarzan Pool site. Format as in Figure 3.

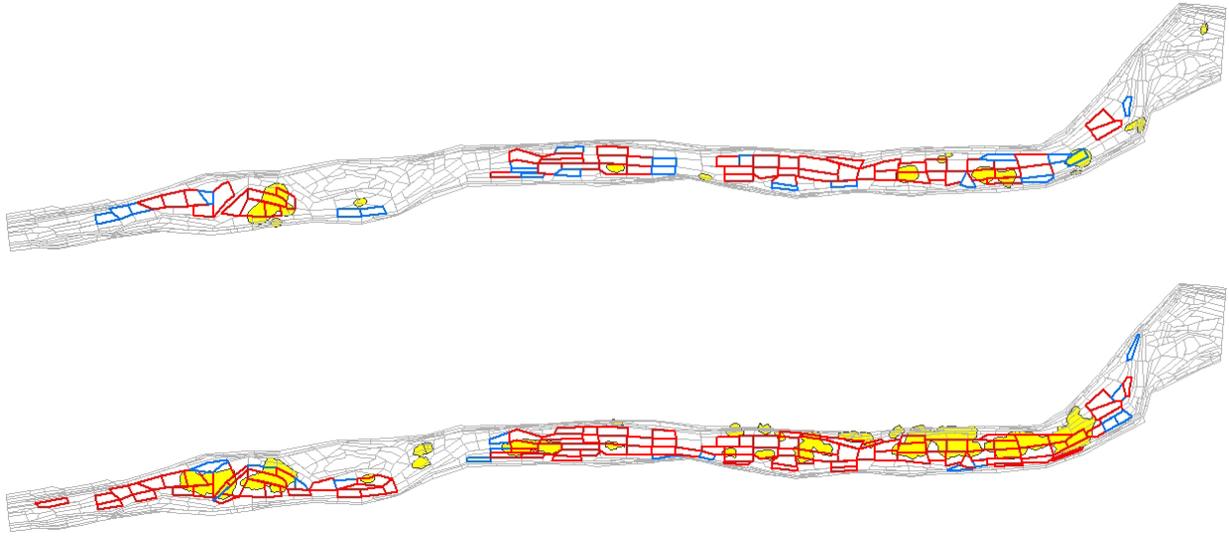


Figure 5. Simulated and observed spawning habitat use at site Restoration 3C. Format as in Figure 4.

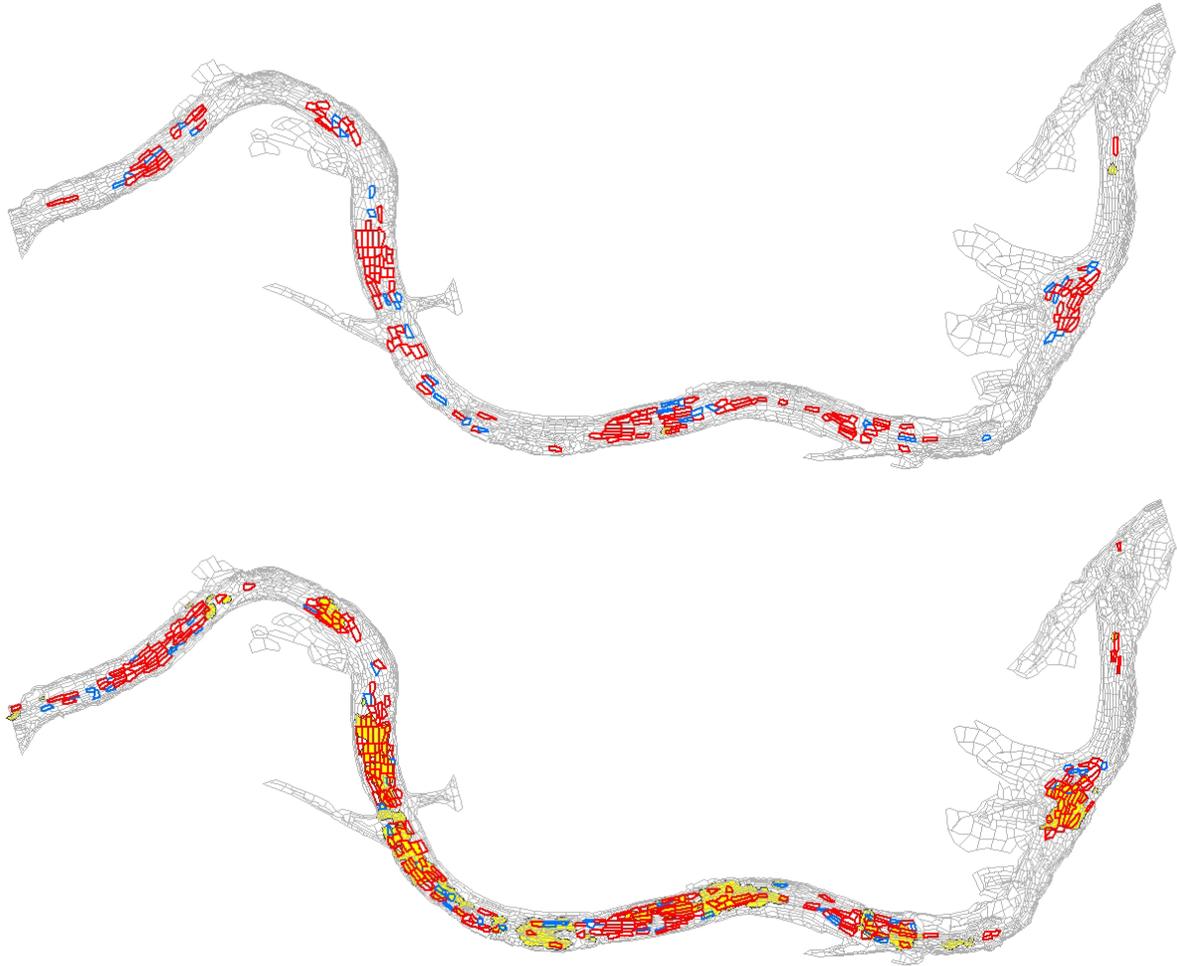


Figure 6. Simulated and observed spawning habitat use at site Restoration 3B. Format as in Figure 4.



Figure 7. Simulated and observed spawning habitat use at site Restoration 3A. Format as in Figure 4.



Figure 8. Simulated and observed spawning habitat use at site North State Riffle. Format as in Figure 4.

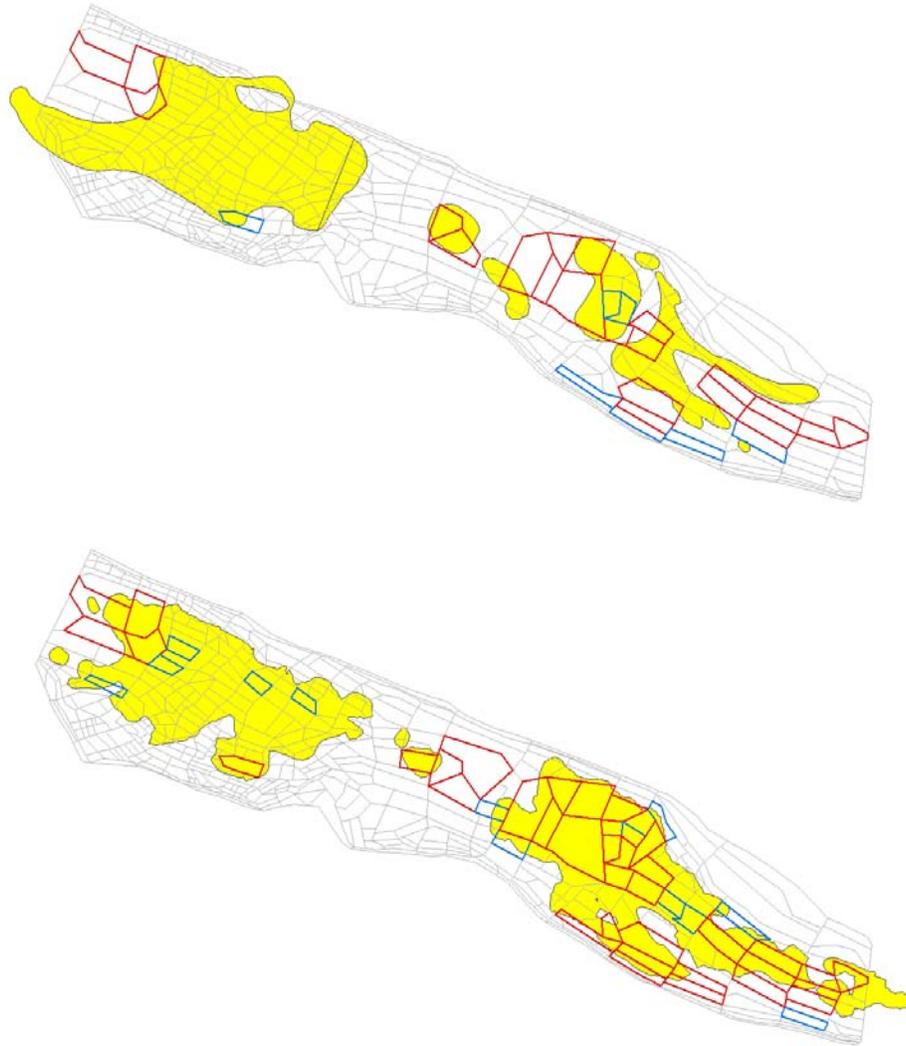


Figure 9. Simulated and observed spawning habitat use at site Upper Isolation. Format as in Figure 4.



Figure 10. Simulated and observed spawning habitat use at site Lower Renshaw. Format as in Figure 4.

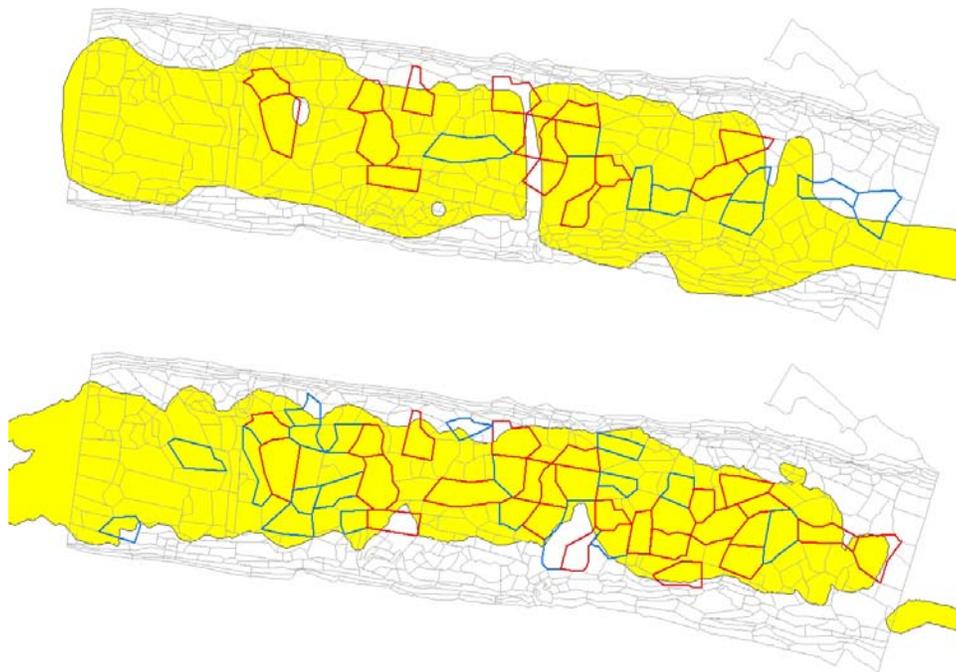


Figure 11. Simulated and observed spawning habitat use at site Upper Renshaw. Format as in Figure 4.

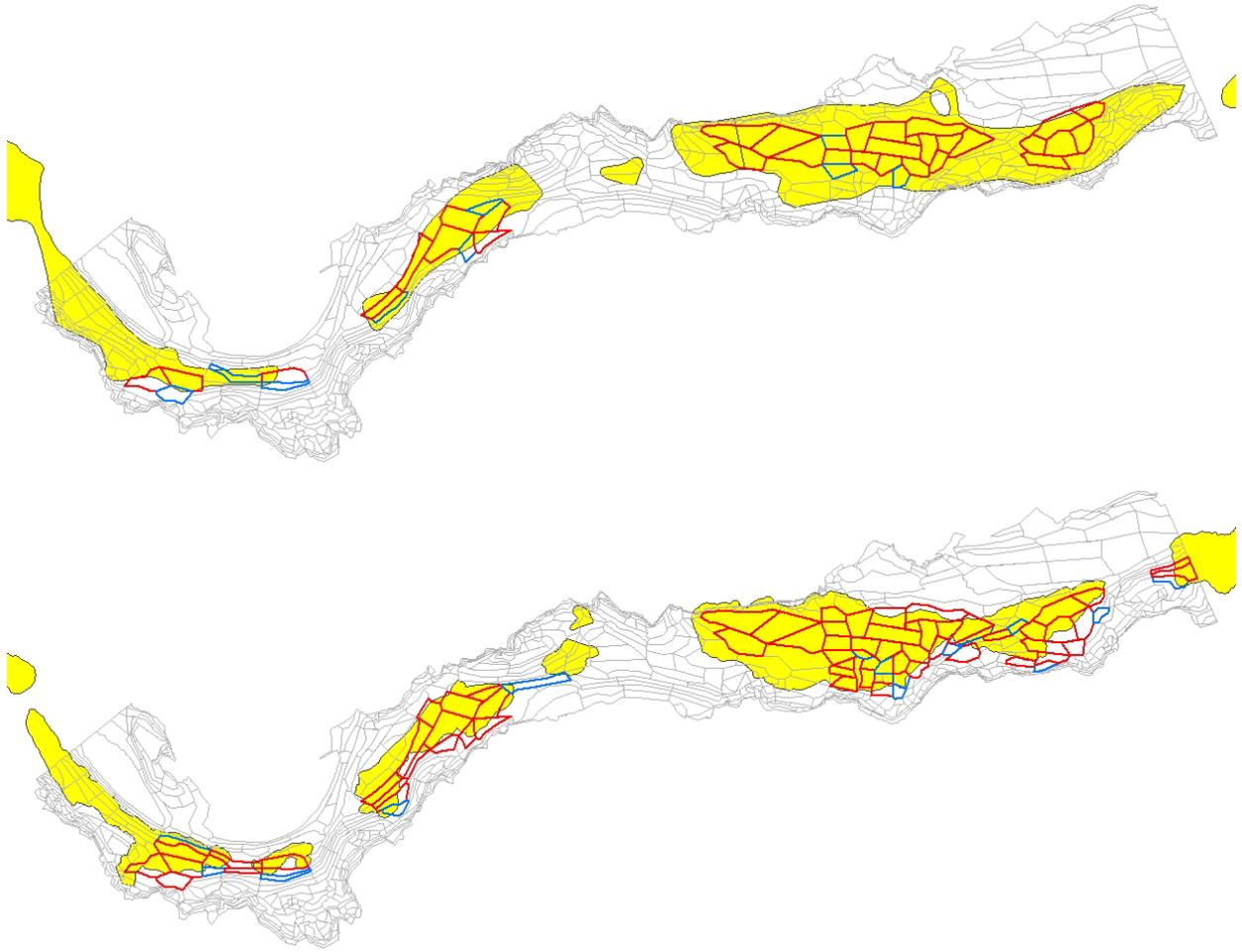


Figure 12. Simulated and observed spawning habitat use at site Lower Gorge. Format as in Figure 4.

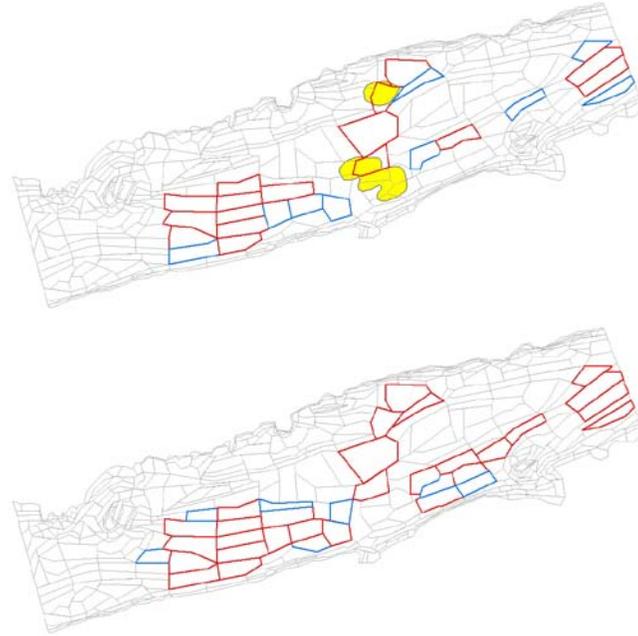


Figure 13. Simulated spawning habitat use at site Side Channel Run Pool. Format as in Figure 4.

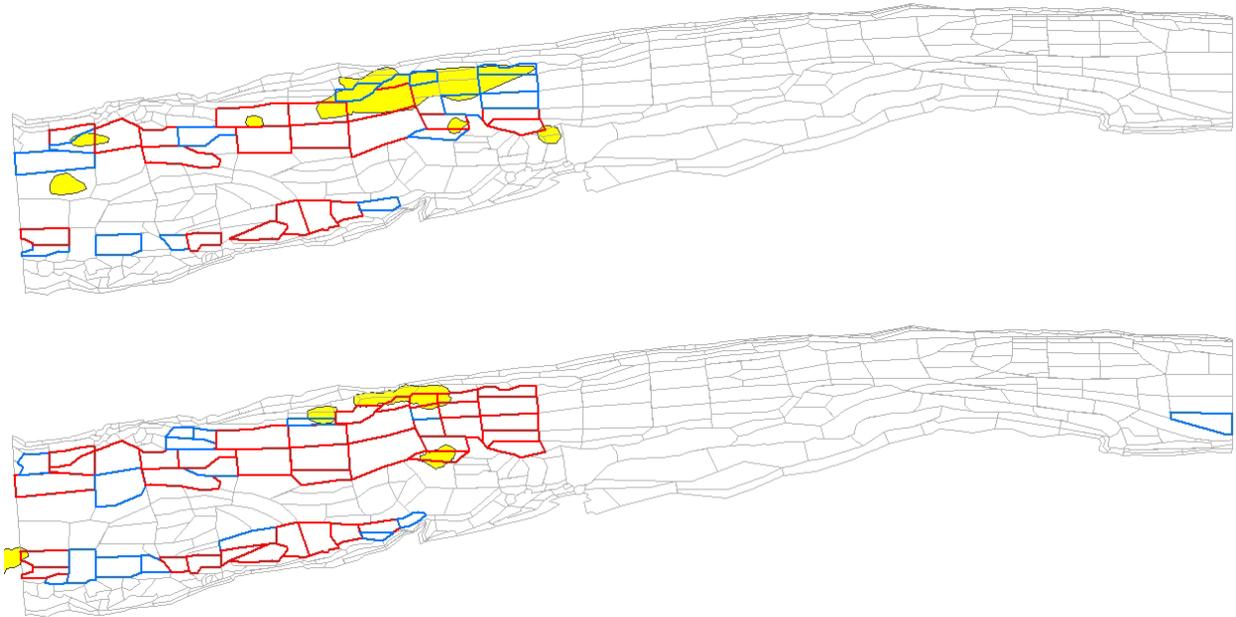


Figure 14. Simulated and observed spawning habitat use at site Shooting Gallery. Format as in Figure 4.

A pattern apparent in these results is that the model tended to under-predict spawning area at sites where observed spawning was widespread (especially, North State Riffle, Upper Isolation, Lower Renshaw, and Upper Renshaw); and over-predict spawning area at sites with relatively little observed spawning area (ACID Glide, Restoration 3C, Side Channel Run Pool, Shooting

Gallery). This pattern very likely results from (a) the model's rule that adults cannot move among reaches to select spawning habitat, and (b) the assumption we used in developing spawner input of constant spawner density among reaches. Real spawners very likely select spawning habitat over larger areas than our model reaches, producing variation among sites in spawner density. While salmon are widely believed to spawn near where they were spawned, it is reasonable to expect spawners to search over ranges of several hundred meters—longer than many of our reaches—for good redd conditions. The assumption of constant spawner density among reaches we used to produce spawner input cannot reproduce this larger-scale spawning habitat selection.

We tested one model modification to see if it would overcome this limitation of inSALMO. Instead of strictly requiring adults to spawn in the reach they are initialized to (an assumption made so that users can control spawner densities among sites), we tried a model version that allowed adults to use cells in adjacent reaches as long as those cells are within the adults' habitat selection radius (350-400 m for typical adults). (For this radius, the distance between adjacent reaches is assumed zero.) This modification resulted in only minor improvement such as somewhat less spawning simulated in less-used reaches (Figure 15); spawning habitat selection appears to vary over larger scales than the adults' habitat selection radius. We did not simply increase this radius because it is likely that processes not represented in inSALMO (especially, homing to natal locations) are likely to be important for larger-scale spawning site selection.

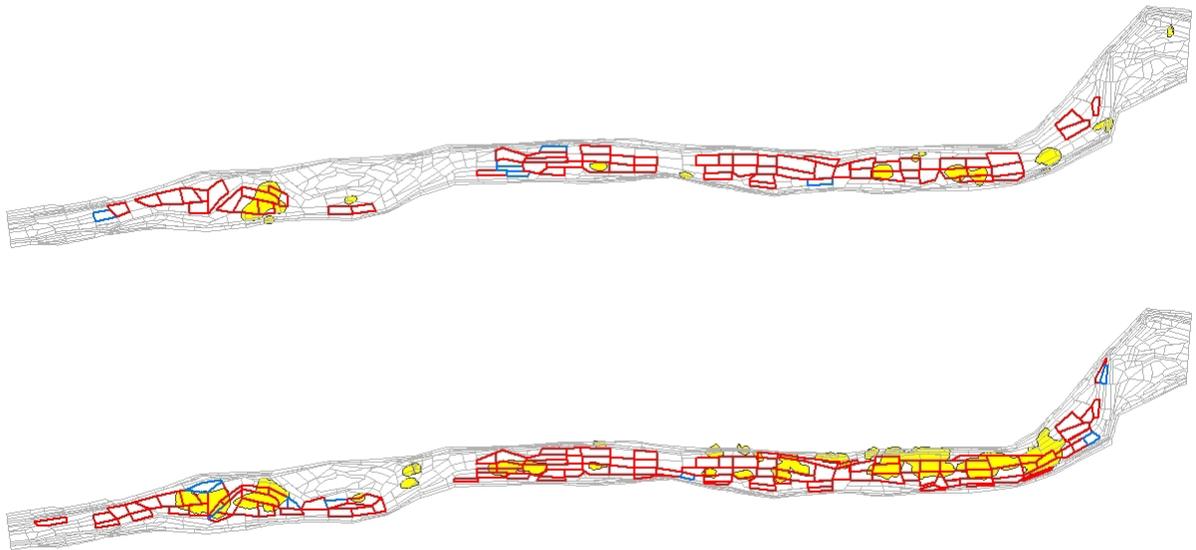




Figure 15. Simulated and observed spawning habitat use with spawners allowed to move to adjacent reaches, at sites Restoration 3C (upper) and Lower Renshaw (lower). Format as in Figure 4. Compare to Figure 5 and Figure 10.

### 2.3 Conclusions and model revisions

Our primary conclusion from the spawning habitat validation is that inSALMO can reproduce observed spawning habitat selection well. This conclusion is not surprising because the model's methods for how adults select a cell to spawn in are simple and strongly impose observed depth, velocity, and spawning gravel selection.

The second conclusion is that patterns of spawning habitat selection at scales larger than inSALMO reaches can be modeled only by accounting for them in the model input that defines the number of spawners in each reach. These patterns are likely driven in part by processes such as homing to natal locations that are not currently in inSALMO. Where observations of spawning habitat use are available, they can be used to estimate adult numbers per model site.

As a result of this validation analysis, we made one modification to inSALMO's input for Lower Clear Creek. We revised the spawner initialization input by using the SAM data to weight the number of spawners per reach. This change did substantially improve the match between simulated and observed spawning areas (e.g., Figure 16). The revised spawner input was used in subsequent calibration steps and incorporated in our standard model input.

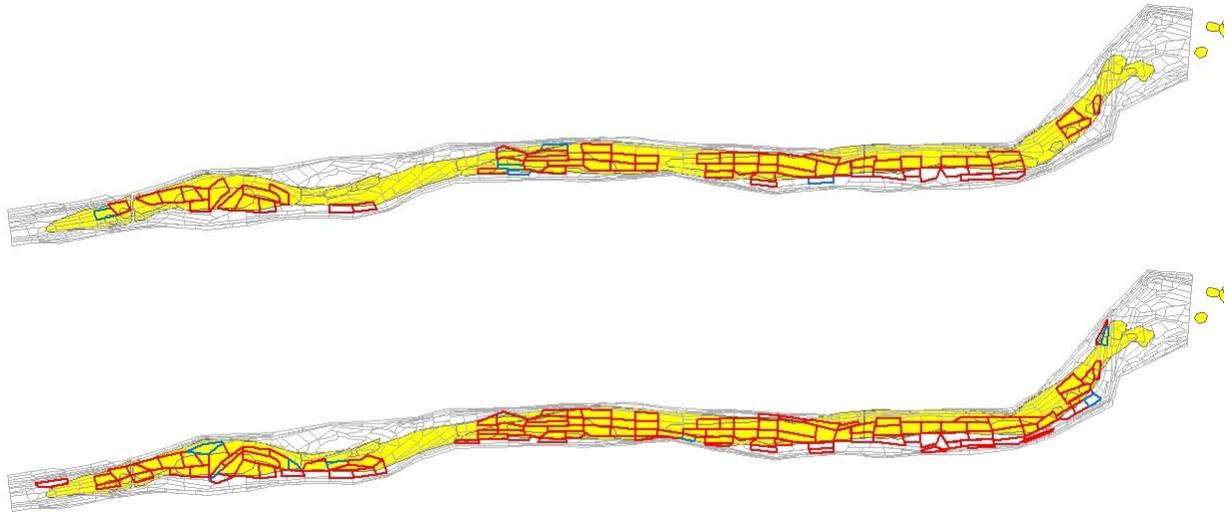


Figure 16. Simulated and observed spawning habitat use with revised spawner density input, at site Restoration 3C. Compare to Figure 5.

### 3 Calibration of Outmigrant Abundance, Size, and Timing

The second set of calibration and validation experiments addressed characteristics of simulated outmigrating juvenile salmon: how many there are, how big they are, and when they migrate out.

#### 3.1 Methods

The data useful for this exercise are from a USFWS rotary screw trap (RST) that captures outmigrating juvenile salmon at RK 2.7 (Earley et al. 2009, 2010). The RST has been operated from mid-November through mid-July, since 1998. Trap catches, combined with periodic mark-recapture studies to estimate trap efficiency, are used to estimate the total number of juveniles moving downstream. Each captured Chinook salmon is measured for length and, for fish longer than 5 cm, weight; and is assigned to one of the Clear Creek runs (late-fall and spring as well as fall) on the basis of its length and the date. Results are reported as weekly counts and mean lengths.

inSALMO can produce output directly comparable to the outmigrant trap data: weekly counts and mean lengths of outmigrants from the downstream-most simulated reach. (The downstream-most model reach is actually downstream of the RST, but represents habitat that also occurs just upstream of the trap.) We used the outmigrant trap data for the following two analyses.

##### 3.1.1 Reproduction of general patterns in RST data

The first step in calibration to the RST data was a preliminary comparison of model results to general patterns in the observed data. This comparison used weekly outmigrant numbers and mean length, following a preliminary calibration of model parameters for predation, drift food, and the relation between juvenile length and willingness to migrate downstream (using methods similar to those in Section 3.1.2). We noted differences between model results and data likely to affect subsequent calibration and validation steps, and explored model revisions to eliminate them.

##### 3.1.2 Parameter calibration of outmigrant abundance and length

The second step was a more formal calibration of model parameters to RST data. Calibration involved selecting model parameters to calibrate, identifying calibration target measures and values, executing simulation experiments, and analyzing results to identify best parameter values.

**Calibration parameters.** Sensitivity analysis of inSALMO (Railsback et al. 2011) identified several parameters that are appropriate for calibration because they have particularly strong effects on results while being especially uncertain. Model predictions of total outmigrant numbers are not highly amenable to calibration; few parameters affect this result strongly because the vast majority of juveniles migrate downstream immediately after emergence. In contrast, the number of large outmigrants—those that grew to at least 5 cm before outmigration—was sensitive to several parameters. One of those parameters is *mortFishAqPredMin*, which controls the overall risk of predation by larger fish. We chose *mortFishAqPredMin* for calibration because (after model modifications resulting from the first phase of this analysis; Section 3.2.1) it strongly affected inSALMO's predictions of outmigrant production, and because predation by fish (e.g., the numerous large pikeminnow observed in Lower Clear Creek) is likely a dominant cause of mortality and factor affecting habitat selection

yet particularly difficult to evaluate via means other than calibration. The second calibration parameter is *fishOutmigrateSuccessLI*, which controls how the willingness of a juvenile to migrate downstream varies with its length. (The parameter is the length, in cm, above which a juvenile prefers outmigration to staying in a reach where it's best expected probability of future survival is 0.1.) This parameter also strongly affects the number of juveniles that stay and grow to larger size before outmigration and, therefore, the number and size of outmigrants later in the season.

We also conducted a single-parameter calibration experiment on another important parameter: *habDriftConc*, which controls the primary food supply for juvenile salmon.

**Calibration targets.** This step identifies the specific measures and values from the RST data that inSALMO was calibrated to match. We selected two sets of calibration targets.

The first set of calibration targets is the weekly number of outmigrants observed at the trap. Both observed and simulated outmigrant numbers were transformed to base-10 logarithms because these numbers vary over many orders of magnitude during the outmigration season. Counts of zero in either observations or model results were given a log value of 1.0, reflecting the “superindividual” value of 20 juveniles per model individual: the model is not able to resolve outmigrant numbers less than 20.

The second set of calibration targets is the weekly mean outmigrant length (cm). Observed values were not transformed, as we assume model results for mean length are directly comparable to observations. Weeks in which either the RST data or model results had no observations were omitted from the analysis.

We chose the range of dates for calibration carefully. The RST data reported by USFWS include fall Chinook outmigrants as early as the first of December. However, the first month of outmigration coincides with spring run Chinook outmigration, so these two runs may not be distinguished accurately. The egg incubation submodel of inSALMO predicts that fry emerge and potentially migrate downstream only after mid- to late January; this submodel is relatively reliable. Therefore, uncertainty in the RST data appears to be a likely explanation for differences between observed and predicted outmigration before and during January. Calibration late into the summer outmigration season is desirable because large outmigrants—which may be more likely to survive to adulthood, and are more affected by calibration parameters—migrate out later. However, later in the outmigration season (after June) outmigrants become much scarcer, so the data become more uncertain. We therefore used results from weeks 5-26 of the calendar year.

Three years were used in the calibration: 2008 through 2010 (these are calendar or water years, which are equivalent during the outmigration period). These are the first years after collection of the habitat data used in the model, and after the habitat restoration work in the model's Restoration 3A and 3B reaches was completed. Table 2 provides the calibration target data.

Table 2. Calibration data for outmigrant number and length.

| Week* | Log <sub>10</sub> Outmigrant Number |      |      | Mean Length (cm) |      |      |
|-------|-------------------------------------|------|------|------------------|------|------|
|       | 2008                                | 2009 | 2010 | 2008             | 2009 | 2010 |
| 5     | 5.76                                | 5.79 | 4.93 | 3.8              | 3.7  | 3.7  |
| 6     | 6.03                                | 6.32 | 4.90 | 3.9              | 3.7  | 3.7  |
| 7     | 5.58                                | 6.28 | 4.57 | 3.9              | 3.8  | 3.7  |
| 8     | 5.99                                | 5.62 | 4.39 | 3.8              | 3.8  | 3.7  |
| 9     | 5.66                                | 5.68 | 4.46 | 3.8              | 3.8  | 3.7  |
| 10    | 4.96                                | 5.11 | 4.11 | 3.8              | 3.8  | 3.7  |
| 11    | 5.16                                | 5.08 | 3.80 | 3.8              | 3.7  | 3.8  |
| 12    | 4.84                                | 4.87 | 3.51 | 3.8              | 3.7  | 3.8  |
| 13    | 4.90                                | 4.43 | 3.28 | 3.8              | 3.7  | 3.9  |
| 14    | 4.74                                | 4.14 | 3.46 | 3.7              | 3.8  | 3.9  |
| 15    | 4.13                                | 3.96 | 3.26 | 3.8              | 3.8  | 4.7  |
| 16    | 3.60                                | 3.22 | 3.24 | 4.4              | 4.4  | 4.6  |
| 17    | 3.35                                | 3.21 | 2.84 | 5.2              | 5.9  | 6.2  |
| 18    | 3.66                                | 3.48 | 2.72 | 5.5              | 5.6  | 6.1  |
| 19    | 4.19                                | 3.89 | 3.11 | 5.6              | 5.9  | 6.0  |
| 20    | 4.29                                | 3.94 | 2.75 | 5.5              | 6.0  | 7.1  |
| 21    | 4.18                                | 3.86 | 3.04 | 5.7              | 6.2  | 6.3  |
| 22    | 3.57                                | 3.49 | 2.88 | 6.0              | 6.3  | 6.0  |
| 23    | 4.03                                | 3.00 | 3.06 | 6.1              | 6.5  | 6.2  |
| 24    | 3.52                                | 3.92 | 2.40 | 6.2              | 6.3  | 6.1  |
| 25    | 3.08                                | 3.04 | 2.05 | 6.5              | 6.6  | 6.5  |
| 26    | 2.61                                | 3.13 | 1.75 | 6.7              | 6.8  | 6.2  |

\*Week 1 is the week containing January 1.

**Simulation experiments.** The calibration experiments simulated the three calibration years, for many combinations of the three calibration parameters. The parameter combinations used in each experiment are presented with the results (Section 3.2) because the combinations used in each experiment depended on results of previous experiments. Parameter combinations were not replicated because model results are not highly stochastic.

**Analysis.** The calibration analysis was designed to find the parameter combination that provided the best fit of model results to the target values. “Best fit” was evaluated as the smallest sum of square error (SSE), the sum of the squared difference between the target values in Table 2 and the corresponding model results. To supplement the SSE analysis, we also developed time series plots of model results and observed target values; these plots illustrated when the model was less and more accurate.

Model results were transformed prior to the analysis to account for the model representing only some of the LCC habitat, while the RST data measure outmigration from the whole stream. Model results for outmigrant numbers were simply multiplied by the ratio 14/4 to reflect that the model represents 4000 of the total 14,000 m of LCC. This simple adjustment for the difference between simulated and actual stream length does not account for simulated juveniles migrating over a shorter distance, with fewer opportunities to feed and grow, or be eaten. Hence, model

results are likely biased toward earlier outmigration and smaller size; calibration can at least partially counteract such biases.

(The USFWS instream flow studies that created the study sites used a more complex method for adjusting site results to represent the whole stream; USFWS 2011. They developed weighting factors for separate mesohabitat units within each site, with separate weighting factors for spawning and juvenile rearing. This approach is not feasible with inSALMO: because the simulated fish move among all the cells in a reach, the effects of different areas within a reach cannot be distinguished or weighted separately.)

## **3.2 Results and model revisions**

### **3.2.1 General patterns**

The comparison of outmigrant simulations and RST data after pre-calibration (Figure 17) identified several general patterns of difference.

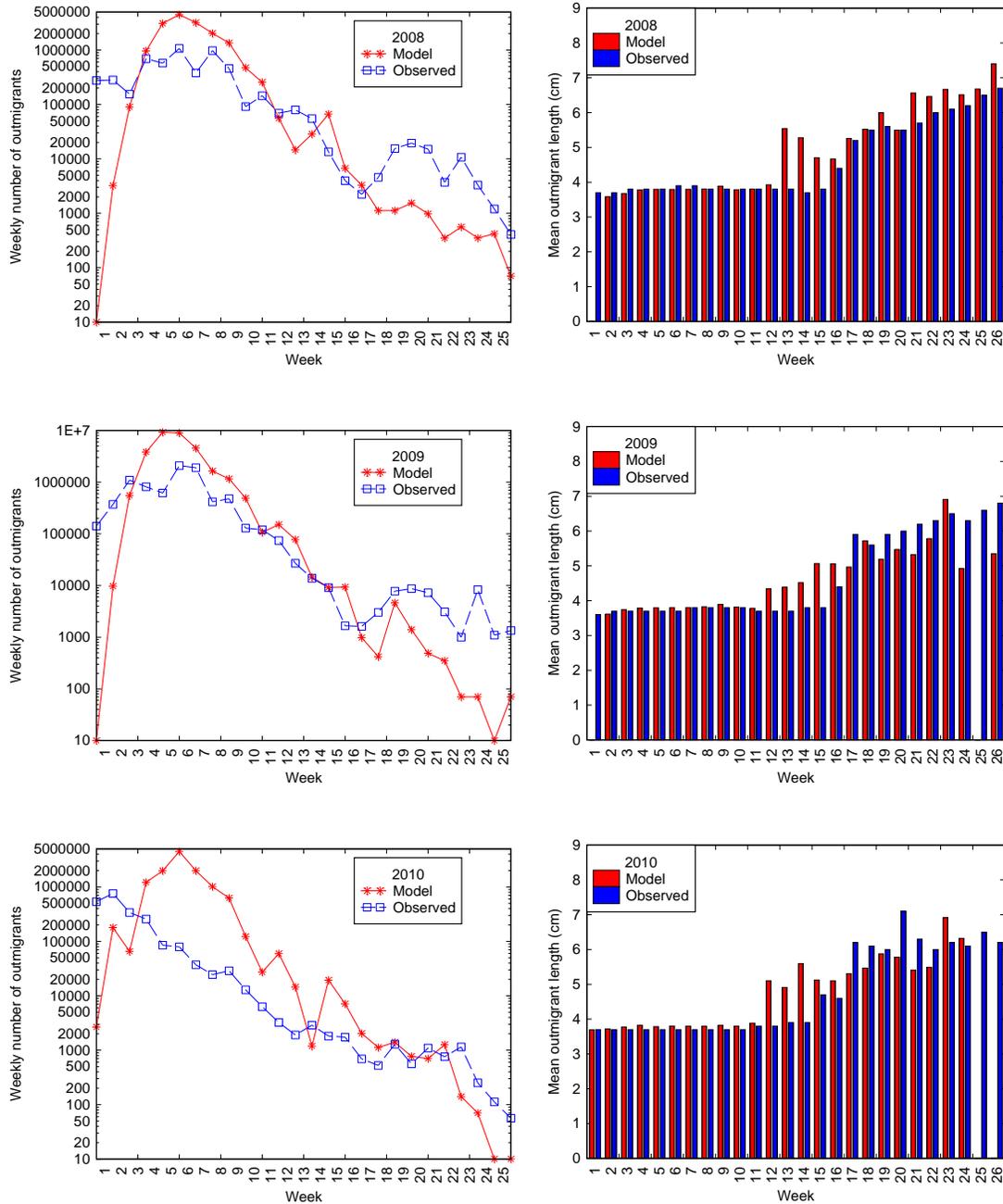


Figure 17. Simulated and observed outmigrant numbers (left) and mean length (right), for 2008-2010, after preliminary calibration. “Week” on the X axis is the calendar-year week, with Week 1 the week (Sunday through Saturday) that includes January 1.

First, the RST data show outmigration of small juveniles even before January 1, whereas the model predicted no emergence or outmigration of juveniles until January 1 and only a few outmigrants until mid-January. As discussed in Section 3.1.2, the date of first outmigration in inSALMO is strongly determined by the input and parameters that define when adults arrive and spawn; and by the egg incubation submodel, which is well-tested and documented (being taken from Beacham and Murray 1990). Hence, this difference in early outmigration rate is likely due

to processes intentionally not included in inSALMO and its input for LCC, especially adults that arrive and spawn before the main fall run spawn in October-November, and outmigrating juveniles that cannot clearly be distinguished as fall or spring run. Consequently, we tried no modifications or calibration of the model to address this pattern.

Second, the model consistently predicted higher numbers of outmigrants during the early peak of outmigration (approximately weeks 3-10) than indicated by RST data, and lower-than-observed numbers at the end of the season.

The third general difference between simulated and observed outmigration is in the date at which mean outmigrant length increases to above 4 cm (which occurs when outmigration is dominated by juveniles that have grown at least a small amount). The model predicts this increase in mean length 3-4 weeks before it was observed at the RST (right panels of Figure 17). This difference could not be corrected via the parameters we used for calibration. While simulated and observed lengths correspond well, we considered this difference important because inaccurate prediction of when large outmigrants are present strongly affects our final set of validation analyses, which examine (among other results) when large juveniles are present in the stream (Section 4).

The second and third patterns of difference between model results and RST data could be explained in part by simulated outmigration being overly rapid. inSALMO assumes that, on any day when habitat conditions near a juvenile's current location (including in the cell of its redd) are poor for feeding and survival, it can "migrate" to the next reach downstream. In the pre-calibration version, juveniles then evaluate conditions near its initial location in that next reach, and potentially keep moving down to further reaches. It is possible for a newly emerged juvenile to find no good habitat near the cell where it emerges (most often, because velocity is too high for very small fish to gain weight) and then move downstream through several, many, or even all the remaining reaches on one day. Consequences of this assumption include that many small juveniles can arrive at the downstream end and be counted as outmigrants unrealistically soon after they emerge, and with unrealistically little exposure to predation risk.

To reduce these differences, we made several changes to inSALMO's formulation and parameters.

The first change was reducing the parameter for the probability of an adult female spawning on a day when spawning conditions are good (*fishSpawnProb*) from 0.2 to 0.1. This change delays the average spawning date and, consequently, improves the model's prediction of when outmigrant mean length exceeds 4 cm.

The second change in inSALMO was to reduce the speed with which juveniles can migrate downstream. We simply changed the model so that a juvenile can migrate at most one reach per day. This new assumption (like the original one) is somewhat arbitrary and potentially unrealistic, especially if simulating many small reaches that are close together. However, the assumption remains simple and appears more appropriate than unlimited downstream migration.

The third change was to make it more likely that juveniles are exposed to relatively good habitat as they migrate downstream. Instead of assuming downstream-migrating fish are placed in one of the upstream-end cells of the reach they migrate down into (which can tend to concentrate

juveniles and limit opportunities to find moderate hydraulic conditions), we assume that such fish are placed in a cell chosen randomly from among all those in their new reach that have velocity less than the fish's current maximum sustainable swimming speed. (Note that small channel-margin cells are just as likely to be chosen as large mid-channel cells, possibly increasing the likelihood of fish landing near good habitat.) If there are no cells in the downstream reach with velocity less than the fish's maximum sustainable speed, the fish selects the best available cell within its current reach instead of migrating downstream.

The final change was to remove an assumption that any female adults that have not previously spawned do so on the last day of the spawning period (defined by the parameter *fishSpawnEndDate*, which has a value of November 30 for LCC). Instead, such fish simply do not spawn.

These changes had several consequences. First, inSALMO can now reproduce the observed date at which mean outmigrant length exceeds 4 cm. In addition, predicted spawning dates correspond well to CDF&G observations. CDF&G conducts weekly carcass surveys for fall Chinook at LCC, marking carcasses when they are first encountered. For each survey date, they report a total count and a count of previously marked carcasses (data provided by Matt Johnson, CDF&G, Red Bluff). We subtracted the marked from the total to obtain the number of newly encountered carcasses on a given survey date, and assumed that new carcasses correspond with spawning within the previous week. Usable carcass survey data exist for two years for which we also have model input: 2007 and 2011. (Water temperature input, which has little effect on spawn timing in these simulations, was not available for WY 2011 but we used input from 2010.) In those two years, simulated spawning dates coincided closely with those inferred from the carcass data (Figure 18), though simulated spawning was more concentrated over time.

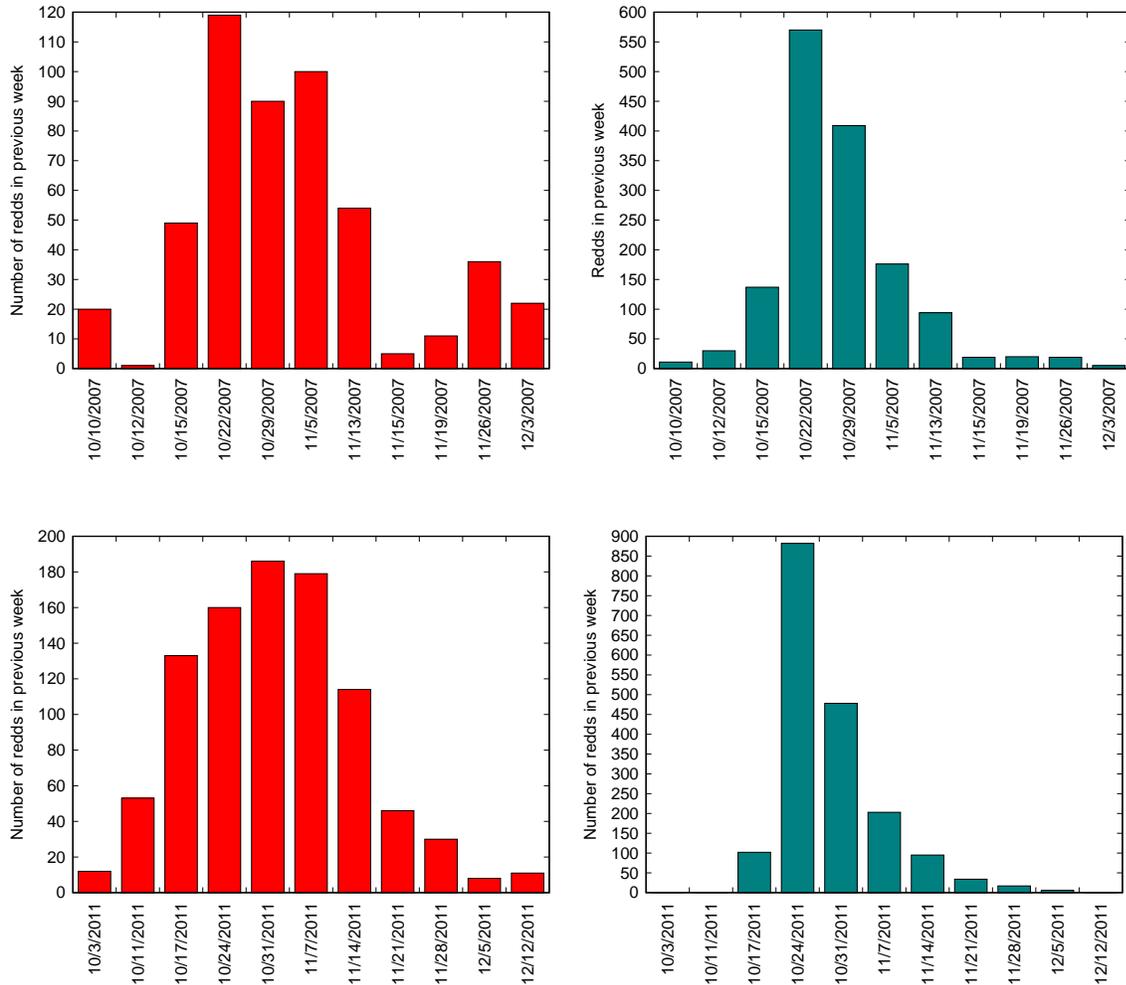


Figure 18. Comparison of observed and simulated spawn timing. Bars represent the number of redds created in the week ending on the label date. Left: spawn dates inferred from CDF&G carcass surveys (equal to the number of new carcasses found on the label date). Right: simulated spawn dates in inSALMO, with *fishSpawnProb* = 0.1.

Another consequence of these changes, important for subsequent calibration steps, is that predicted numbers and size of outmigrants is now sensitive to fish predation. Simulated juveniles now spend enough time in the simulated stream for predation to be the dominant cause of juvenile mortality, which seems realistic.

### 3.2.2 Parameter calibration

The final parameter calibration started with a single-parameter experiment varying drift food concentration (*habDriftConc*; Figure 19). Drift concentration had relatively little effect on outmigrant numbers. The pre-calibration value of  $3E-10 \text{ g/cm}^3$  produced the lowest error in mean length and relatively low error in outmigrant numbers, so we left it unchanged.

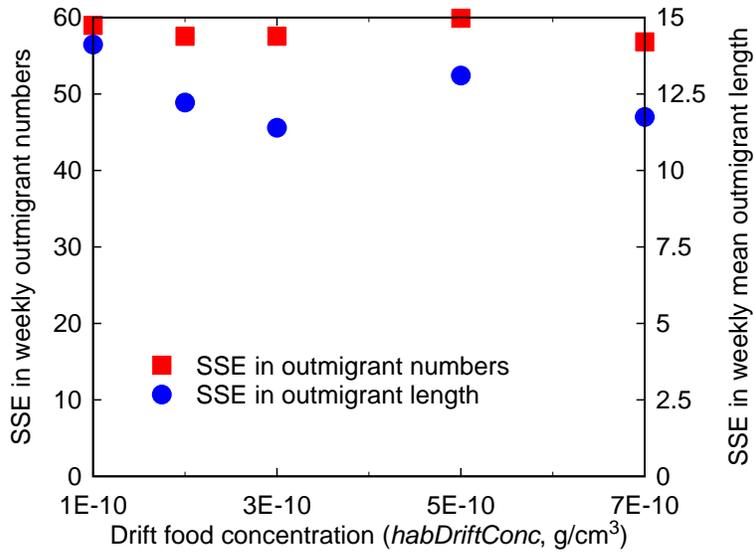


Figure 19. Calibration results for drift food concentration.

The final calibration step was the two-parameter experiment varying aquatic predation risk (parameter *mortFishAqPredMin*) and the relation between fish length and outmigration tendency (parameter *fishOutmigrateSuccessL1*). The value of *mortFishAqPredMin* was varied from 0.8 to 0.92 in five steps; *fishOutmigrateSuccessL1* was varied from 4.0 to 6.0 cm in five steps of 0.5 cm. The results (Figure 20) indicate a region where SSE is relatively low in both numbers and length. We selected as best parameter values *mortFishAqPredMin* = 0.88 and *fishOutmigrateSuccessL1* = 5.0 cm.

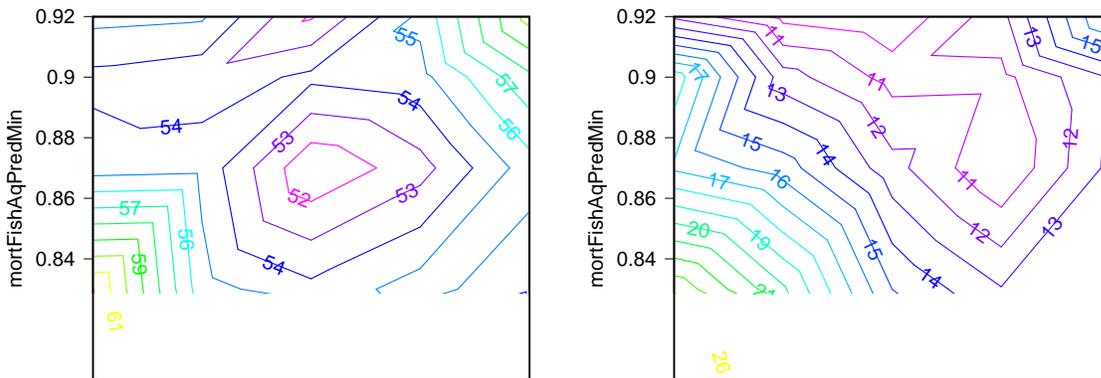


Figure 20. Calibration results for aquatic predation risk and outmigration length. Left: SSE in weekly number of outmigrants. Right: SSE in weekly mean outmigrant length.

These calibrated parameter values produced the time-series results in outmigrant numbers and length compared to RST data in Figure 21. The calibrated model reproduces several key patterns well:

- The timing of peak outmigration,
- The rapid post-peak decrease in outmigrant numbers,
- Outmigration of small numbers of larger fish through June, and
- A sudden increase in mean outmigrant length above the size of newly emerged fry in about mid-April, followed by gradually increasing mean length.

However, inSALMO even after calibration over-predicts total outmigrant numbers and under-predicts the number of large, late-season outmigrants. It is also clear from Figure 21 that 2010 RST data are atypical, with outmigration of small juveniles peaking very early, and inSALMO did not reproduce this difference from the other calibration years. Comparison of Figure 21 to Figure 17 shows that the final calibration improved the match between model results and data for outmigrant numbers at their peak and at the end of the season, and in outmigrant lengths, but did not improve the match in outmigrant numbers in the middle of the season.

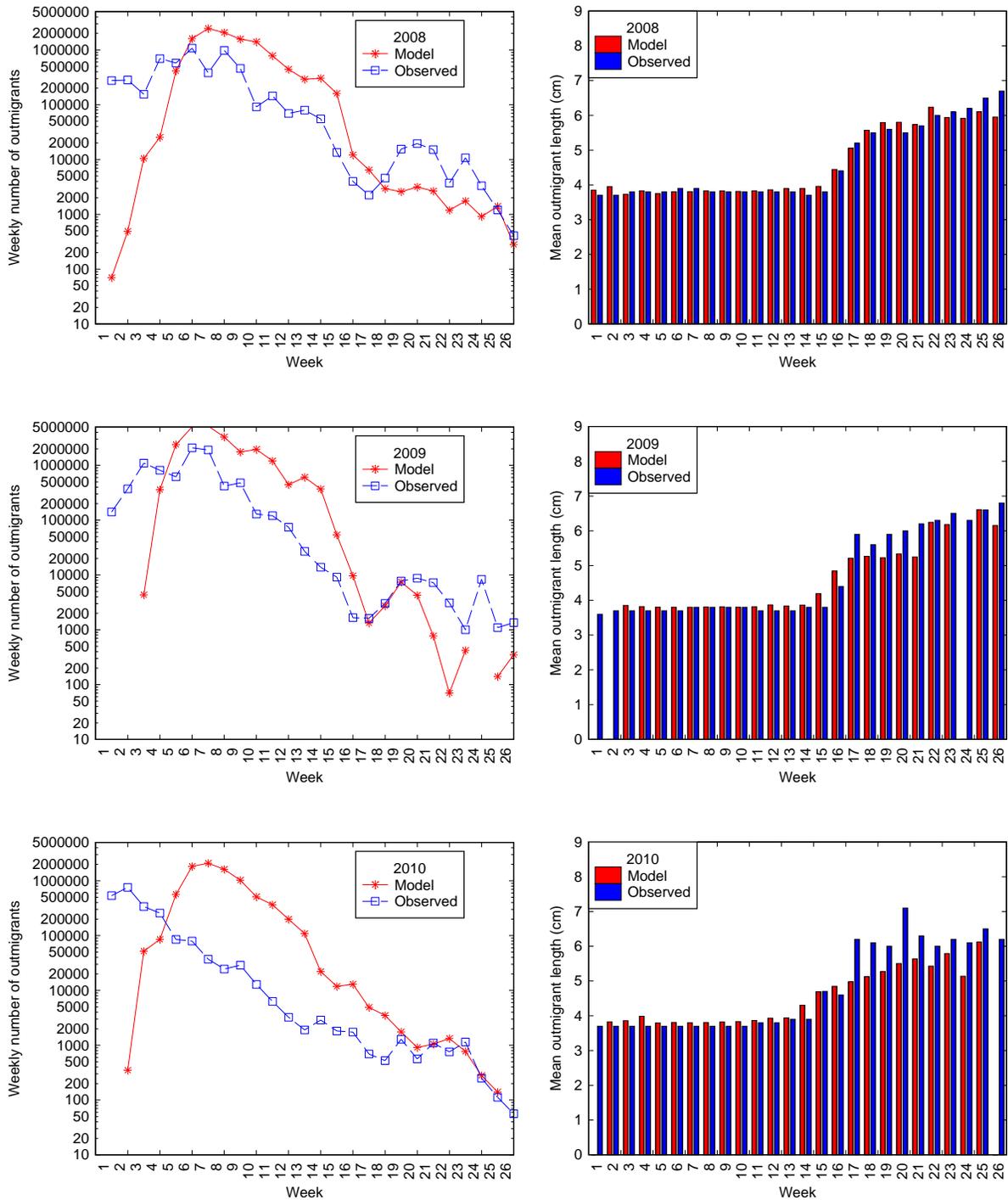


Figure 21. inSALMO results with calibrated parameters. Format as in Figure 17.

We conducted a final experiment to investigate the extent to which remaining differences between model results and RST data might be a consequence of the model representing less than a third of the actual stream length. To evaluate the effect of simulated stream length, we executed a simulation using the calibrated parameters and input (used to produce Figure 21), except with each of the 12 reaches included three times, to triple the simulated length. This experiment

(Figure 22; compared to Figure 21) produced later outmigration, as expected. The results better fit observed outmigration near the end of the season but not at the beginning. The delayed outmigration peak could likely be offset via changes in the parameters controlling timing of spawning, as discussed above. (This simulation was also computationally challenging.)

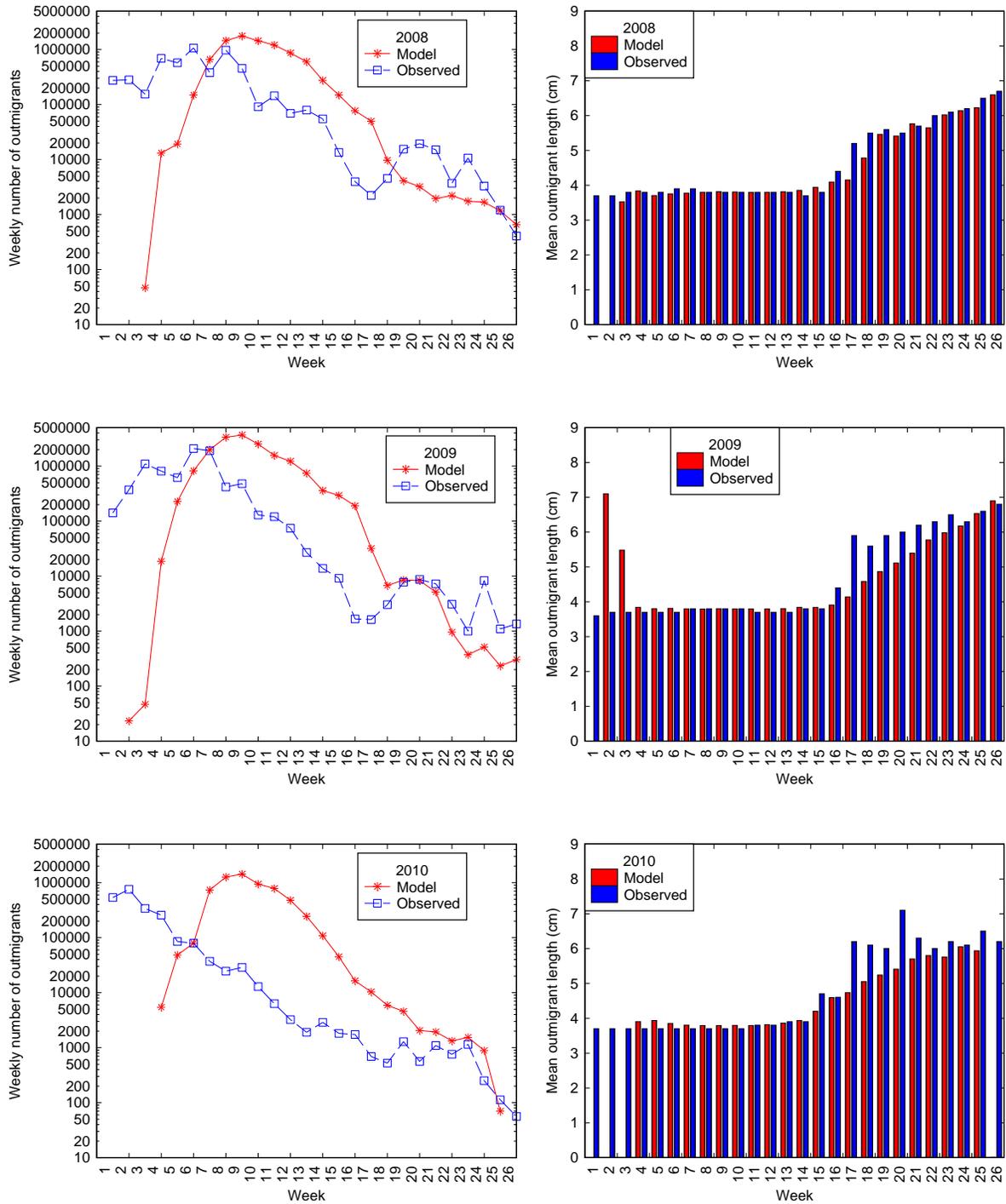


Figure 22. inSALMO results with calibrated parameters and simulated stream length tripled. Format as in Figure 17. The anomalous simulated lengths in weeks 2 and 3 of 2009 were due to a very few fish born in 2008 and migrating a year later.

### 3.3 Conclusions and model revisions

The RST data provide a variety of patterns for testing and calibrating inSALMO, though not much information from which to infer why model results differ from them. The calibration

process resulted in production of a revised version of inSALMO (designated version 1.3) with the changes listed in Section 3.2.1. Values of parameters that were calibrated, or otherwise revised during the calibration and validation process, are provided in Table 3.

Table 3. Updated parameter values.

| Parameter                      | Meaning  | Value                     |
|--------------------------------|--|---------------------------|
| <i>habDriftConc</i>            | Concentration of drift food  | 3.0E-10 g/cm <sup>3</sup> |
| <i>fishSpawnProb</i>           | Daily probability of spawning under suitable conditions                                | 0.1                       |
| <i>mortFishAqPredMin</i>       | Daily probability of surviving fish predation for unprotected fish                     | 0.88                      |
| <i>fishOutmigrateSuccessLl</i> | Juvenile length at which the expected outmigration success function has a value of 0.1 | 5.0 cm                    |
| <i>mortFishAqPredL9*</i>       | Fish length at which survival of fish predation is increased by 90%                    | 12 cm                     |
| <i>mortFishAqPredT9*</i>       | Temperature at which survival of fish predation is increased by 90%                    | 6.0 °C                    |
| <i>mortFishAqPredD1*</i>       | Depth at which survival of fish predation is increased by 10%                          | 50 cm                     |
| <i>mortFishAqPredD9*</i>       | Depth at which survival of fish predation is increased by 90%                          | 15 cm                     |

\*These aquatic predation parameters were not calibrated but revised prior to calibration to reflect fish predators prevalent in LCC.

There are still several key differences between RST data and calibrated inSALMO results. One is that the model produces more outmigrants than measured by the RST, by factors ranging from 2.2 (for 2008) to 3.8 (2010). Several factors could contribute to this difference:

- Superimposition mortality of eggs may be higher than the model predicts. (Superimposition in the model could be increased by adjusting inputs to spread spawning out over more time, reducing the ability of females to guard redds against later spawners, or by changing the model's assumption that spawners do not prefer previously-used gravel.)
- Redd mortality due to scour may be more prevalent than the model predicts. We did not estimate the site-specific shear stress parameters used to model scour and hence likely underestimated scour.
- The RST data may underestimate outmigration, especially of newly emerged fry. Especially small juveniles may be difficult to represent in the mark-recapture studies used to estimate trap efficiency, and may concentrate along channel margins where they are less likely to be captured. Recent studies show that RST capture efficiency can vary substantially with fish size (Tattam et al. 2013).

- The model may underestimate the exposure of some outmigrants to predation, even though the revised model (Section 3.2.1) exposes outmigrants to at least one day's risk per reach as they move downstream. (In calibration, lower predation survival improved the prediction of total outmigrant numbers but resulted in too few large outmigrants late in the season.)

A second unexplained difference is the high outmigration reported by the RST during and even before January. This difference almost certainly is due to spawning that occurs earlier than we assumed possible when defining the model's input for when fall Chinook adults arrive in LCC. Our input was based on CDF&G spawner escapement studies. These inputs could be modified to include earlier arrival of fall Chinook (or the presence of other races), but we chose not to without knowing more about the origin of the early outmigrants.

The inSALMO results also still tend to produce fewer of the large outmigrants observed in the RST late in the outmigration season. This difference could result in part from trapping uncertainty, and could reflect fish spawned above the modeled reach. The difference could also result from small areas of productive rearing habitat not captured in our model input.

One source of uncertainty in all model results is that we use 12 reaches totalling 4000 m length to represent the entire 14,000 m length of LCC. These reaches were originally placed by USFWS for habitat modeling studies that represent all of LCC. However, to represent all of LCC the USFWS used a complicated weighting system (e.g., multiplying different parts of a reach by different weighting factors) that cannot be used with spatially explicit models like inSALMO. We could only multiply inSALMO results by the ratio 14,000/4000 to estimate total outmigrant numbers, instead of weighting results from each reach (or mesohabitat units within reaches) separately as the USFWS instream flow studies intended. This difference between PHABSIM-like habitat models and inSALMO should be kept in mind when planning studies that use the same sites for both approaches.

## **4 Juvenile Abundance and Mesohabitat Use**

This section addresses key intermediate results of inSALMO: the number, size, and habitat use of juvenile salmon before they migrate all the way out of the simulated stream.

### **4.1 Methods**

#### **4.1.1 Analysis of simulated habitat selection**

This analysis simply examined habitat selection by simulated juvenile salmon. We used model output reporting the habitat characteristics (depth, velocity, area of velocity shelter, distance to hiding cover) of each cell and the number of juveniles in the cell. Because these results are extensive, we used them only from one reach: Restoration 3B, which is the largest and most diverse. Results were used from each day of March and April, when juveniles are most abundant, of 2008 and 2010.

Habitat selection was evaluated as mean density of juveniles; this approach is recommended (e.g., Manly et al. 2002) as simple and meaningful. Cells were aggregated into depth and velocity bins at 5 cm intervals (e.g., depths of  $\leq 5$  cm, 5-10 cm, etc.; velocities of 0, 0-5, 5-10 cm/s, etc.). The mean juvenile density was then calculated for each combination of depth and velocity. Cells with and without velocity shelter were analyzed separately because velocity shelter strongly influences the effect of velocity on fish growth. Cells with depth  $> 200$  cm or velocity  $> 100$  cm/s were excluded because fish were extremely rare in them. The analysis included 60,594 observations (cell-days) without velocity shelter and 41,103 observations with shelter.

Results of this analysis were displayed as contour plots of mean juvenile density vs. depth and velocity. Separate plots were generated for juveniles with length less than and greater than 5 cm.

#### **4.1.2 Comparison of mesohabitat use to observations**

The USFWS has collected data on mesohabitat selection by juvenile salmon during the rearing period from mid-February to early June (e.g., Newton et al. 2004; Newton and Brown 2005). These data have been collected specifically to monitor the effects of habitat restoration work at sites Restoration 3A and 3B. In years including 2008 and 2010, data were collected at Restoration 3A and 3B, as well as at two adjacent unrestored control sites. Juvenile salmon densities are estimated at a mesohabitat scale and, in some cases, at individual restoration structures such as placed boulders. First, mesohabitat units (individual pools, riffles, etc.) are delineated for later mapping in GIS. These mesohabitat units are delineated once at the start of data collection each year. Then each survey estimates the number of juvenile Chinook salmon in a subset of the units, via snorkeling. These observations are made primarily near the bank in wide, main-channel units, but can encompass entire units in smaller, side-channel units and those around individual structures. Separate counts are made for fish above and below 5 cm in length, using visual estimation of length to distinguish fish in these two categories.

We compared the habitat use survey results for a particular date to simulation results by overlaying polygons approximating the USFWS survey units on a map of the corresponding inSALMO reach. We then displayed both the count from each USFWS unit and the number of fish in each model cell on the same date. While the USFWS counts provide information only for

the sampled units and the model data reflect fish distribution in the entire modeled reach, this display does allow at least qualitative evaluation of habitat use patterns.

There are several kinds of uncertainty in using these mesohabitat data for model validation. First are the uncertainties inherent in visual estimation of the abundance and size of small fish. The large numbers of newly emerged juveniles migrating downstream seem especially difficult to count accurately. Second, real fish may aggregate in areas and for reasons not well represented in the model. For instance, the hydraulic model does not reflect velocity refuges created by non-bed elements such as brush and aquatic vegetation. Additionally, the model does not represent schooling behavior that may cause fish to aggregate.

The simulation experiments for juvenile abundance and habitat use included all 12 study sites, but model results could be compared to field data only for the areas of sites Restoration 3A and 3B where field data were collected. We analyzed results only from Restoration 3A. The comparisons were made for several dates when fish abundance was relatively high.

#### **4.1.3 Comparison of juvenile abundance to observations**

The second use we made of the USFWS juvenile habitat use data was comparing it to simulated juvenile abundance over time. This analysis tests inSALMO's predictions of when juveniles are present in the Restoration 3A site as they rear and move downstream. We simply plotted the number of juveniles observed at the site in the juvenile habitat use surveys on the sampling dates, with the simulated number of juveniles on the same dates.

## **4.2 Results**

### **4.2.1 Simulated habitat selection**

Several interesting patterns are apparent in the habitat selected by juvenile salmon (Figure 23). One might expect larger juveniles to use a broader range of habitat because they have better swimming ability and are slightly less vulnerable to predation by larger fish. However, the opposite occurred in inSALMO: juveniles > 5 cm length never used depths or velocities > 50, and strongly selected depths < 20 cm and velocities < 25 cm/s. Smaller fish were more widely distributed, with nearly half using depths or velocities > 50 and less clearly defined preferences. However, smaller juveniles in cells with velocity shelter strongly selected depths and velocities around 10 (upper right panel of Figure 23). The same processes explain these results: because inSALMO assumes size-based competition for habitat and a habitat selection radius that increases with length, larger fish are better able to find and use the most productive habitat. The smallest juveniles are most dispersed because they have a smaller radius within which to select habitat and are unable to displace larger juveniles from the cells with low depths, moderate velocities, and velocity shelter.

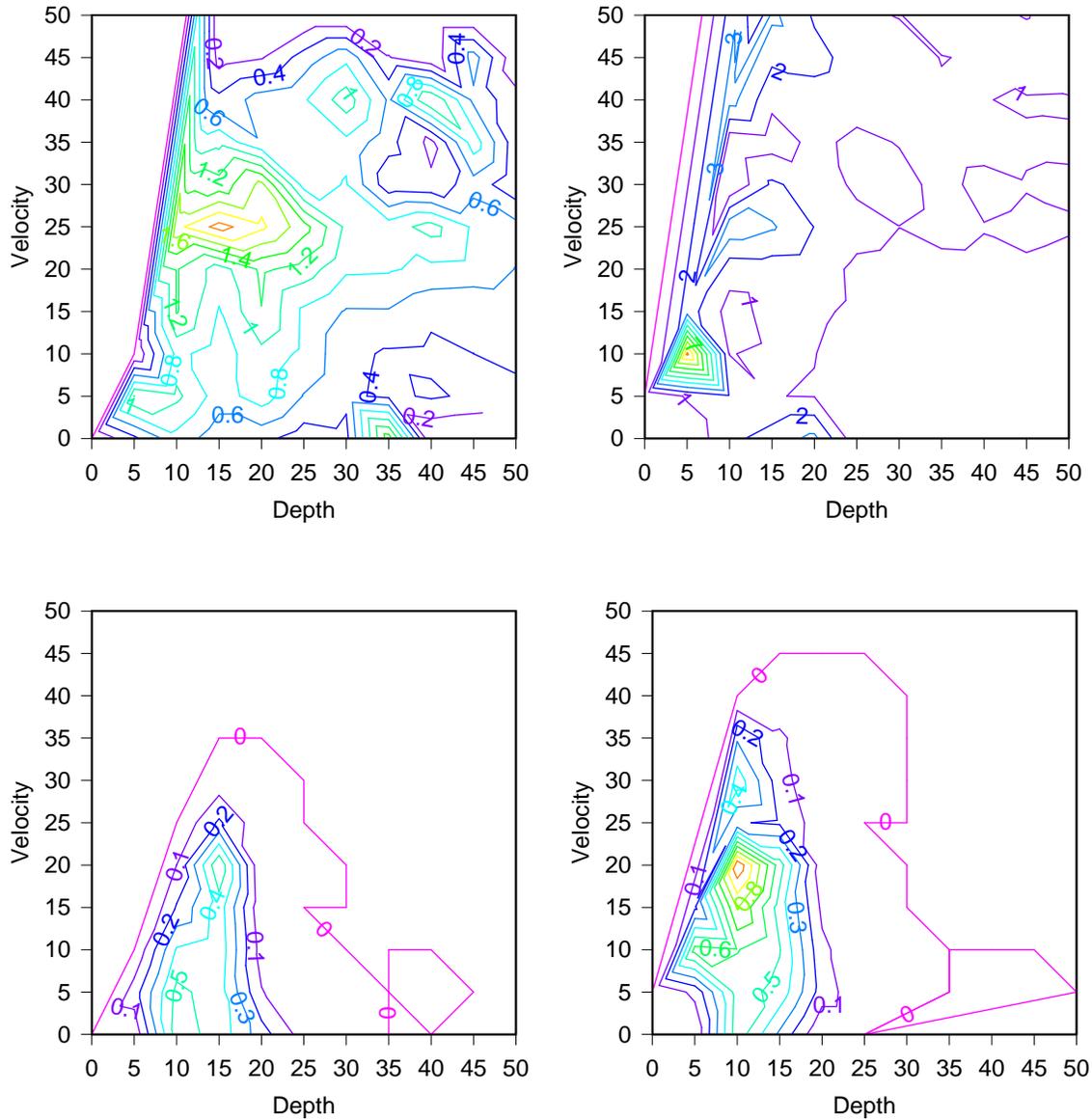


Figure 23. Simulated juvenile habitat selection during March-April of 2008 and 2010, site Restoration 3B. Contoured values of mean density (fish per m<sup>2</sup> of cell area). Top row: juveniles < 5 cm length; bottom row: juveniles > 5 cm length. Left panels: juveniles in cells lacking velocity shelter; right: juveniles in cells with velocity shelter. Plots are limited to depth and velocity values < 50, where densities are highest.

#### 4.2.2 Mesohabitat use

The mesohabitat use analysis indicates that inSALMO did a good job of representing juvenile habitat selection among habitat types: the model consistently placed fish in the same kinds of habitat where they were observed in the USFWS surveys (Figure 24, Figure 25): along banks and in shallow and side-channel habitat. Further, juveniles very strongly avoided deep mid-channel habitat in both the simulation and observations.

At a finer scale, looking at individual polygons, there were some strong differences between model and field observation. Some of the bank polygons, especially in the rootwads on the north side of the channel at its west end, had few fish in simulations but many in the field observations. These differences are likely due in part to the hydraulic simulation and habitat variable input not doing a good job of representing such complex habitat. (Keep in mind that habitat variable input for this study was developed from existing data, not based on direct observation.) Differences could also be partly explained by variability in fine-scale processes such as drift production and consumption that are represented only coarsely in inSALMO.

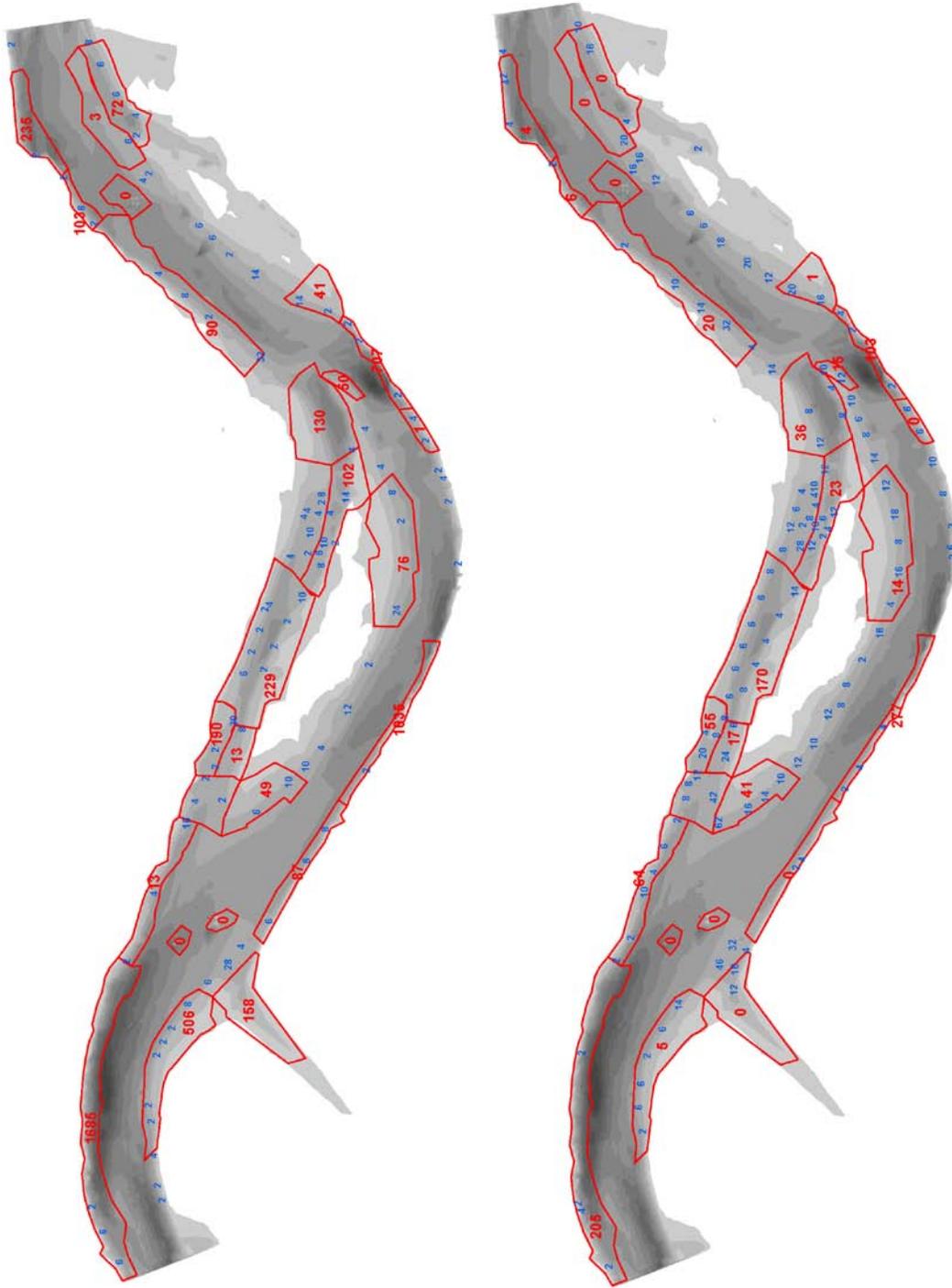


Figure 24. Observed and simulated juvenile distributions, for site Restoration 3A, April 23, 2008. Red polygons denote areas dive-sampled by USFWS; red numbers indicate the number of juveniles counted in each polygon. Blue numbers are how many simulated juveniles were in inSALMO cells, including all cells containing any fish (not just cells in or near the dive polygons). Left: small juveniles (fork length < 5 cm); right: large juveniles (length > 5 cm).



juveniles (left panels of Figure 26) approximately four weeks before they were observed in 2008, while in 2010 no peak in large juveniles was observed.

Results for the total number of juveniles (right panels of Figure 26) are harder to interpret as they indicate low numbers of juveniles at the site during a time (mid-February through mid-April, approximately weeks 17-15) when juvenile outmigration observed in the RST is high (Figure 21). It seems likely that the juvenile habitat use surveys are not effective at counting outmigrating small juveniles, especially those that are in poor condition and unable to maintain a feeding position.

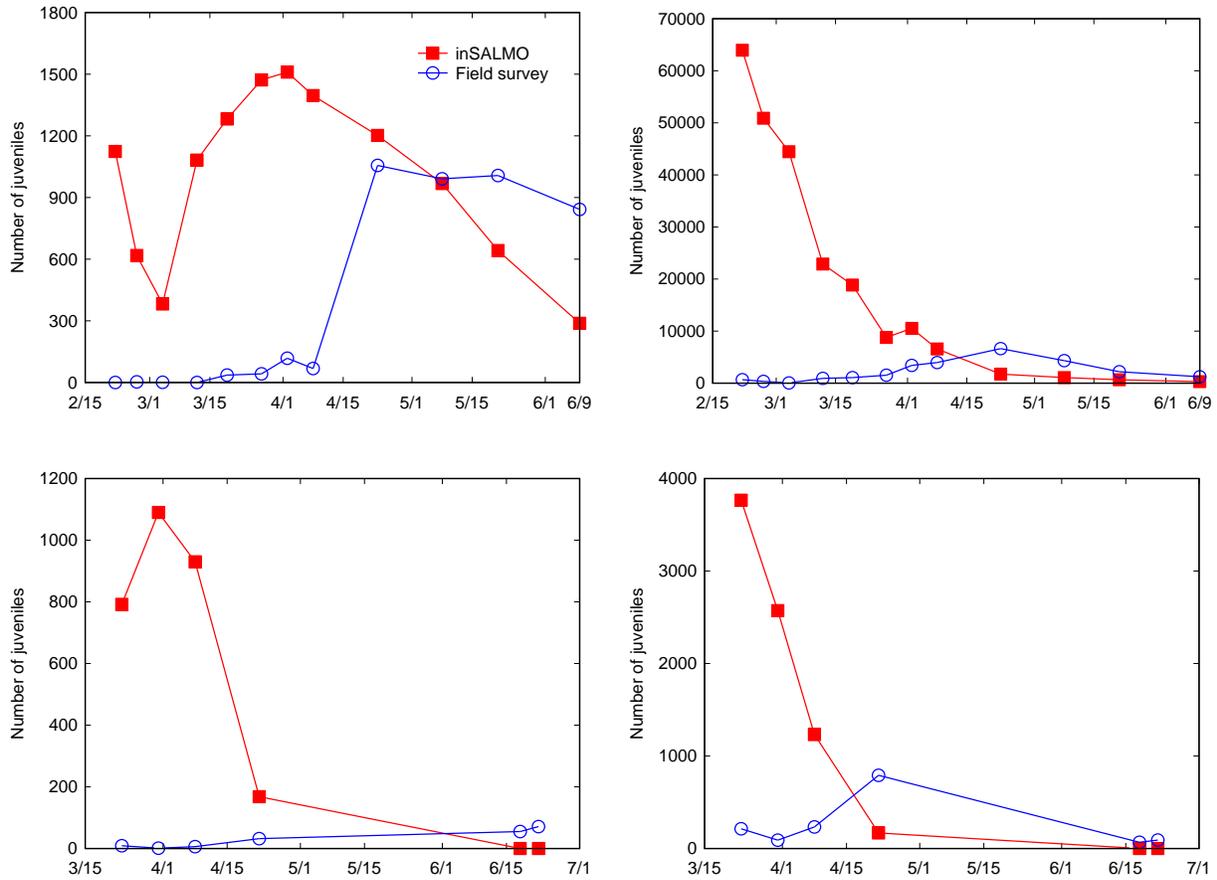


Figure 26. Time series of simulated and observed juvenile abundance at Restoration 3A. Field surveys did not include the entire site, so magnitude of observed values are not comparable to model results. Top: 2008; bottom: 2010. Left: large juveniles; right: total of all juveniles.

### 4.3 Conclusions

The analyses in this section confirm that inSALMO produces realistic habitat selection in simulated fish, across natural gradients in depth and velocity. The model produced the interesting result that larger fish were more closely associated with good habitat, while the smaller (and much more abundant) juveniles were more dispersed into deeper and faster water because they are less able to find and compete for the best habitat. Hence, the basic assumption of habitat selection modeling (that highest densities indicate the best habitat) was not true across all juveniles.

At the same time, inSALMO did not always put high densities of fish in exactly the same locations where they were observed in the USFWS mesohabitat use surveys. We expect that one reason for these differences is the limitations of our input, especially the variables for hiding cover and velocity shelter being extracted from data originally collected for other reasons. Such differences must also be expected from models like inSALMO that intentionally simplify representations of processes such as hydraulics, cover, and food distributions in order to limit model complexity and make large-scale and long-term simulations feasible. Other potential explanations include the stochasticity of real outmigration (e.g., which patch of calm habitat newly emerged fry end up in after drifting downstream from their redd), and perhaps a tendency of fry to school that is not in the model. The differences between observed and simulated fish locations should have little effect on model results when there are relatively large areas of similar habitat.

The comparison of juvenile abundance over time at Restoration 3A between simulations and field observations was limited by data interpretation difficulties, especially the apparent differences between the mesohabitat use and RST data. In this analysis, abundance of juveniles generally peaked earlier in the model than in the mesohabitat use observations, whereas in calibration the model produced outmigration later than observed at the RST. It seems reasonable to assume that the mesohabitat use data includes primarily juveniles that established feeding stations at the site, while abundance in the model (and at the RST) includes fish drifting downstream.

## 5 Validation of Interannual Variation in Outmigrant Numbers

The final validation analysis was a comparison between model results and RST data of year-to-year variation in total outmigration. This analysis was intended to provide a rough estimate of how well the model reproduces observed interannual variation in outmigrant production, despite a number of limitations in both model and data. More importantly, the analysis can help identify processes that can affect real outmigrant success that are not included in inSALMO.

### 5.1 Methods

We simulated water years 2000 through 2011, using habitat input collected mainly between 2007 and 2009. (RST data are available for 1998 and later, but the temperature data needed as model input are available only since 2000.) Results for each year were summarized into two numbers: the total number of fall Chinook outmigrants, and the number of “large” outmigrants (fork length > 5 cm). Numbers produced by inSALMO were multiplied by 14/4 to account for the model representing 4 km of the total 14 km length of LCC.

The number of large outmigrants observed at the RST was not yet available for 2011, so we had 12 years of comparison for total outmigrants and 11 years for large outmigrants. Five replicate simulations (differing only in the pseudorandom numbers used in inSALMO’s stochastic processes) were included. We used regression analysis (Smith and Rose 1995) to analyze the relation between model results and trap observations.

Important limitations of this comparison include:

- Uncertainty in the screw trap data;
- Uncertainty in the field estimates of spawner abundance used to initialize each year’s inSALMO simulations;
- Using single “snapshots” to simulate physical habitat at each site when actual habitat conditions changed over time due to restoration projects, gravel injection, and sediment transport; and
- Our assumption that the 12 simulated reaches totalling 29% of LCC represent all of the stream, without adjusting results for availability of habitat types as USFWS (2011) did.

### 5.2 Results

The comparison between annual simulated and RST-observed outmigrant numbers highlights differences noted in the calibration experiments (Section 3.2). In all years except 2001, the total number of outmigrants predicted by inSALMO is greater than the number observed by the RST (Figure 27). The number of large outmigrants is, however, much higher in the RST data, by factors up to 100 (Figure 28).

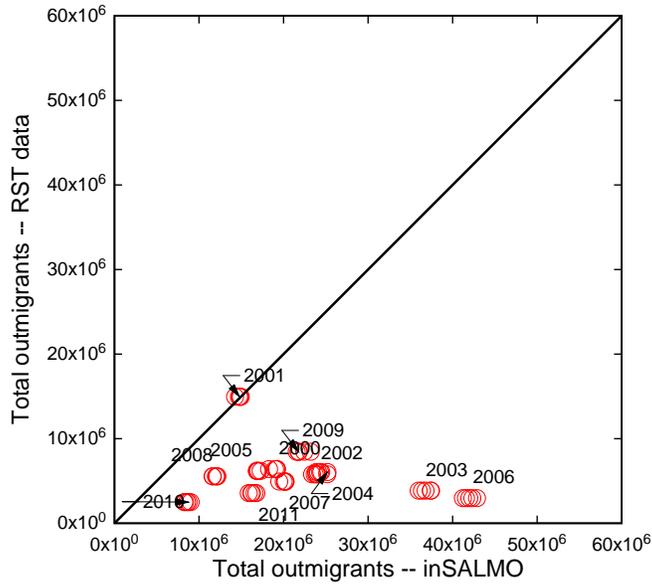


Figure 27. Comparison of model-predicted and RST-observed total number of outmigrants by year. The diagonal line represents 1:1 correspondence of model and data.

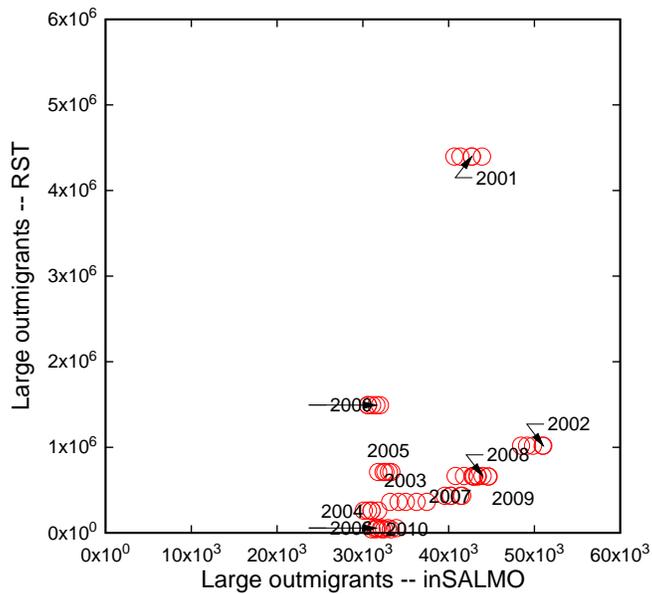


Figure 28. Comparison of model-predicted and RST-observed number of large outmigrants by year. Note the different scales on X and Y axes.

One way to try to explain these differences is to look at the relations between numbers of spawner and outmigrants in both model and RST data. The total number of outmigrants predicted by inSALMO is very closely related to the number of spawners each year (Figure 29, top panel), with a consistent 2200-2300 outmigrants per spawner. The relation between total outmigrants and spawners in the RST data would be consistently positive except for three years: 2001, 2003, and 2006 (Figure 29, bottom panel).

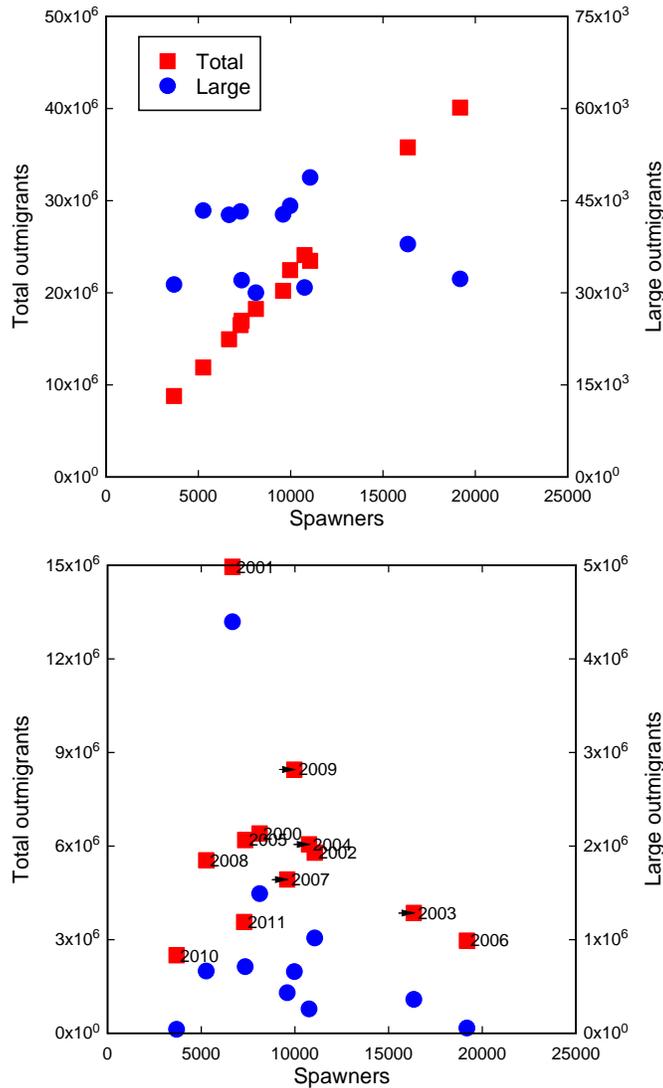


Figure 29. Relations between the number of spawners (adult females) and outmigrants in (top) inSALMO results and (bottom) RST data.

### 5.3 Conclusions

Several factors may explain the low outmigrant numbers observed at the RST in 2003 and 2006 (personal communication, Matt Brown, USFWS, 25 March 2013). One is high flows; these two years (2003 especially) had the highest flows of the 2000-2011 period. High flows could have caused redd scour (which can be modeled with inSALMO but the necessary site input to calibrate it was not available). High flows after emergence could also contribute to low survival of newly emerged fry (the highest flows in these years occurred in April and May, after fry should have emerged). Perhaps coincidentally, the year 2001 had lowest spring flows and anomalously high outmigrants per spawner. High superimposition due to high spawner escapement may have contributed to the low outmigrant numbers by eliminating the redds

spawned earliest; the remaining later redds and the fry emerging from them would be more vulnerable to the April-May high flows.

The relation between numbers of total and large outmigrants also differs between inSALMO and the RST data. The trap data contain a strong positive relation, whereas in model results the number of large outmigrants is unrelated to the total (Figure 30). Variation in RST efficiency with outmigrant size could contribute to this difference.

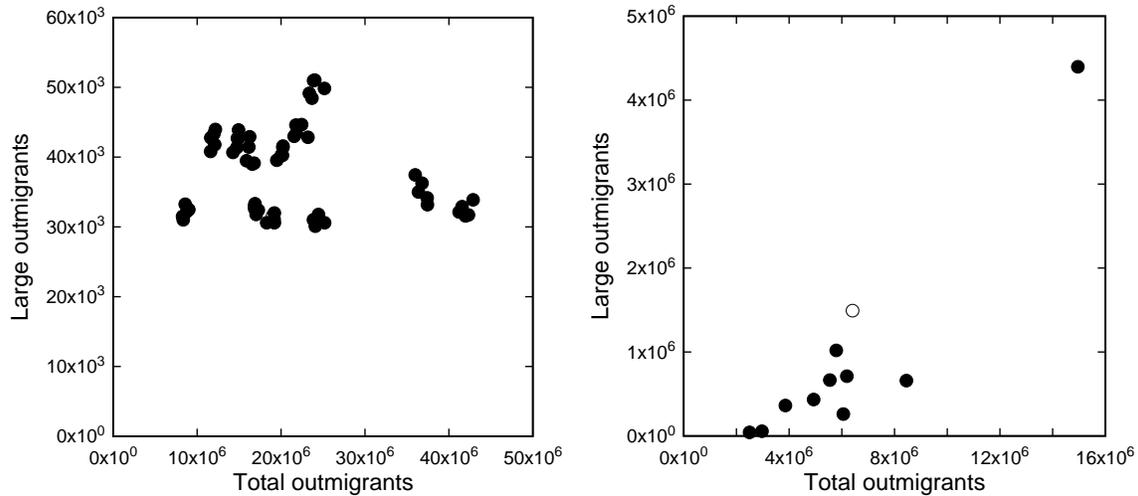


Figure 30. Relation between total number of outmigrants and number of large outmigrants in the same year, in (left) inSALMO results and (right) RST data. Each point represents one year; model results include five replicates of each year.

A final point from this analysis is that there was little difference in inSALMO results among the five replicate simulations (Figure 27-Figure 30). This observation is not surprising because the large numbers of simulated fish reduce the effects of stochasticity in results. There appears to be little reason to replicate simulation experiments.

## **6 Summary and Conclusions**

inSALMO was designed as a habitat management tool, especially for understanding and predicting the effects of flow, temperature, and channel shape on freshwater life stages of salmon. In the model, the primary results—numbers and size of outmigrating juveniles—emerge from a number of inputs and intermediate processes. In this study we examined both intermediate and final model results in comparison to field observations, to understand and improve the model's predictive abilities.

### **6.1 Summary of calibration and validation results**

The calibration and validation analyses simulated 12 reaches that represent a diversity of channel types in lower Clear Creek. Input for these reaches was developed from data collected for other instream flow studies by the USFWS. The study was subject to some important uncertainties and potential sources of error. Input for each reach was developed using an automated but approximate process to estimate habitat variables from USFWS observations of related but different variables. The 12 simulated reaches total 4 km of LCC's 14 km length, so simulations of 29% of the stream length were compared to observations on the entire length. The field data from a rotary screw trap and snorkeling surveys are themselves limited in accuracy and representativeness.

The calibrated model reproduced a number of observed patterns relatively well. Redd locations within inSALMO corresponded well with observed spawning areas, especially after input for the number of spawners was adjusted to reflect among-site variation in spawner density. The model also closely reproduced the timing of peak spawning, as estimated from carcass count data. General trends in the number and size of outmigrants over the spring and summer were reproduced, including an uptick in outmigrant numbers late in the season. The calibrated model closely matched the observed sudden mid-season increase in mean outmigrant length. Simulated juveniles expressed believable patterns of microhabitat depth and velocity selection, though no comparable field observations were available. Mesohabitat-scale habitat use by simulated fish resembled observations in being concentrated along channel margins and in sidechannels and backwaters, with few fish in deep mid-channel habitat.

There were also model results that did not closely match observations. The most striking difference was that the model predicted more total outmigrants but far fewer large (>5 cm fork length) outmigrants than observed at the RST. The RST data indicate large numbers of early outmigrants in December, whereas the model did not produce outmigrants until mid-January. Patterns in juvenile abundance over time from habitat-use snorkeling surveys were not closely reproduced by the model, but those patterns also conflicted with patterns in the RST data. Finally, year-to-year variation in outmigration, and the relation between spawner abundance and total outmigrant numbers, differed between model and RST data.

### **6.2 Conclusions for future applications and validation**

We identified a number of potential explanations for the differences between model results and field observations. These explanations are essentially important conclusions about the limitations of modeling and model calibration and validation.

One conclusion is that some model results (and, therefore, calibration success) depend strongly on the input and parameters that define how many adults arrive and when they spawn. Future model applications and calibration should focus on spawner numbers and timing before examining subsequent parts of the life cycle. Modeling one distinct race with spawning over a limited period is desirable because it reflects management priorities (e.g., here on fall Chinook) and because it limits the complexity of model input and results. However, multiple races are difficult to distinguish in field observations and may in reality overlap in characteristics such as when adults arrive and spawn. One potential way to make model results more comparable to observations would be to include all races in the same simulation (a capability inSALMO already has).

Second, model results on where adults spawn within a reach are strongly dependent on the input that defines how many adults spawn in each reach. More precise validation of these intermediate results requires more highly resolved input on spawner densities than we initially had. (We adjusted spawner densities using the spawning area observations, reducing the value of those observations for model validation.) While we did not observe that primary model results (e.g., how the number of large outmigrants varies with flow or temperature) depended strongly on spawner distribution among reaches, more highly resolved input is desirable.

Third, small outmigrants that grow little between emergence and outmigration seem particularly difficult to observe and model. These small juveniles dominate the outmigration from LCC and may be important to the population if even a small fraction survive downstream. However, sensitivity analyses of inSALMO (Railsback et al. 2011) indicate that the number of small outmigrants is insensitive to management variables such as flow and habitat quality because they spend very little time in the stream. Because small outmigrants are insensitive to most of the management variables that inSALMO is designed to address, and hard to observe (passively moving small juveniles seem especially unlikely to be observed in snorkel surveys), they may be less important for calibration and validation than their numbers indicate.

Fourth, the process we used to develop habitat input from USFWS instream flow study data seemed satisfactory overall, being based on large numbers of quantitative observations. However, this process seems likely to produce occasional but potentially important inaccuracies. Inaccuracies could result from the differences in type between the USFWS data and inSALMO input (the USFWS data is focused more on what is present—substrate sizes, whether wood is present, etc.—whereas inSALMO input reflects the biological function of what is present: is the substrate suitable for spawning? Where could a juvenile salmon hide from a predator?). Spatial resolution differences could also cause errors; a small patch of hiding cover or velocity shelter may not appear in the USFWS data if it is not at an observation point, whereas it should contribute to inSALMO's input for the percent of cell area providing cover or shelter. (We expect such resolution problems to be minor in this study because of the USFWS data's high resolution.) Direct observations to check or supplement this habitat input would be desirable.

Fifth, discussions with USFWS biologists involved in Clear Creek monitoring and restoration indicate that the large difference between model and RST data in total numbers of outmigrants could result in part from several processes that were not represented in the simulations. One process is sedimentation and its effects on egg survival. We have so far chosen not to represent this process in inSALMO because of its complexity and because it is less directly linked to the

primary purposes of the model. Another process is intentional superimposition. We experimented with having model spawners intentionally destroy existing redds, which could substantially increase egg mortality (e.g., from 40-50% up to 80%). However, we did not implement this change without more evidence to support it. Finally, redd scour may be much more widespread than in our simulations. inSALMO does have a redd scour function, which we parameterized previously for sites Restoration 3A and 3C (Railsback et al. 2011). We did not attempt to parameterize it to all 12 sites due to a lack of information and because the extent of spawning gravel and its susceptibility to scour changes substantially over time in LCC as a result of restoration work and gravel injection.

This calibration and validation study resulted in several changes to model assumptions and parameter values (Section 3.2). These changes have been incorporated into what we now refer to as version 1.5 of inSALMO, which will be documented and distributed as a subsequent product of this project. While these changes improve the model's fit to observations, they do not appear to dramatically change the model's behavior or to invalidate key results of previous analyses.

### **6.3 Conclusions about inSALMO's validity**

It is difficult to draw simple and broad conclusions from studies such as this that compare many results of a complex model to a variety of field observations that are both uncertain and not quite directly comparable to the model. In this case, inSALMO reproduced some important patterns in data well and yet did not closely reproduce what seem like very important relations such as year-to-year variation in outmigrant numbers.

It is important to remember that inSALMO, like all models, is intentionally simplified to make it useful for particular purposes. Good models should not be more complex than necessary to solve the problems they are designed for. The primary purposes of inSALMO are to predict and understand how changes in flow and temperature regime, and channel shape, affect spawning and rearing success. Processes (such as sedimentation) that may sometimes have strong effects but are not directly related to the primary purposes, have been left out of inSALMO to limit its complexity. We cannot expect inSALMO's results to match patterns that are driven by processes not in the model. (Redd scour, potentially important for some of this study's results, could be re-activated in inSALMO by conducting a relatively modest parameterization process. This process has been conducted only at two sites so far.)

Unfortunately, it is very unlikely that we will ever have the opportunity to "cleanly" test the primary predictions of inSALMO; that would require relatively accurate data from a number of years in which little varied except the flow, temperature, and spawner densities that drive the model. Instead, we can test and improve the separate components of inSALMO that represent intermediate processes such as spawn timing and site selection, juvenile habitat selection and growth, and the outmigration decision.

The analyses here indicate that inSALMO does a generally good job of predicting these kinds of intermediate results. One potential exception is the model's underprediction of the number of large outmigrants. This discrepancy could result from limitations of the input (e.g., underrepresenting exceptionally good rearing habitat at either the reach or microhabitat scale) or could indicate a weakness of the model's method for deciding when to migrate downstream. The other results of this study, combined with realistic responses to habitat variables in previous

analyses (Railsback et al. 2011) continue to give us confidence in inSALMO's usefulness for its original purposes.

## 7 Literature Cited

- Beacham, T. D., and C. B. Murray. 1990. Temperature, egg size and development of embryos and alevins of five species of Pacific salmon: a comparative analysis. *Transactions of the American Fisheries Society* 119:927-945.
- Earley, J. T., D. J. Colby, and M. R. Brown. 2010. Juvenile salmonid monitoring in Clear Creek, California, from October 2008 through September 2009. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.
- Earley, J. T., D. J. Colby, and M. R. Brown. 2009. Juvenile salmonid monitoring in Clear Creek, California, from October 2007 through September 2008. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.
- Giovannetti, Sarah L., Matthew R. Brown, and Laurie A. Stafford. 2008. Fall Chinook salmon spawning area mapping for the Clear Creek Restoration Program, 2007. U.S. Fish and Wildlife Service Red Bluff Fish and Wildlife Office 10950 Tyler Road Red Bluff, California 96080.
- Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals, Statistical design and analysis for field studies. Second edition. Kluwer Academic Publishers, Boston.
- Newton, J. M. and M. R. Brown. 2005. Juvenile Chinook Habitat Use in Lower Clear Creek, 2005 Fisheries Evaluation for Stream Channel Restoration Project, Phase 3A and 3B of the Lower Clear Creek Floodway Rehabilitation Project USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.
- Newton, J. M., J. R. Grigg, and M. R. Brown. 2004. Juvenile Chinook habitat use in lower Clear Creek, 2003: fisheries evaluation for Phase 3A of the Lower Clear Creek Floodway Rehabilitation Project. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.
- Railsback, S. F., B. C. Harvey, and J. L. White. 2011. inSALMO version 1.0: Model improvements and demonstration application to Chinook salmon spawning, incubation, and rearing in Clear Creek, California. Lang, Railsback & Associates, Arcata, CA. Available at: [www.fws.gov/sacramento/Fisheries/Instream-Flow/fisheries\\_instream-flow\\_inSalmo.htm](http://www.fws.gov/sacramento/Fisheries/Instream-Flow/fisheries_instream-flow_inSalmo.htm).
- Railsback, S. F., B. C. Harvey, and J. L. White. In preparation. Effects of spatial extent on simulated relations between habitat and salmon populations. Draft manuscript prepared by Lang Railsback & Associates, Arcata CA.
- Smith, E. P., and K. A. Rose. 1995. Model goodness-of-fit analysis using regression and related techniques. *Ecological Modelling* 77:49-64.

Tattam, I. A., J. R. Ruzycki, P. B. Bayley, H. W. Li, and G. R. Giannico. 2013. The influence of release strategy and migration history on capture rate of *Oncorhynchus mykiss* in a rotary screw trap. *North American Journal of Fisheries Management* 33:237-244.

USFWS. 2011. Flow-habitat relationships for fall-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Clear Creek Road and the Sacramento River. USFWS, Sacramento Fish and Wildlife Office, Sacramento, California. Available at: [www.fws.gov/sacramento/Fisheries/Instream-Flow/fisheries\\_instream-flow.htm](http://www.fws.gov/sacramento/Fisheries/Instream-Flow/fisheries_instream-flow.htm).