Comprehensive Passage (COMPASS) Model – version 2.0

Review DRAFT

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1 Background and Model Overview

The Comprehensive Passage (COMPASS) model was developed by scientists from throughout the Pacific Northwest. The purpose of the model is to predict the effects of alternative operations of Snake and Columbia River dams on salmon survival rates, expressed both within the hydrosystem and latent effects which may occur outside the hydrosystem. Accordingly, the model has the following capabilities: 1) realistically simulate survival and travel time through the hydrosystem under variable river conditions; 2) produce results in agreement with available data, particularly PIT-tag data; 3) allow users to simulate the effects of alternative management actions; 4) operate on sub-seasonal time steps; 5) produce an estimate of uncertainty associated with model results; 6) estimate hydrosystem-related effects that may occur outside of the hydrosystem.

The COMPASS model simulates downstream migration and survival of juvenile salmon through the tributaries and dams of the Columbia and Snake rivers (via in-river migration and transportation) to the estuary (Figure 1). In addition, the model applies any latent mortality related to hydrosystem passage expressed outside of the hydrosystem (Figure 1). Thus, the model attempts to simulate all mortality associated with passage through the hydrosystem.

Although the COMPASS model will be used for a variety purposes, including in-season monitoring of survival and travel time, the primary function of the model is to compare hydrosystem survival across management scenarios. The three main operations that vary among management scenarios are flow (based on releases from storage reservoirs), proportion of river flow passed through the spillway, and transportation scheduling. Changes in these operations can change in-river survival and adult return rate through a variety of mechanisms (Table 1). Also, dam configurations have changed across years, notably the addition of spillway weirs, and certain management scenarios may involve further dam configurations. Additional management scenarios that may be visited at a future time include reducing reservoir elevations to increase water velocity, predator removal, and dam breaching.

COMPASS is capable of representing any salmonid population that migrates through the Snake and Columbia rivers, including the Upper Columbia River. We have currently calibrated the model for the Snake River spring/summer Chinook salmon and steelhead Evolutionarily Significant Units (ESUs). While this manual presents results for these two ESUs, we plan to expand the modeling capabilities in the future to other ESUs.

The model is supported by extensive data sets, particularly PIT-tag data, which provide information on survival and travel time. Additionally, dam passage parameters were estimated from radio-telemetry, acoustic tag, and hydroacoustic studies. The model was calibrated by fitting survival and migration rate relationships to historical data. During this calibration phase, we assembled historical data sets of river conditions (water flow, water temperature, and reservoir elevations) and dam operations (spill and transportation schedules), and we also implemented historical dam configurations.

To run the model prospectively, we needed to assemble data files of river conditions (primarily flow and temperature) that reasonably reflect the variability in future conditions. As has been implemented in past modeling efforts, we use a hydrological model such as HYDSIM that reconstructs river conditions in the hydrosystem based on historical outflows from headwaters during the years 1929-2008. The HYDSIM model also takes into account current storage reservoirs and scheduled water releases. Because temperature is an important factor in some reservoir survival relationships, we also simulate water temperatures during these years based on flow-temperature relationships.

For each of the "water years" described above, we produce key information on juvenile fish migration through the hydrosystem – annual survival through the entire hydrosystem, percentage of fish transported, and arrival timing below Bonneville (along with other diagnostic information). We then apply post-Bonneville mortality. For some post-Bonneville hypotheses, information from the downstream migration module – arrival timing, water travel time, percent fish transported – are incorporated into predictions of post-Bonneville survival.

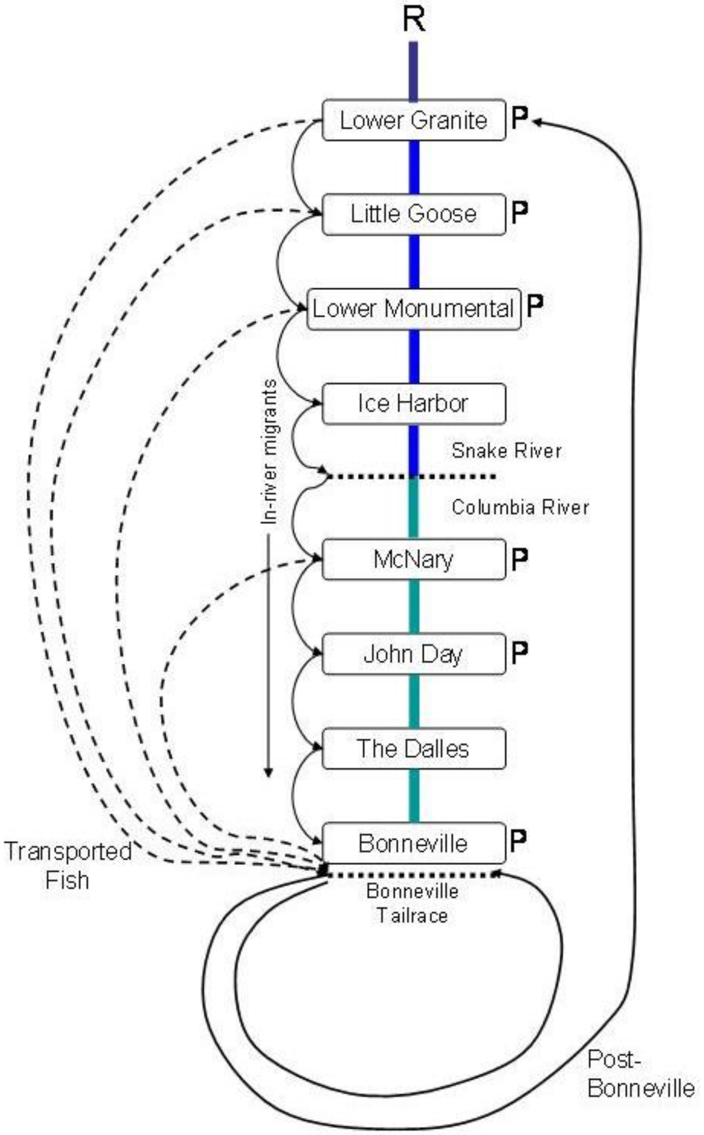

Figure 1. Features of the Snake and Columbia River hydrosystem modeled in COMPASS for Snake River fish. “R” represents the release site or the site where fish enter the hydrosystem (head of Lower Granite reservoir). Fish move downstream via in-river migration or by transportation. “P” represents PIT-tag detection sites. The post-Bonneville component of the model takes fish from the Bonneville tailrace and returns them to either Bonneville Dam or Lower Granite Dam, depending on the hypothesis.

Table 1. List of potential management actions and their effects on survival, as expressed through the model.

Action	Effect on Model	Effect on Survival
Flow Augmentation	Flow increases	Reservoir survival increases
	Temperature decreases (or increases)	Reservoir survival increases (or decreases)
	Water velocity increases	Reservoir survival increases due to decreased exposure time resulting from decreased travel time
	Water velocity increases	Increased SAR of in-river migrants due to earlier arrival in the estuary resulting from decreased travel time
Increased spill (but at or below gas cap)	More fish pass via spillway	Dam survival increases
	More fish pass via spillway	Reservoir survival increases due to relationship with spill
	Fewer fish transported	SAR increases or decreases depending on post-Bonneville survival
	Delay in dam passage decreased	In-river survival increases due to decreased travel time
	Delay in dam passage decreased	SAR of in-river migrants increases because of earlier arrival to estuary
Transportation schedule	Change timing of transportation	SAR increases or decreases depending on post-Bonneville survival
	Change timing of transportation	Overall in-river survival increases or decreases because of altered timing of in-river migrating population and consequently altered

population-wide exposure to river conditions

2 Downstream Passage

2.1 Model Overview

The downstream passage component of COMPASS models downstream migration and survival of juvenile salmon populations (where population is synonymous with ESU) through the Snake and Columbia rivers. COMPASS computes daily fish passage for all river segments and dams on a release-specific basis. The model is composed of four submodels: reservoir survival, dam passage, travel time, and hydrological processes. A brief description of the submodels follows.

The structure of COMPASS allows incorporation of different algorithms to simulate hydrosystem processes for each of these models. The reservoir survival module in particular allows the substitution of different algorithms to represent different hypotheses concerning reservoir survival.

Reservoir Survival. Reservoir survival is computed as fish move through each reservoir. Reservoir survival is potentially related to river flow, river temperature, spill rate, travel time, and travel distance. The relationship varies among populations and among major river segments (e.g., Snake and Columbia rivers). The specific relationships are based on statistical analyses of PIT-tag survival data.

Dam Passage. Fish can pass dams by several passage routes: spillways, removable spill weirs, sluiceways, turbines, and fish bypass systems. Each of these routes has an associated probability of passage and survival. Day/night (diel) differences may exist in these passage and survival probabilities. Further, fish that enter the bypass systems of collector dams (Lower Granite, Little Goose, Lower Monumental, and McNary) can be diverted into trucks or barges for transportation to below Bonneville Dam.

Travel Time. The travel time submodel moves release groups downstream according to a migration rate and a rate of spreading. Migration rate is based on water velocity, date of release, water temperature, and spill passage rate. The spreading rate of a release group determines its temporal distribution as it passes through dams and reservoirs. Travel time parameters are specified by population and are based on statistical analyses of PIT-tag data.

Hydrological Processes. Daily river flow, water velocity, and water temperature are represented through a detailed hydrological submodel. Daily flows and temperatures at headwaters are either taken directly from historical data or from system hydroregulation models external to the COMPASS model.

The four submodels interact to simulate the survival and timing of release groups as they pass through a project (Figure 2). The user specifies release information, provides input parameters for survival and travel time relationships and dam passage, specifies dam operations (spill and transportation), and provides a data file for water temperature and flow. The model outputs number of fish per day entering the next downstream river segment and the number of fish transported by day.

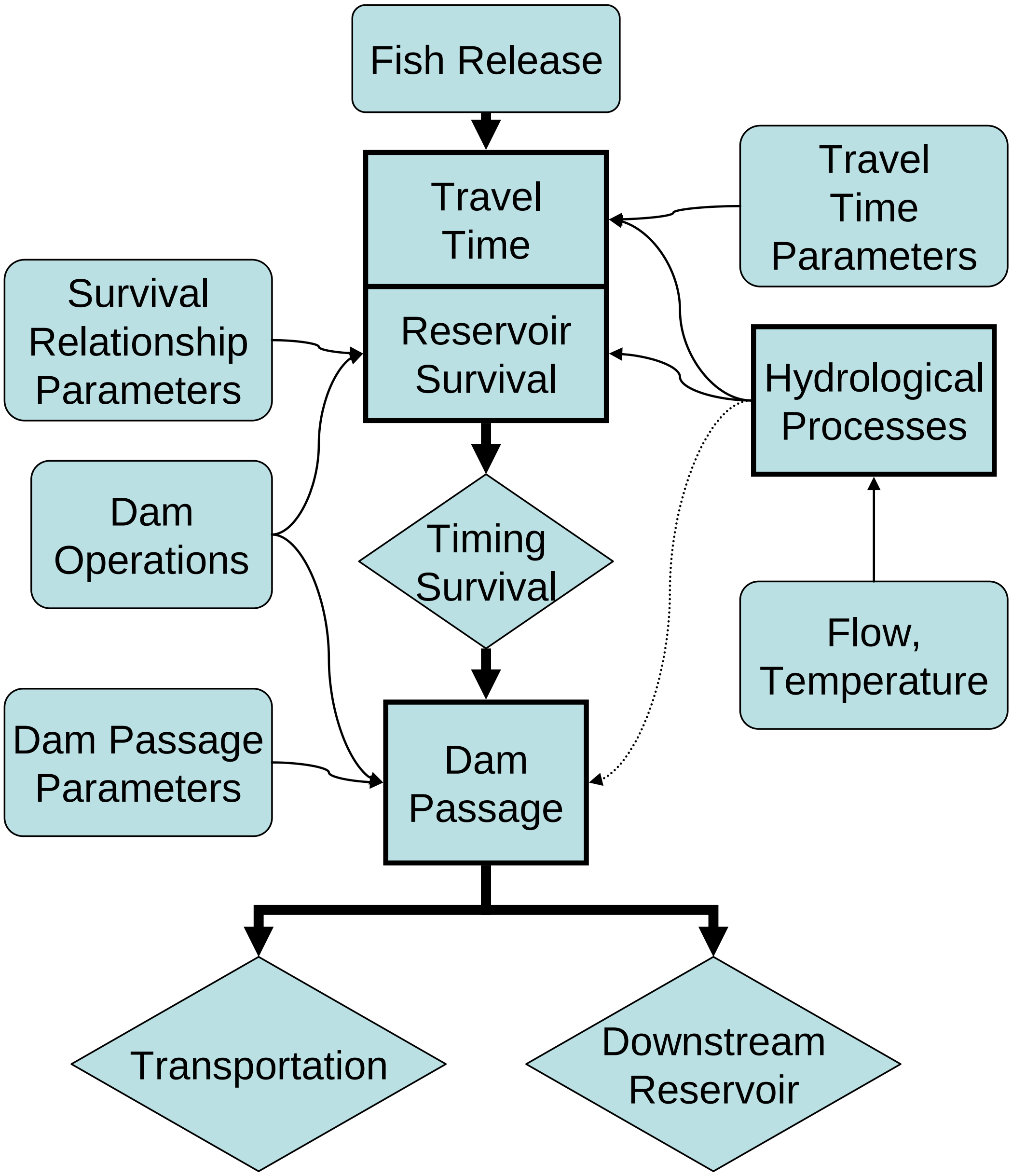

Figure 2. Schematic diagram of fish passage through a project (reservoir and dam). The rectangular boxes represent the model submodels. The boxes with rounded corners represent user inputs. The diamonds represent model outputs.

The model is initiated with a release group specified at a particular release site. Release groups may be distributed across days with varying numbers of fish per day. For historical runs and calibration we use release distributions based on observed arrivals of fish at the release location. For prospective runs we use a predictive model to generate release distributions using relationships between observed arrivals and flow and water temperature (see Appendix 7).

All fish in a release group share behavioral characteristics; that is, they have common travel time and survival parameters. The model proceeds by moving fish, in sub-daily time increments, through river segments and dams following a sequence of steps (Figure 3). The length of time steps is variable, from a minimum of two time steps per day (12 hour steps) to a maximum of sixteen time steps per day (1.5 hour steps). We currently use sixteen time steps per day when calibrating prospective models.

The first step is to take all fish released into a reservoir on a given time step or all fish arriving at the top of a reservoir on a given time step and distribute them at the bottom of the reservoir according to the travel time model, described in detail below. Next, reservoir survival (details below) is applied to these fish before they move to the dam passage algorithm. At the dam, arriving fish are distributed across passage routes according to specified passage probabilities. Route-specific survival probabilities are then applied. Surviving fish are then formed into time step release groups to enter the next downstream reservoir. Note that these time step release groups are composed of all the fish from the initial release group that arrive at a dam on the same time step (but may have entered the top of the reservoir on different time steps). Fish that enter the bypass system at collector dams may be transported, according to specified transportation schedules.

There are two modes that COMPASS can use: a Scenario Mode that produces deterministic results, and a Monte Carlo Mode, which produces measures of uncertainty in predicted passage survival. In the latter case, the model will be run repeatedly, drawing parameters from distributions for each run, and presenting survival information as probability distributions. At present, only the deterministic mode is self-contained within the COMPASS program; the Monte Carlo mode is currently implemented via an external setup that uses a series of scripts to repeatedly modify input files and run the model.

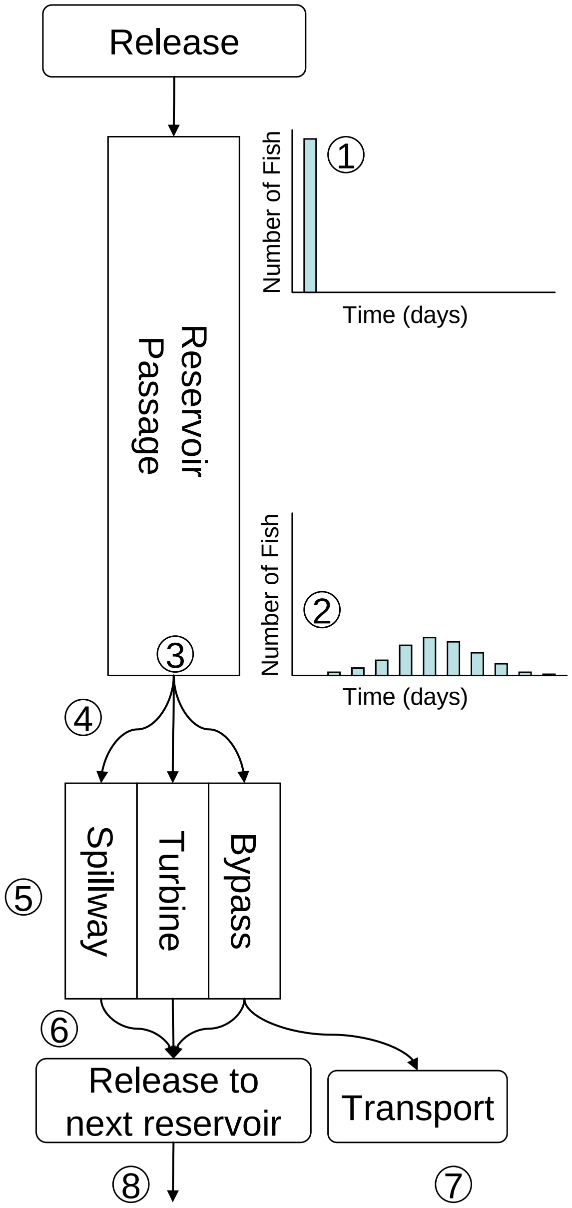

Figure 3. Passage model algorithm, features the steps taken to move a time step release of fish through a project. (1) Fish released at the top of a reservoir. (2) Fish distributed (across sub-daily time steps) at bottom of reservoir according to travel time model. (3) Reservoir mortality applied. (4) Fish assigned to passage routes. (5) Dam mortality applied. (6) Surviving fish pooled to form release group for next reservoir. (7) Fish that entered bypass system may be transported. (8) Fish released, in time step increments, into next downstream reservoir; return to step (1). Note that in the final step, the release groups are composed of all fish passing the dam on a given time step, regardless of when they were released at the upstream site.

2.2 Reservoir Survival

Foundation of Survival Modeling

A standard form for survival functions is

$$S(t) = \exp(-r \cdot t)$$

where $S(t)$ is the probability of surviving through t units of time and r is the mortality rate, which has units 1/time (Kalbfleish and Prentice 1980, Hosmer and Lemeshow 1999). The parameter r is interpreted as the instantaneous probability that an individual will die in the next short time increment given that the individual has survived to the current time (Ross 1993). Thus, as r increases survival across a time period decreases (Figure 4). If survival is measured across an extended time period during which the instantaneous mortality rate is not constant, then the rate term r can be interpreted as the mean mortality rate over the time period (Ross 1993).

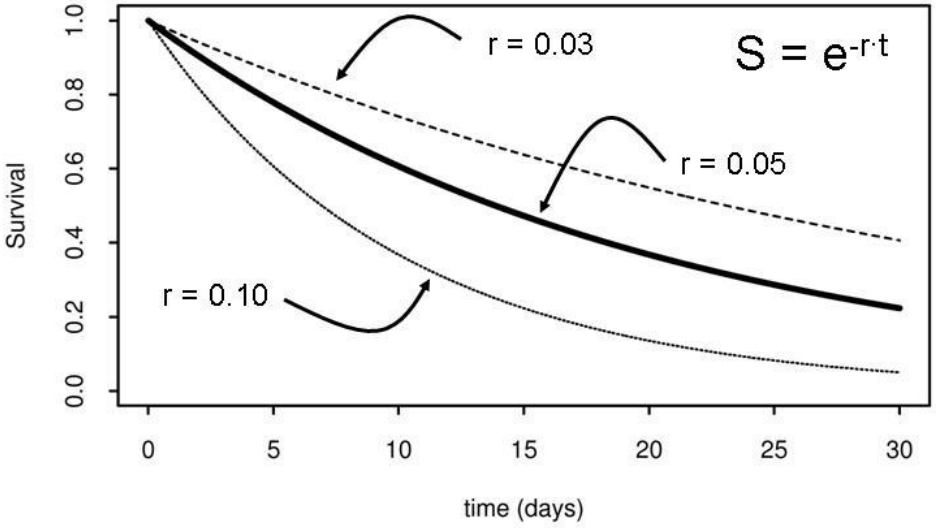

Figure 4. Exponential survival relationships as a function of exposure time for various values of the parameter r (instantaneous mortality). As r increases, survival decreases at a greater rate.

In addition to the mechanistic foundation, the exponential formulation has a number of desirable properties. Like the survival process itself, the exponential equation above begins at 1.0 when $t = 0.0$ and falls to 0.0 as t gets large (given that r is positive). Another desirable feature is that survival over a sequence of time intervals is multiplicative. That is, for example,

$$S(t_1 + t_2) = \exp(-r \cdot (t_1 + t_2)) = \exp(-r \cdot t_1) \cdot \exp(-r \cdot t_2).$$

Also, log[1] survival is additive:

$$\log(S(t_1+t_2)) = \log(\exp(-r\cdot(t_1+t_2))) = -r\cdot(t_1+t_2)$$

This property is extremely useful when we want to partition survival across river segments, and we know how much time fish spent in each segment and the overall survival across all segments (for example, we have survival estimates from Lower Monumental Dam to McNary Dam, but we need to estimate, in the passage model, survival from Lower Monumental to Ice Harbor and Ice Harbor to McNary).

However, a strict exposure time model isn't consistent with the survival data, otherwise we would expect to observe stronger survival vs. travel time relationships than have been found previously (Smith et al. 2002). An alternative explanation is that survival is related to distance traveled (Muir et al. 2001, Anderson et al. 2005). An exposure model also works here, but the exposure is to distance traveled,

$$S(d) = \exp(-r\cdot d)$$

This formulation also has the desirable property that survival over shorter segments can be multiplied together to give survival over a longer reach. To accommodate both types of survival process, we implemented a hybrid model where survival is a function of both travel time and distance traveled:

$$S(t,d) = \exp(-(r_t\cdot t + r_d\cdot d)),$$

or, on the log scale:

$$\log(S(t,d)) = -(r_t\cdot t + r_d\cdot d)$$

In our approach, the survival data determine the relative importance of distance versus travel time.

To relate reservoir survival to varying river conditions we modeled the instantaneous mortality rate related to travel time, r_t, as a function of predictor variables. We restricted the mortality rate related to distance, r_d, to be a constant to simplify the models, avoid overfitting, and avoid problems with unidentifiable parameters. To determine which factors to include in the model and in which form, we first assumed that predation is the primary cause of mortality in the reservoir. Thus mortality rate in our model is analogous to predation rate (per unit time). Predation rate is typically nonlinear in response to temperature (e.g., Vigg & Burley 1991), and thus we believe a quadratic term for temperature is justified. We also allow for lethal threshold effects of temperature by allowing the slope on temperature to potentially change at an estimated threshold level. Evidence also exists to support the hypothesis that predation rate is negatively related to river flow, perhaps through turbidity effects (Gregory & Levings 1998). We included

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[1] Note that for here and the remainder of this document, log refers to natural log.

proportion of fish passing through the spillway of the dam upstream of a river segment as a potential predictor variable, based on the assumption that increased spill leads to increased survival in the reservoir due to a quicker and safer passage through the upstream dam. We also allow for there to be an additional effect of zero spill on mortality by including the proportion of time fish experience zero spill. We relate these covariates to the time mortality rate as a log-linear function:

$$r_{t,i,j} = \exp(\beta_0 + \beta_1 F_{i,j} + \beta_2 T_{i,j} + \beta_3 T_{i,j}^2 + \beta_4 (T_{i,j} - \tau) I_{T>\tau} + \beta_5 Sp_{i,j} + \beta_6 ZSp_{i,j})$$

where the mortality rate and covariates are indexed for a group of fish entering a particular reservoir segment on time step *i* and exiting on time step *j*. Here *F* is flow in kcfs, *T* is temperature in degrees Celsius, *Sp* is the proportion of fish passing the spillway of the upstream dam, and *ZSp* is the portion of time with zero spill at the upstream dam. These covariates are averages over the time steps from *i* to *j*. The β's are regression parameters, τ is a parameter for the threshold temperature, and $I_{T>\tau}$ is an indicator variable with value 1 when $T_{i,j} > \tau$ and 0 otherwise. We model the mortality rate related to distance as $r_d = \exp(\alpha_0)$. Modeling these rates as log-linear constrains the mortality to be non-negative, which constrains survival to be in the interval [0, 1].

We can also model density-dependent predation effects where the density of both the predators and the migrating smolts is considered. As an approximation to a Holling Type II functional response (Holling 1959), we write the mortality rate due to density-dependent predation as:

$$r_{p,i,j} = \frac{\exp(\omega_1)\, P_{1,i,j}}{N_{i,j} + \exp(\gamma_1)} + \frac{\exp(\omega_2)\, P_{2,i,j}}{N_{i,j} + \exp(\gamma_2)}$$

where $N_{i,j}$ is the density of smolts, and $P_{s,i,j}$ is the density of predator *s*, ω_s is the log of the maximum consumption rate, and γ_s is the log smolt density at which the consumption rate is half of maximal for species *s*, where s = 1, 2. Here we assume the rate of mortality due to density dependent predation is related to time spent in the river segment.

Putting all of the sources of mortality together, the full reservoir survival function for fish entering a particular river segment on time step *i* and exiting on step *j* is:

$$S_{i,j} = \exp\{-r_d d\} \exp\{-(r_{t,i,j} + r_{p,i,j}) t_{i,j}\}$$

where *d* is the length of the reservoir and $t_{i,j} = j - 1$ is the travel time through the segment in time steps.

2.3 Dam Passage

2.3.1 Dam Passage Algorithms

Fish are passed to the dam module from the reservoir module on a sub-daily time step according to diel passage probabilities. The length of time steps is variable, from a minimum of two time steps per day (12 hour steps) to a maximum of sixteen time steps per day (1.5 hour steps). Dam passage is represented primarily by a sequence of algebraic expressions representing passage probabilities. Most of these probabilities vary with river conditions according to passage efficiency relationships, while other passage probabilities are constant.

Constant Passage Efficiencies

Passage efficiencies represent the probability of passing through a particular passage route. Since they are probabilities, they range from 0.0 to 1.0.

At some dams, fish can pass via sluiceways or surface bypass collectors. The probability of passing through these routes is sluiceway passage efficiency (SLE). We currently use constant proportions for SLE, based on estimates from data (see Appendix 5 for details).

Passage Efficiency Relationships

An "efficiency curve" describes the relationship between the proportion of fish passing through a passage route as a function of factors such as the proportion of flow passing through the route. These curves are applied to passage through a bypass system, spillway, passage through a removable spillway weir (RSW, described below), and passage through multiple powerhouses (at Bonneville Dam and Rock Island Dams).

These relationships are typically nonlinear but are constrained to pass through the points 0.0, 0.0 and 1.0, 1.0. We developed a flexible, nonlinear model to fit a variety of relationships while also satisfying the constraints. First, we define y as logit(P), where P is the proportion of fish passing through a passage route, where the logit transformation is defined as log(P/(1-P)). This is a common transformation for data that are probabilities. The efficiency relationship is expressed as

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \ldots .$$

where the x's are explanatory variables.

In the case of spill passage efficiency, one of the predictor variables is F_{SPILL} (proportion of flow through the passage route). Since this is also in effect a probability, we also applied the logit transform to F. These transformations result in a flexible relationship that approaches 0.0, 0.0 as F_{SPILL} approaches 0.0 and 1.0, 1.0 as F_{SPILL} approaches 1.0 (with $\beta_1 > 0.0$) (Figure 7). In addition, we also express SPE as a function of total river flow (F_{TOTAL}), so the relationship is

$$\log it(P_{SPILL}) = \beta_0 + \log it(F_{SPILL}) + F_{TOTAL}$$

where P_{SPILL} is the proportion of fish passing via the spillway.

The equation above is easily fit to the data using simple linear regression. Appendix 4 provides details of the data analysis, estimated parameters, and plots of model fits.

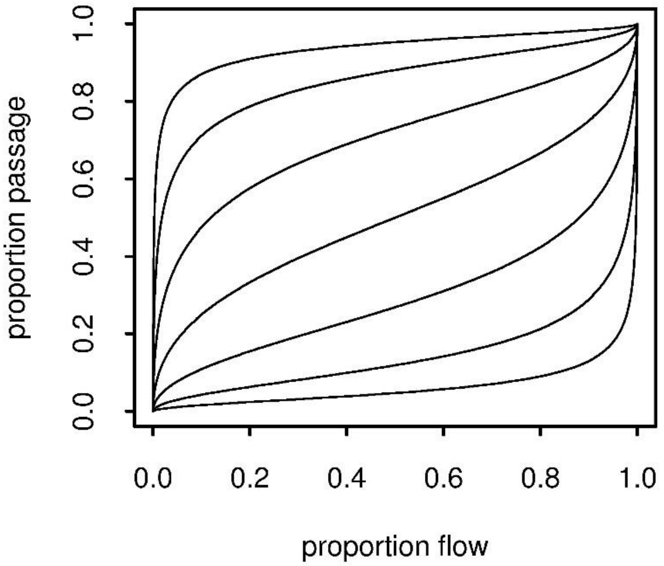

Figure 7. Examples of passage efficiency relationships. In these examples, the β_0 parameter was varied from -3 to 3 in unit increments while the β_1 parameter was fixed at 0.5. Note this plot only presents some of types of curves possible.

Removable Spill Weir (RSW) or Raised Crest Spillway devices are designed to route fish preferentially. These spillways do not exist at every project in the system, but where they do exist, they are considered to be the preferred route for fish. The efficiency of the RSW passage route is defined as the fraction of fish that are passed through this route as a function of the proportion of flow passing through the RSW relative to all flow passing through the spillway (RSW spill + normal spill). When there is RSW spill, COMPASS calculates the proportion of fish going through all spill routes with one spill efficiency equation and then the proportion going through the RSW with a second equation, then takes the difference (proportion through all spill - proportion through RSW) to get the proportion that went through normal spill routes.

The proportion of flow spilled at each dam is retrieved from data files, which are either based on historical records, or they can be generated from hydroregulation models (HYDSIM). Spill is specified for both daytime and nighttime periods.

Fish Guidance Efficiency (FGE) is defined as the proportion of fish entering the powerhouse (and thus pass via either the bypass system or turbines) that pass via the fish bypass system. FGEs can be specified for day and night at each dam, if sufficient data exist. Some dams do not have bypass systems, and in these cases, FGE = 0.0. For those dams with ample data, we developed models where FGE is a function of flow through the powerhouse (F_{PH}) and day in the season as follows:

$$\log it(FGE) = \beta_0 + \beta_1 \cdot F_{PH} + \beta_2 \cdot day$$

FGE can also be expressed as a function of temperature, but because day in the season and temperature are highly correlated, we used one or the other.

Calculating route-specific passage probabilities (for dams with single powerhouses)

The order of computations is (Figure 8a):

1. Proportion of fish passing through all spillway routes.
2. Proportion of fish passing through the RSW, if one exists.
3. Proportion of fish passing via the sluiceway or surface bypass collector (SLE).
4. Proportion of fish passing through the juvenile bypass system (FGE).
5. Proportion of fish passing through a Turbine.

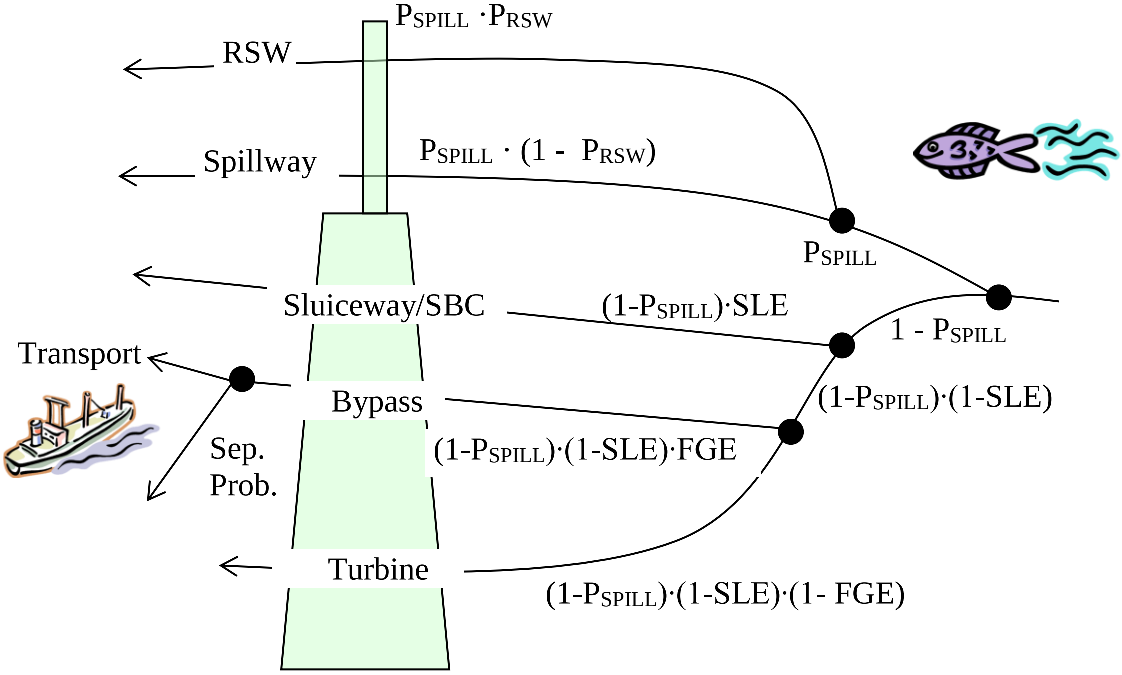

Figure 8a. Possible routings of fish at a dam. The black dots represent bifurcations of the population where there are only two possible routes. P_{SPILL} = proportion of fish passing via the spillway, and P_{RSW} = proportion of fish passing the spillway that pass via the RSW. SLE = Sluiceway Efficiency or Surface Bypass Collector Efficiency, in COMPASS, these are equivalent. FGE = Fish Guidance Efficiency, the fraction of fish entering the powerhouse that are bypassed.

Multiple Powerhouses

Bonneville Dam and Rock Island Dam each have two powerhouses that can be operated independently to optimize survival during the fish passage season. Each project has a single spillway (Figure 8b).

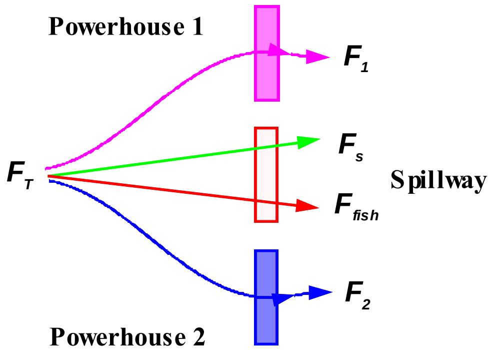

Figure 8b. Passage through multiple powerhouses. Abbreviations: F_T = total flow; F_1 = flow through powerhouse 1; F_2 = flow through powerhouse 2; F_{fish} is planned spill for fish passage; F_s = other flow through the spillway.

For multiple powerhouse dams, flow is allocated fractionally as follows:

1. Flow is first allocated to planned spill in fish passage hours.
2. Remaining flow is partitioned between the primary and secondary powerhouses and additional spill as follows:
    - operate highest priority powerhouse up to its hydraulic capacity
    - spill water up to another level called the spill threshold
    - above the threshold, use the second powerhouse
    - above the second powerhouse hydraulic capacity, spill extra flow.

Fish are passed through the spillway and the powerhouses according passage efficiency relationships (Appendix 4).

2.3.2 Dam passage survival

Each dam passage route (turbine, bypass system, spillway, RSW, etc.) has an associated survival probability that varies by species and dam. The survival probabilities are typically based on site-specific radio-telemetry studies and are contained in Appendix 5. This appendix also lists data sources for each estimate.

At this point, all dam survival probabilities are deterministic, due to insufficient data to fully characterize their distributions. However, as mentioned above, per-project survival, which contains dam survival, is derived from PIT-tag estimates. Thus, any uncertainty in dam survival estimation is contained in the overall project survival variability.

2.3.3 Delay in Dam Passage

Migrating juveniles may spend considerable time in the forebay of dams before passing. This delay in dam passage can also vary among passage routes, with fish passing via the spillway or RSW typically delaying less than fish passing other routes. To account for this, we have incorporated percentage of fish passing through the spillway as a parameter in the travel time model, described below. The effect of this is that spilled fish experience less dam delay, and thus passing more fish via the spillway leads to decreased travel times. In future versions of COMPASS, we plan to model this delay process more directly based on observations from telemetry data.

2.4 Fish Travel Time

Fish travel time through a reservoir is based on a model developed by Zabel and Anderson (1997; see also Zabel 2002) and is governed by two parameters: r, migration rate, and σ, the rate of population spread. The travel time distribution is typically right-skewed, which is consistent with the data (Figure 9). In some cases, the travel time model appears to "miss" the mode of the distribution.

The migration rate term is related to river velocity, date in the season, and water temperature, as described below. In the current version of the model, migration rate is also related to percentage of fish passing through the spillway. This accounts for the fact that spilled fish pass over dams more quickly than non-spilled fish (or, spilled fish experience less delay than non-spilled fish). We note that both the model and the data incorporate any delay experienced during dam passage.

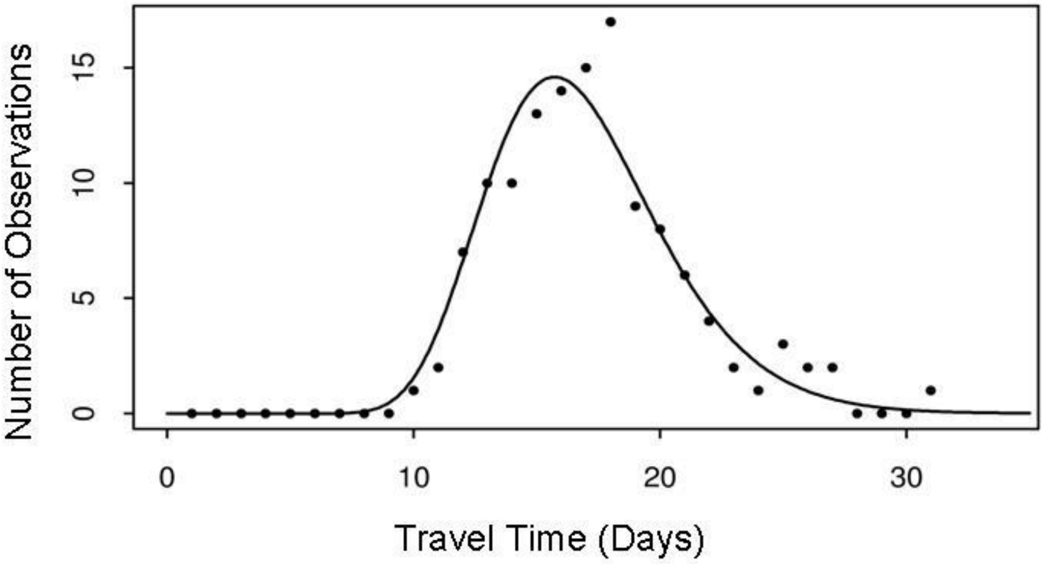

Figure 9. Fish travel time model (from Zabel 2002) for Snake River spring/summer Chinook salmon migrating from Lower Granite Dam to McNary Dam. Points represent data; solid line is model fit.

Migration Rate Models

The goal of the migration rate equation is to be flexible enough to capture a variety of migratory behaviors without requiring an excessive number of parameters to fit. Accordingly, we modified the migration rate model of Zabel et al. (1998). We created two different migration rate models; the first model uses a variety of linear terms and interactions. The second model incorporates a nonlinear temporal relationship between river velocity and migration rate, as well as linear terms.

The first model expresses fish migration rate (mi/day) as a function of several variables:

$$r_i = \beta_0 + \beta_1 \bar{T}_i + \beta_2 \bar{T}_i^2 + \beta_3 \bar{W}_i + \beta_4 d + \beta_5 \bar{V}_i + \beta_6 \bar{V}_i d + \beta_7 d^2 + \beta_8 M + \beta_9 (\bar{T}_i - C) I_{\bar{T}>C} + \beta_{10} Z_i + \varepsilon_i$$

where r_i is the migration rate of the *i*th cohort, T_i is the mean temperature over the cohort's migration period, W_i is the percentage of fish passing the spillway measured at the day the cohort passes the downstream dam, *d* is the day the cohort enters the top of a reservoir, V_i is mean water velocity over the migration period, *M* is an indicator that is either one or zero for all cohorts in a given year (this parameter is sometimes used to account for explicit year effects in calibration, but is not used prospectively), C is a threshold value of temperature, $I_{T>C}$ is an indicator term that is 1 when average temperature T exceeds C and 0 otherwise, Z_i is an indicator that is 1 if W_i is zero and 0 otherwise, and ε_i, is a normally distributed error term. The model above is an expanded version of the model proposed by Zabel et al. (1998).

The second migration rate model uses many of the same variables as the first model, but has a nonlinear seasonal effect of velocity:

$$r_i = \beta_0 + \beta_1 \bar{W}_i + \beta_2 \bar{V}_i \left[\frac{1}{1+\exp\left(-\alpha(d - T_{SEASN})\right)}\right] + \beta_3 M + \beta_4 \bar{T}_i + \beta_5 \bar{T}_i^2 + \beta_6 (\bar{T}_i - C) I_{\bar{T}>C} + \beta_7 Z_i + \varepsilon_i$$

where r_i is the migration rate of the ith cohort, W_i is the percentage of fish passing the spillway measured at the day the cohort passes the downstream dam, V_i is mean water velocity over the migration period, d is the day the cohort enters the top of a reservoir, α is a fitted parameter that describes the slope of the logistic velocity relationship, T_{SEASN} is a seasonal inflection point, M is an indicator that is either one or zero for all cohorts in a given year (this parameter is sometimes used to account for explicit year effects in calibration, but is not used prospectively), T_i is the mean temperature over the cohort's migration period, C is a threshold value of temperature, $I_{T>C}$ is an indicator term that is 1 when average temperature T exceeds C and 0 otherwise, Z_i is an indicator that is 1 if W_i is zero and 0 otherwise, and ε_i, is a normally distributed error term.

The velocity dependent component uses the logistic equation (term in square brackets) because upper and lower bounds can be set. This eliminates the problem of unrealistically high or low migration rates that can occur outside observed ranges with linear equations. Also, for suitable parameter values, the logistic equation effectively mimics a linear relationship.

The magnitude of the velocity dependence is determined by β_2, which determines the percentage of the average river velocity that is used by the fish in downstream migration. This term has a seasonal component determined by T_{SEASN}, which has the effect of the fish using less of the velocity early in the season and more of the velocity later in the season.

2.5 Hydrological Process

The COMPASS model simulates river flow, water velocity, and water temperature throughout the hydrosystem daily (Figure 11). The model operates by reading daily headwater flows and temperatures from an input file. Headwaters are either regulated (storage reservoir upstream) or unregulated and represent the major inputs of water into the hydrosystem (Figure 11). The flows and temperatures are propagated downstream according to water movement algorithms and water mixing at confluences (see Appendix 6 for more details). Water flow is converted to water velocity based on reservoir geometry, including reservoir water depth (Appendix 6). Water flow can be adjusted at dams to account for water losses (due to evaporation or irrigation withdrawals) or additions from minor tributaries. These adjustments are typically based on measurements taken at the dams. Similarly, temperature can be adjusted at the dams to account for heating or cooling processes.

The COMPASS modeling group has relied on two sources of data for the input data. First, for calibration purposes, we have generated historical data files for the years 1997-2017. Second, for prospective modeling, to represent the effects of year-to-year variability in river conditions on survival, we used reconstructed river conditions (river flows and water temperatures) over the years 1929-2008. This involved running observed headwater flows through a hydro-regulation model that emulates river flows in the current hydrosystem configuration. The hydro-regulation model provided monthly or bi-monthly average flows. These flows were then modulated to represent daily flows. Further, a temperature flow relationship was developed to generate daily temperatures.

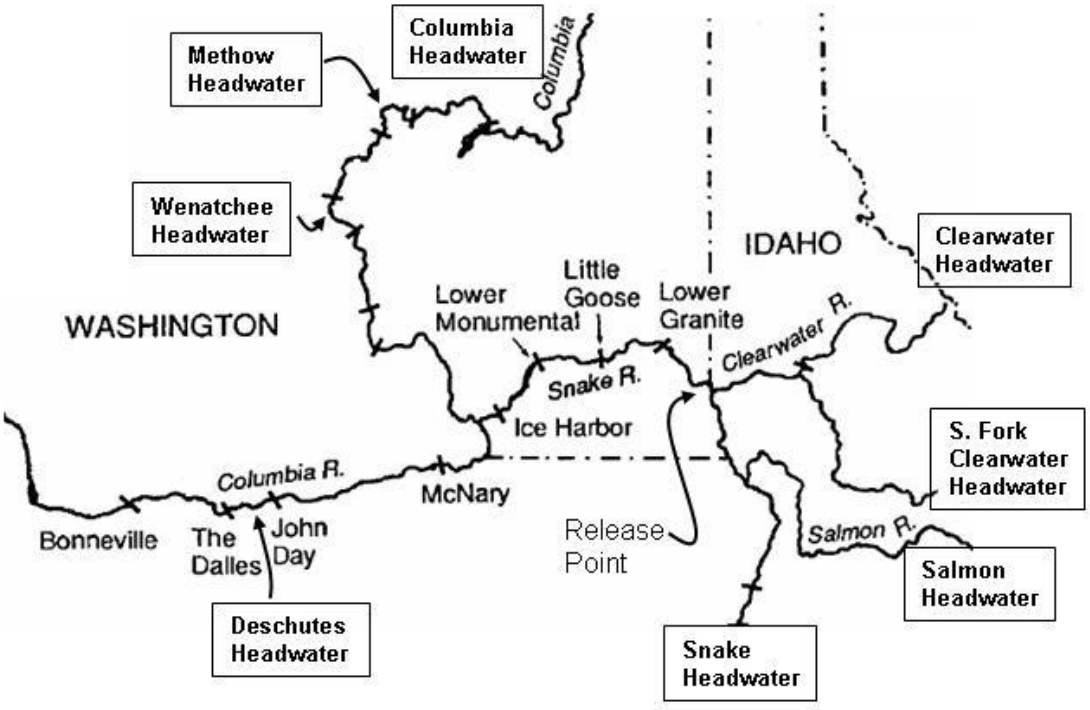

Figure 11. Map of the Columbia River basin showing the location of headwaters.

2.6 Model Uncertainty

Background

The primary reason for implementing Monte Carlo simulation mode in COMPASS is to reflect uncertainty in survival predictions. The deterministic version of COMPASS, like any deterministic model, always gives the same output for a given set of inputs. There may sometimes be a tendency for model users and consumers to overlook that even for a high quality model that matches observations very well, knowledge of the real system is never perfect. For many reasons, when working with models there is always a range of predictions that are reasonable from a given set of inputs. By implementing the Monte Carlo mode in COMPASS, our aim is to characterize that reasonable range, given the imperfect understanding represented by our model.

Uncertainty in COMPASS predictions of survival arises from several sources, including sampling error in available survival data (e.g., project survival estimates based on PIT-tag data) and environmental data (e.g., indices of exposure to environmental conditions), and uncertainty in selection of a particular regression model from among a suite of candidate models. Moreover, even if environmental indices and survival probabilities were measured without error, two cohorts of fish with the exact same exposures are not likely to have exactly the same survival probability. Such “natural variability”, also known as “process error,” is another important source of uncertainty in model outputs.

In the presence of process error, predictions of survival for a given set of explanatory variables represent predictions of the mean survival for cohorts with those variables, and the reasonable range of predictions must reflect the magnitude of the process error. Reservoir survival models in COMPASS were developed using PIT-tag survival estimates. Variance among these estimates depends on the environmental variables that influence expected survival, on process error, and on sampling error.

We have applied a statistical method (“random effects” modeling, also known as “variance components”) to separately estimate the contribution of process error to the overall variance in PIT-tag survival estimates, simultaneously accounting for explanatory variables and sampling error. In a sense, the sampling error in the estimates represents an artifact of the data collection that has occurred in the past, while process error represents the “real” variability in the process we are modeling.

Statistical random effects modeling offers two critical advantages over weighted least squares methods. The first we have already discussed: separating components of variability into process error and sampling error allows insight into underlying processes that weighted least squares cannot provide. Our method of implementing uncertainty in COMPASS predictions makes critical use of this partitioning of total variability. The second advantage is that through the use of a general weighting matrix, random effects models explicitly account for the correlation that arises mathematically between PIT-tag survival estimates in successive reaches for a given cohort in the Cormack-Jolly-Seber model (see Figure 12). Weighted least squares methods incorporate only the variances of the individual reach estimates and improperly ignore the covariance terms.

When our estimate of the amount of variability due to process error is of sufficient quality, our goal for implementing Monte Carlo mode is to produce a range of reasonable predictions that account separately for the contribution of process error and uncertainty in model parameters. When the model is run in Monte Carlo mode, multiple runs of the model are conducted for each set of environmental conditions. Each run has different parameter inputs to appropriately represent the uncertainty of our knowledge of the mean fitted parameters, as well as multiple random draws of the process error based on the estimated process variance. The result of these repeated runs is a distribution of values that describes the range of reasonable predictions for mean survival under the set of environmental conditions, and can be parsed to show only variation stemming from uncertainty in model parameters, or both model uncertainty and process error.

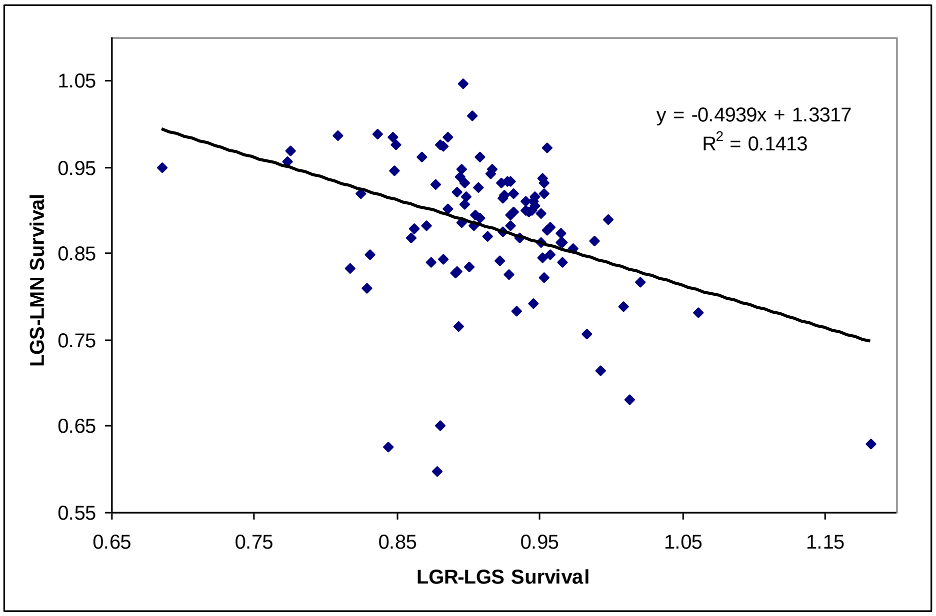

Figure 12. Negative correlation between successive project-survival estimates (each point on the graph represents two successive estimates for the same release groups) in the Snake River for Snake River spring/summer Chinook salmon.

Scale on Which to Match Uncertainty of Survival Estimates

Using data on PIT-tag detections at dams, it is possible to estimate survival probabilities for “projects” (one project is one reservoir plus one dam), but not for reservoirs and dams separately. Estimates of survival probabilities and associated estimates of sampling variability are available between successive detection sites; for the Snake and Columbia rivers this means one project (e.g., Little Goose Dam plus its reservoir, or Lower Granite Dam tailrace to Little Goose Dam tailrace) or two projects (e.g., Lower Monumental Dam tailrace to McNary Dam tailrace). Thus our approach for implementing the Monte

Carlo version of COMPASS is to randomly sample parameter sets according to the scale of the data underlying the survival relationships. In other words, because survival is estimated per cohort across a project (or projects), we will draw a unique set of parameters for each cohort as it migrates through a project corresponding to the data.

More specifically, when we estimate a vector of model parameters, $\hat{\boldsymbol{\beta}}$, for the survival relationships, we can also estimate the corresponding variance-covariance matrix, $\mathbf{VC}(\hat{\boldsymbol{\beta}})$. To draw a set of parameters during a Monte-Carlo simulation, we simply draw from the following multivariate normal distribution:

$$MVN\left[\hat{\boldsymbol{\beta}}, \mathbf{VC}(\hat{\boldsymbol{\beta}})\right]$$

We then will apply the randomly sample parameter set to the appropriate cohort/river segment combination. Each iteration of the model will produce a different survival prediction, and running the model repeatedly will produce of distribution of predictions.

As mentioned above, several methods exist to estimate the variance-covariance matrix. When we run COMPASS in Monte Carlo mode, we set the variance-covariance matrix to the matrix estimated by the Hessian in the maximum likelihood fit of the survival parameter set in use.

Implimentation of the Monte Carlo Mode

As mentioned in Section X, Monte Carlo mode is currently implemented via a series of scripts external to the COMPASS model program. These scripts run the COMPASS model multiple times for every water year in a given scenario, drawing new parameters and process error for every iteration.

Currently, the Monte Carlo mode only draws parameters for the reservoir survival model. This means that our present Monte Carlo results only account for uncertainty stemming from the fitted reservoir survival model and the CJS survival estimates used to fit the model. In the future, we plan to expand the Monte Carlo mode to also add the possibility to draw random parameters for the migration rate model, the FGE and SPE models, and route-specific dam survival. Once all of these are implemented, all major sources of uncertainty will be accounted for.

At present, we typically do 500 separate iterations of each water year when we do a run in Monte Carlo mode. More iterations are desirable, but the computational intensity of the COMPASS model makes the runtime too long to be practical. We explicitly set the random seed used for every parameter draw and store that seed, so that the results of each Monte Carlo iteration will be reproducible. When comparing two or more scenarios via Monte Carlo mode, we use the same sets of random seeds for the survival parameter draws, but different sets of random seeds for process error draws. This is because while the survival model parameters are not perfectly known, we do not expect the true underlying survival relationship to change from one management scenario to another.

3 Post-Bonneville Survival

COMPASS has several options to model survival of fish once they have passed the hydrosystem. To standardize the discussion, we introduce the following notation (Figure 13).

First, we designate survival terms using S and mortality terms using $L = 1 - S$. Terms for in-river migrants are denoted by the subscript I and terms for transported fish by the subscript T. We partition survival and mortality into the following life stages: downstream migration through the hydropower system (subscript *ds*), estuary/ocean (subscript *e/o*), and upstream migration through the hydropower system (subscript *us*).

We further partition the estuary/ocean stage to reflect mortality that would occur independent of the hydropower system ($1\text{-}S_{e/o}$), and hydropower system-related latent mortality (L), which applies to both transported fish and in-river migrants. This partitioning of estuary/ocean survival reflects an assumption that for in-river fish, latent mortality is essentially entirely expressed in the estuary/ocean stage.

D refers to the ratio of smolt-adult survival (measured from below Bonneville Dam as juveniles to Lower Granite Dam as adults) of transported fish relative to that of in-river migrants. Using our earlier notation, the corresponding SARs are

$$SAR_{T,BON \rightarrow LGR} = S_{e/o}(1 - L_T)S_{T,us} \text{ , and}$$

$$SAR_{I,BON \rightarrow LGR} = S_{e/o}(1 - L_I)S_{I,us} \,.$$

Therefore, D is simply

$$D = \frac{SAR_{T,BON \rightarrow LGR}}{SAR_{I,BON \rightarrow LGR}} = \frac{(1 - L_T)S_{T,us}}{(1 - L_I)S_{I,us}} \,.$$

Note that we assume the same natural estuary/ocean survival ($S_{e/o}$) for both in-river and transported fish. Also, we use different upstream survival terms for in-river and transported fish. Differential upstream survival for the two groups, for example, could result from latent mortality for transported fish related to impaired homing. Further, it is not necessary to delineate any latent mortality when estimating D as it is simply the ratio of SARs.

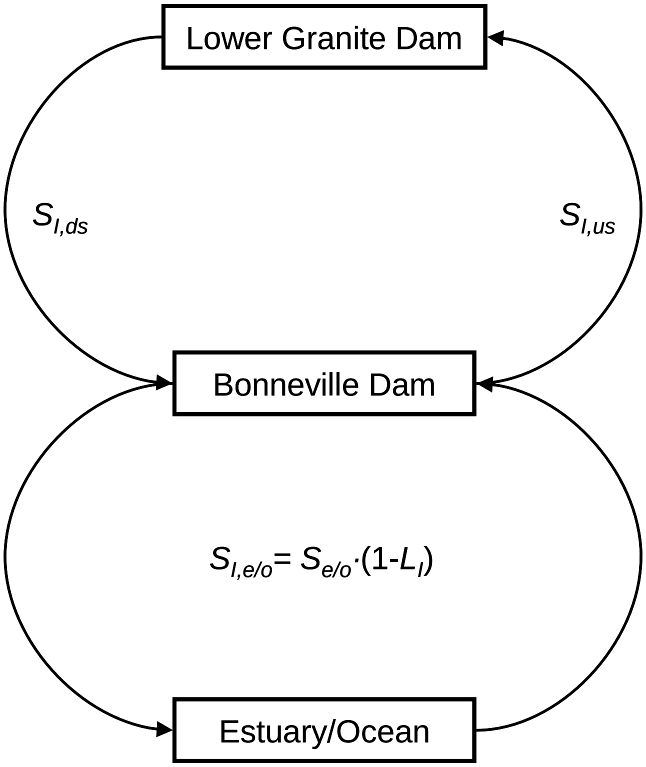

Figure 13. Survival (*S*) and mortality (*L*) affecting Snake River anadromous salmonids migrating in-river (denoted by subscript *I*) at various life stages. The life stages are downstream migration through the hydropower system (*ds*), estuary/ocean (*e/o*), and upstream migration through the hydropower system (*us*). The estuary/ocean survival is partitioned into survival that would occur in the absence of the hydropower system ($s_{e/o}$) and latent mortality associated with the passage through the hydropower system (L_I). Transported fish (denoted by subscript *T*) are affected by the same survival and mortality processes and are represented by changing the subscript *I* to *T*.

3.1 Hypotheses on post-Bonneville survival

The model user has 4 options for specifying post-Bonneville survival.

1) Third year ocean survival (S_3) is related to water travel time. This method computes mean water travel time over a specified time period (usually April and May) and over a specified river segment (usually Lower Granite Dam to Bonneville Dam). The user specifies model parameters, and the model returns survival through the third year.

2) Constant D. In this method, a user-specified D is applied to the fish arriving below Bonneville via transportation. Overall hydrosystem survival is then adjusted accordingly.

3) Latent mortality. The user specifies L_I and L_T (latent mortality for inriver and transported fish, respectively). The model produces and overall survival related to the hydrosystem.

4) Smolt-to-adult return (SAR) related to arrival timing below Bonneville. Separate relationships are specified for inriver and transported fish that relate survival from Bonneville to Lower Granite as a function of arrival date. The model produces an overall survival from Lower Granite (juvenile) to Lower Granite (adult).

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PIT Tag Data

PIT-tag data are the primary source for calibrating survival, migration rate, and dam passage parameters in COMPASS. During 1998-2017, juvenile Snake River spring/summer Chinook salmon and steelhead were captured, PIT tagged, and released at Lower Granite Dam or upstream from the dam (see Smith et al. 2004 and references cited within for details of tagging). Tagged fish were grouped into weekly cohorts based on day of release or day of passage at Lower Granite Dam (Table A1.1). As they migrated seaward, tagged fish potentially could be detected at 6 downstream detection sites located in juvenile bypass systems at dams (see Figure 1 of the main text). In addition, a small proportion of fish were detected downstream from Bonneville Dam. Because cohorts of fish spread out as they migrate downstream, we regrouped fish (of Snake River origin) at McNary Dam to form new weekly cohorts for analyses through the lower Columbia River.

We also used PIT tag data to calibrate survival and migration rate for reaches above Lower Granite Dam. For these reaches, we grouped fish tagged at the Snake River, Grande Ronde River, and Imnaha River traps into weekly cohorts based on day of tagging at the traps (Table A1.2). Lower Granite Dam was used as the downstream detection site for all of these releases.

We examined several issues related to these data. First, we considered whether to separate wild and hatchery fish in our analyses. We assessed the availability of PIT tag data through time, as the operation of the hydropower system changed substantially from the 1998-2005 period to the 2006-2017 period. For the purposes of prospective modeling, future operations will more closely resemble those from the 2006-2017 period rather than older years. After examining the PIT tag data available in the two periods, we concluded that the precision of the survival estimates is too poor within the 2006-2017 period to fit robust models to wild or hatchery fish alone; furthermore, data within the earliest and latest periods of the migration season is lacking in the 2006-2017 period. Accordingly, we combined wild and hatchery PIT tag data and used the entire period from 1998-2017 to calibrate the COMPASS models used for prospective analyses.

Regarding precision of survival estimates, Snake River spring/summer Chinook cohorts generally had more precise survival estimates than those of steelhead. Also, survival estimates for cohorts migrating through the Snake River were far more precise than those for cohorts migrating through the Columbia River. In fact, survival estimates through the lower Columbia River were so poor that we believe we were severely limited in our ability to relate survival to environmental factors in these river segments. Accordingly, we identified obtaining more precise survival estimates through the lower Columbia River as a high priority for future monitoring. As a way to partially rectify this problem, we examined whether forming cohorts over two-week periods would yield better precision. Unfortunately, this did little to improve precision but substantially reduced the number of cohorts available. We thus opted to continue using one-week cohorts.

The year 2001 poses a problem for calibration for reaches within the hydrosystem, between Lower Granite Dam and Bonneville Dam. In 2001, a year with both high temperatures and very low flows, spill was turned off at almost all dams in the Snake and Columbia rivers. Zero spill results in very high detection rates, as fish are forced to pass dams via the powerhouse and are accordingly more likely to go through the bypass route. Zero spill also results in extremely slow migration rates and consequently much lower survival, as fish struggle to find routes to pass the powerhouse. The combination of high detection rates (which result in high precision and high weight in our model fitting) and extreme values for both survival and migration rate result in data from 2001 exerting undue leverage on our model fitting. The circumstances in 2001 have never been repeated; managers now know that spill is critical for juvenile fish passage and never turn off spill completely, even in low-flow years. In order to avoid calibrating models to a schema of the river that will not occur in the future, we exclude PIT-tag data from 2001 for all models between Lower Granite Dam and McNary Dam.

Table A1.1. Summary of PIT-tag data used to calibrate COMPASS reservoir survival. Lower Granite cohorts were used for the reach from Lower Granite to Bonneville Dam; McNary cohorts were used for the reach from McNary to Bonneville Dam.

	Snake River spring/summer Chinook				Snake River steelhead			
	Lower Granite cohorts		McNary cohorts		Lower Granite cohorts		McNary cohorts	
Year	Cohorts	Released	Cohorts	Released	Cohorts	Released	Cohorts	Released
1998	11	96,055	1	7,876	9	43,307	0	0
1999	15	98,240	5	56,085	12	79,344	7	11,650
2000	10	91,299	5	30,563	8	107,270	4	6,729
2002	12	66,541	5	70,630	9	67,778	4	3,575
2003	13	74,400	7	52,663	10	60,088	3	4,456
2004	14	78,109	4	17,599	11	55,442	0	0
2005	10	88,327	4	30,247	6	42,501	0	0
2006	9	197,315	5	67,578	9	40,872	1	2,514
2007	7	120,775	4	83,088	6	30,618	5	5,376
2008	9	82,016	4	29,080	9	51,781	3	8,862
2009	9	103,709	5	78,332	10	85,418	4	18,995
2010	8	85,215	5	64,409	7	41,731	5	14,458
2011	10	67,852	3	33,103	12	78,939	2	8,518
2012	10	67,861	5	34,822	10	75,526	1	743
2013	8	37,339	6	43,373	6	37,421	4	7,348
2014	10	70,915	6	40,775	10	62,702	2	3,483
2015	4	17,601	4	27,944	5	41,511	6	10,887
2016	9	93,981	5	34,789	7	72,864	5	14,975
2017	10	52,332	0	0	12	73,258	0	0

Table A1.2. Summary of PIT-tag data used to calibrate COMPASS survival above Lower Granite Dam. Abbreviations used: LGR = Lower Granite Dam; SNKTRP = Snake River trap; GRNTRP = Grande Ronde River trap; INMTRP = Imnaha River trap.

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
CH1	SNKTRP:LGR	1998	Snake_River_Trap	9	3,264
	SNKTRP:LGR	1999	Snake_River_Trap	10	7,796
	SNKTRP:LGR	2000	Snake_River_Trap	8	5,213
	SNKTRP:LGR	2001	Snake_River_Trap	1	389
	SNKTRP:LGR	2002	Snake_River_Trap	6	1,590
	SNKTRP:LGR	2003	Snake_River_Trap	7	3,068
	SNKTRP:LGR	2004	Snake_River_Trap	10	3,477
	SNKTRP:LGR	2005	Snake_River_Trap	5	1,280
	SNKTRP:LGR	2006	Snake_River_Trap	7	7,641
	SNKTRP:LGR	2007	Snake_River_Trap	5	1,918
	SNKTRP:LGR	2008	Snake_River_Trap	5	3,675
	SNKTRP:LGR	2009	Snake_River_Trap	7	6,086
	SNKTRP:LGR	2010	Snake_River_Trap	4	2,428
	SNKTRP:LGR	2011	Snake_River_Trap	8	8,247
	SNKTRP:LGR	2012	Snake_River_Trap	8	7,452
	SNKTRP:LGR	2013	Snake_River_Trap	4	1,314
	SNKTRP:LGR	2016	Snake_River_Trap	5	3,180
CH1	GRNTRP & IMNTRP:LGR	1998	Imnaha_Trap	8	5,876
	GRNTRP & IMNTRP:LGR	1999	Imnaha_Trap	11	6,606
	GRNTRP & IMNTRP:LGR	2000	Imnaha_Trap	12	6,999
	GRNTRP & IMNTRP:LGR	2001	Imnaha_Trap	13	12,893
	GRNTRP & IMNTRP:LGR	2002	Imnaha_Trap	8	5,169
	GRNTRP & IMNTRP:LGR	2003	Grande_Ronde_Trap	12	4,020
	GRNTRP & IMNTRP:LGR	2003	Imnaha_Trap	12	5,197
	GRNTRP & IMNTRP:LGR	2004	Grande_Ronde_Trap	11	4,461
	GRNTRP & IMNTRP:LGR	2004	Imnaha_Trap	15	9,746
	GRNTRP & IMNTRP:LGR	2005	Grande_Ronde_Trap	11	3,376
	GRNTRP & IMNTRP:LGR	2005	Imnaha_Trap	12	3,255
	GRNTRP & IMNTRP:LGR	2006	Grande_Ronde_Trap	11	5,019
	GRNTRP & IMNTRP:LGR	2006	Imnaha_Trap	4	822
	GRNTRP & IMNTRP:LGR	2007	Grande_Ronde_Trap	11	3,960
	GRNTRP & IMNTRP:LGR	2007	Imnaha_Trap	13	7,197
	GRNTRP & IMNTRP:LGR	2008	Grande_Ronde_Trap	9	3,798
	GRNTRP & IMNTRP:LGR	2008	Imnaha_Trap	10	3,210
	GRNTRP & IMNTRP:LGR	2009	Grande_Ronde_Trap	11	4,835
	GRNTRP & IMNTRP:LGR	2009	Imnaha_Trap	13	5,836
	GRNTRP & IMNTRP:LGR	2010	Grande_Ronde_Trap	7	5,373
	GRNTRP & IMNTRP:LGR	2010	Imnaha_Trap	11	7,590
	GRNTRP & IMNTRP:LGR	2011	Grande_Ronde_Trap	9	4,506
	GRNTRP & IMNTRP:LGR	2011	Imnaha_Trap	9	3,115
	GRNTRP & IMNTRP:LGR	2012	Grande_Ronde_Trap	8	4,485

Species	**Calibration Reach**	**Year**	**Release Site**	**# Cohorts**	**# Fish**
CH1	GRNTRP & IMNTRP:LGR	2012	Imnaha_Trap	8	2,020
	GRNTRP & IMNTRP:LGR	2013	Grande_Ronde_Trap	11	5,295
	GRNTRP & IMNTRP:LGR	2013	Imnaha_Trap	9	4,120
	GRNTRP & IMNTRP:LGR	2016	Grande_Ronde_Trap	11	4,215
	GRNTRP & IMNTRP:LGR	2016	Imnaha_Trap	10	3,360
	GRNTRP & IMNTRP:LGR	2017	Grande_Ronde_Trap	9	5,199
	GRNTRP & IMNTRP:LGR	2017	Imnaha_Trap	7	2,017
STHD	SNKTRP:LGR	1998	Snake_River_Trap	8	5,347
	SNKTRP:LGR	1999	Snake_River_Trap	8	4,860
	SNKTRP:LGR	2000	Snake_River_Trap	8	4,974
	SNKTRP:LGR	2001	Snake_River_Trap	5	3,249
	SNKTRP:LGR	2002	Snake_River_Trap	10	7,545
	SNKTRP:LGR	2003	Snake_River_Trap	8	4,673
	SNKTRP:LGR	2004	Snake_River_Trap	10	6,752
	SNKTRP:LGR	2005	Snake_River_Trap	8	4,684
	SNKTRP:LGR	2006	Snake_River_Trap	6	2,599
	SNKTRP:LGR	2007	Snake_River_Trap	3	769
	SNKTRP:LGR	2008	Snake_River_Trap	4	2,837
	SNKTRP:LGR	2009	Snake_River_Trap	4	2,385
	SNKTRP:LGR	2010	Snake_River_Trap	7	5,154
	SNKTRP:LGR	2011	Snake_River_Trap	5	1,038
	SNKTRP:LGR	2012	Snake_River_Trap	4	1,442
	SNKTRP:LGR	2013	Snake_River_Trap	6	3,807
	SNKTRP:LGR	2016	Snake_River_Trap	3	793
	SNKTRP:LGR	1998	Snake_River_Trap	8	5,347
	SNKTRP:LGR	1999	Snake_River_Trap	8	4,860
STHD	GRNTRP & IMNTRP:LGR	1998	Imnaha_Trap	10	6,872
	GRNTRP & IMNTRP:LGR	1999	Imnaha_Trap	10	8,806
	GRNTRP & IMNTRP:LGR	2000	Imnaha_Trap	10	10,533
	GRNTRP & IMNTRP:LGR	2001	Imnaha_Trap	9	6,791
	GRNTRP & IMNTRP:LGR	2002	Imnaha_Trap	10	6,868
	GRNTRP & IMNTRP:LGR	2003	Grande_Ronde_Trap	8	2,770
	GRNTRP & IMNTRP:LGR	2003	Imnaha_Trap	11	11,373
	GRNTRP & IMNTRP:LGR	2004	Grande_Ronde_Trap	7	2,266
	GRNTRP & IMNTRP:LGR	2004	Imnaha_Trap	12	10,080
	GRNTRP & IMNTRP:LGR	2005	Grande_Ronde_Trap	7	2,386
	GRNTRP & IMNTRP:LGR	2005	Imnaha_Trap	12	11,161
	GRNTRP & IMNTRP:LGR	2006	Grande_Ronde_Trap	7	4,647
	GRNTRP & IMNTRP:LGR	2006	Imnaha_Trap	8	3,639
	GRNTRP & IMNTRP:LGR	2007	Grande_Ronde_Trap	6	1,808
	GRNTRP & IMNTRP:LGR	2007	Imnaha_Trap	9	7,930
	GRNTRP & IMNTRP:LGR	2008	Grande_Ronde_Trap	5	4,505
	GRNTRP & IMNTRP:LGR	2008	Imnaha_Trap	6	2,419
	GRNTRP & IMNTRP:LGR	2009	Grande_Ronde_Trap	5	4,777
	GRNTRP & IMNTRP:LGR	2009	Imnaha_Trap	9	5,024
	GRNTRP & IMNTRP:LGR	2010	Grande_Ronde_Trap	5	3,233

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
STHD	GRNTRP & IMNTRP:LGR	2010	Imnaha_Trap	8	5,928
	GRNTRP & IMNTRP:LGR	2011	Grande_Ronde_Trap	8	3,894
	GRNTRP & IMNTRP:LGR	2011	Imnaha_Trap	7	2,150
	GRNTRP & IMNTRP:LGR	2012	Grande_Ronde_Trap	3	806
	GRNTRP & IMNTRP:LGR	2012	Imnaha_Trap	10	4,906
	GRNTRP & IMNTRP:LGR	2013	Grande_Ronde_Trap	6	2,772
	GRNTRP & IMNTRP:LGR	2013	Imnaha_Trap	10	6,776
	GRNTRP & IMNTRP:LGR	2016	Grande_Ronde_Trap	6	2,415
	GRNTRP & IMNTRP:LGR	2016	Imnaha_Trap	10	4,132
	GRNTRP & IMNTRP:LGR	2017	Grande_Ronde_Trap	8	4,799
	GRNTRP & IMNTRP:LGR	2017	Imnaha_Trap	9	2,577

Survival Estimates

We used the standard Cormack-Jolly-Seber (CJS) model (Cormack 1964, Jolly 1965, Seber 1965) to estimate survival (and standard errors) between successive PIT-tag detection sites (Skalski et al. 1998). This method takes into account that not all fish are detected at each detection site. The approach involves estimating detection probabilities based on detections at downstream sites. These detection probabilities are then used to estimate survival by inflating the number of fish actually detected. Because of this, it is possible to generate survival estimates from these data that are > 1.0. This is particularly common in cases where true survival is close to 1.0 and sample sizes are limited.

PIT-tag survival estimates represent survival through an entire "project" (reservoir and dam), or two such projects in some cases (e.g., Lower Monumental Dam to McNary Dam, which includes Ice Harbor Dam (Figure 1)).

$$S_{PROJECT} = S_{RESERVOIR} \cdot S_{DAM}$$

When we calibrate the survival sub-model, the unit of comparison is project survival, which incorporates both dam survival and reservoir survival. The COMPASS model produces predictions of project survival that combine dam survival predictions and reservoir survival predictions. We compare model-predicted project survival to project survival estimated from PIT-tag data. Because we purposely included factors in the reservoir survival function (flow and spill) that are potentially related to dam survival, any variability in dam survival related to these is potentially captured in the overall relationship.

Migration Rate Data

We used observations of fish travel time to calibrate the migration rate sub-model. In order to be included in the calibration dataset, a tagged fish must have been detected at both ends of a calibration reach, meaning that their time of travel between the upstream end of the reach and the downstream end of the reach is known. There is no need to estimate detection probability as in the process for survival estimation.

As with survival, for migration rate calibration we group individual fish together into weekly cohorts by date of detection at the upstream end of the reach. The mean travel times of the resulting cohorts then become the unit of comparison for model calibration.

We used observations of fish travel time from PIT-tag data for six different reaches in the Snake and Columbia Rivers: Lower Granite Dam to Lower Monumental Dam; Lower Monumental Dam to Ice Harbor Dam; Lower Monumental & Ice Harbor dams to McNary Dam; McNary Dam to Bonneville Dam; the Snake River trap to Lower Granite Dam; and the Grande Ronde River and Imnaha River traps to Lower Granite Dam. In all reaches there is only one observation site, but for two reaches there are multiple release sites. Even though observed travel times from different release locations will tend to have different mean values due to differing distances from the observation site, data from multiple locations can be used together in calibration as long as the observed migration rates (travel time divided by travel distance) are comparable. A summary of the data used for calibration in the various reaches is presented in Table A1.3.

Table A1.3. Summary of PIT-tag data used to calibrate COMPASS migration rates. Abbreviations used: LGR = Lower Granite Dam; LMN = Lower Monumental Dam; IHR = Ice Harbor Dam; MCN = McNary Dam; BON = Bonneville Dam; SNKTRP = Snake River trap; GRNTRP = Grande Ronde River trap; INMTRP = Imnaha River trap.

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
CH1	LGR:LMN	1998	Lower_Granite_Tailrace	16	28,622
	LGR:LMN	1999	Lower_Granite_Tailrace	17	39,911
	LGR:LMN	2000	Lower_Granite_Tailrace	15	14,189
	LGR:LMN	2002	Lower_Granite_Tailrace	16	21,032
	LGR:LMN	2003	Lower_Granite_Tailrace	17	8,410
	LGR:LMN	2004	Lower_Granite_Tailrace	16	12,190
	LGR:LMN	2005	Lower_Granite_Tailrace	13	26,466
	LGR:LMN	2006	Lower_Granite_Tailrace	13	58,437
	LGR:LMN	2007	Lower_Granite_Tailrace	11	14,753
	LGR:LMN	2008	Lower_Granite_Tailrace	13	15,803
	LGR:LMN	2009	Lower_Granite_Tailrace	13	15,787
	LGR:LMN	2010	Lower_Granite_Tailrace	13	2,684
	LGR:LMN	2011	Lower_Granite_Tailrace	16	20,250
	LGR:LMN	2012	Lower_Granite_Tailrace	13	14,382
	LGR:LMN	2013	Lower_Granite_Tailrace	12	4,584
	LGR:LMN	2014	Lower_Granite_Tailrace	14	13,383
	LGR:LMN	2015	Lower_Granite_Tailrace	10	873
	LGR:LMN	2016	Lower_Granite_Tailrace	12	16,049
	LGR:LMN	2017	Lower_Granite_Tailrace	13	9,380
CH1	LMN:IHR	2005	Lower_Monumental_Tailrace	10	1,238
	LMN:IHR	2006	Lower_Monumental_Tailrace	11	13,238
	LMN:IHR	2007	Lower_Monumental_Tailrace	7	1,489
	LMN:IHR	2008	Lower_Monumental_Tailrace	11	4,066
	LMN:IHR	2009	Lower_Monumental_Tailrace	11	2,965
	LMN:IHR	2010	Lower_Monumental_Tailrace	10	620
	LMN:IHR	2011	Lower_Monumental_Tailrace	14	6,590
	LMN:IHR	2012	Lower_Monumental_Tailrace	11	3,347
	LMN:IHR	2013	Lower_Monumental_Tailrace	8	645
	LMN:IHR	2014	Lower_Monumental_Tailrace	10	1,596
	LMN:IHR	2015	Lower_Monumental_Tailrace	8	44
	LMN:IHR	2016	Lower_Monumental_Tailrace	10	1,454
	LMN:IHR	2017	Lower_Monumental_Tailrace	12	1,242
CH1	LMN & IHR:MCN	1998	Lower_Monumental_Tailrace	14	14,303
	LMN & IHR:MCN	1999	Lower_Monumental_Tailrace	16	26,523
	LMN & IHR:MCN	2000	Lower_Monumental_Tailrace	16	5,736
	LMN & IHR:MCN	2002	Lower_Monumental_Tailrace	13	29,218
	LMN & IHR:MCN	2003	Lower_Monumental_Tailrace	16	4,038
	LMN & IHR:MCN	2004	Lower_Monumental_Tailrace	15	5,625
	LMN & IHR:MCN	2005	Lower_Monumental_Tailrace	9	11,615
	LMN & IHR:MCN	2005	Ice_Harbor_Tailrace	10	1,358
	LMN & IHR:MCN	2006	Lower_Monumental_Tailrace	11	22,896

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
CH1	LMN & IHR:MCN	2006	Ice_Harbor_Tailrace	13	11,172
	LMN & IHR:MCN	2007	Lower_Monumental_Tailrace	7	7,978
	LMN & IHR:MCN	2007	Ice_Harbor_Tailrace	10	3,936
	LMN & IHR:MCN	2008	Lower_Monumental_Tailrace	11	5,601
	LMN & IHR:MCN	2008	Ice_Harbor_Tailrace	12	4,578
	LMN & IHR:MCN	2009	Lower_Monumental_Tailrace	11	10,610
	LMN & IHR:MCN	2009	Ice_Harbor_Tailrace	12	6,452
	LMN & IHR:MCN	2010	Lower_Monumental_Tailrace	10	1,605
	LMN & IHR:MCN	2010	Ice_Harbor_Tailrace	11	2,749
	LMN & IHR:MCN	2011	Lower_Monumental_Tailrace	14	10,152
	LMN & IHR:MCN	2011	Ice_Harbor_Tailrace	14	5,512
	LMN & IHR:MCN	2012	Lower_Monumental_Tailrace	11	6,259
	LMN & IHR:MCN	2012	Ice_Harbor_Tailrace	11	3,840
	LMN & IHR:MCN	2013	Lower_Monumental_Tailrace	8	2,454
	LMN & IHR:MCN	2013	Ice_Harbor_Tailrace	13	1,758
	LMN & IHR:MCN	2014	Lower_Monumental_Tailrace	10	5,144
	LMN & IHR:MCN	2014	Ice_Harbor_Tailrace	10	2,585
	LMN & IHR:MCN	2015	Lower_Monumental_Tailrace	8	498
	LMN & IHR:MCN	2015	Ice_Harbor_Tailrace	8	278
	LMN & IHR:MCN	2016	Lower_Monumental_Tailrace	9	6,759
	LMN & IHR:MCN	2016	Ice_Harbor_Tailrace	9	2,268
	LMN & IHR:MCN	2017	Lower_Monumental_Tailrace	10	2,254
	LMN & IHR:MCN	2017	Ice_Harbor_Tailrace	10	971
CH1	MCN:BON	1998	McNary_Tailrace	11	2,187
	MCN:BON	1999	McNary_Tailrace	16	9,785
	MCN:BON	2000	McNary_Tailrace	13	5,543
	MCN:BON	2002	McNary_Tailrace	14	12,261
	MCN:BON	2003	McNary_Tailrace	15	9,223
	MCN:BON	2004	McNary_Tailrace	14	1,968
	MCN:BON	2005	McNary_Tailrace	11	2,841
	MCN:BON	2006	McNary_Tailrace	13	8,934
	MCN:BON	2007	McNary_Tailrace	13	9,593
	MCN:BON	2008	McNary_Tailrace	12	3,053
	MCN:BON	2009	McNary_Tailrace	11	10,828
	MCN:BON	2010	McNary_Tailrace	12	12,026
	MCN:BON	2011	McNary_Tailrace	13	2,720
	MCN:BON	2012	McNary_Tailrace	14	3,448
	MCN:BON	2013	McNary_Tailrace	14	3,361
	MCN:BON	2014	McNary_Tailrace	13	3,574
	MCN:BON	2015	McNary_Tailrace	10	3,284
	MCN:BON	2016	McNary_Tailrace	11	5,054
	MCN:BON	2017	McNary_Tailrace	9	1,066
CH1	SNKTRP:LGR	1998	Snake_River_Trap	9	1,519
	SNKTRP:LGR	1999	Snake_River_Trap	10	1,880
	SNKTRP:LGR	2000	Snake_River_Trap	7	1,482
	SNKTRP:LGR	2001	Snake_River_Trap	5	313

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
CH1	SNKTRP:LGR	2002	Snake_River_Trap	8	476
	SNKTRP:LGR	2003	Snake_River_Trap	8	540
	SNKTRP:LGR	2004	Snake_River_Trap	8	1,044
	SNKTRP:LGR	2005	Snake_River_Trap	8	638
	SNKTRP:LGR	2006	Snake_River_Trap	8	2,169
	SNKTRP:LGR	2007	Snake_River_Trap	8	558
	SNKTRP:LGR	2008	Snake_River_Trap	8	1,382
	SNKTRP:LGR	2009	Snake_River_Trap	9	2,826
	SNKTRP:LGR	2010	Snake_River_Trap	7	599
	SNKTRP:LGR	2011	Snake_River_Trap	8	2,883
	SNKTRP:LGR	2012	Snake_River_Trap	8	2,382
	SNKTRP:LGR	2013	Snake_River_Trap	8	423
	SNKTRP:LGR	2014	Snake_River_Trap	7	1,322
	SNKTRP:LGR	2015	Snake_River_Trap	8	133
	SNKTRP:LGR	2016	Snake_River_Trap	9	1,332
CH1	GRNTRP & INMTRP:LGR	1998	Imnaha_Trap	10	1,635
	GRNTRP & INMTRP:LGR	1999	Imnaha_Trap	9	1,364
	GRNTRP & INMTRP:LGR	2000	Imnaha_Trap	13	1,948
	GRNTRP & INMTRP:LGR	2001	Imnaha_Trap	12	6,642
	GRNTRP & INMTRP:LGR	2002	Imnaha_Trap	9	933
	GRNTRP & INMTRP:LGR	2003	Grande_Ronde_Trap	12	955
	GRNTRP & INMTRP:LGR	2003	Imnaha_Trap	14	1,496
	GRNTRP & INMTRP:LGR	2004	Grande_Ronde_Trap	10	1,884
	GRNTRP & INMTRP:LGR	2004	Imnaha_Trap	14	3,899
	GRNTRP & INMTRP:LGR	2005	Grande_Ronde_Trap	9	1,634
	GRNTRP & INMTRP:LGR	2005	Imnaha_Trap	13	1,652
	GRNTRP & INMTRP:LGR	2006	Grande_Ronde_Trap	10	1,366
	GRNTRP & INMTRP:LGR	2006	Imnaha_Trap	8	247
	GRNTRP & INMTRP:LGR	2007	Grande_Ronde_Trap	9	861
	GRNTRP & INMTRP:LGR	2007	Imnaha_Trap	12	1,741
	GRNTRP & INMTRP:LGR	2008	Grande_Ronde_Trap	9	1,346
	GRNTRP & INMTRP:LGR	2008	Imnaha_Trap	9	1,007
	GRNTRP & INMTRP:LGR	2009	Grande_Ronde_Trap	10	1,620
	GRNTRP & INMTRP:LGR	2009	Imnaha_Trap	10	1,953
	GRNTRP & INMTRP:LGR	2010	Grande_Ronde_Trap	9	1,126
	GRNTRP & INMTRP:LGR	2010	Imnaha_Trap	10	1,229
	GRNTRP & INMTRP:LGR	2011	Grande_Ronde_Trap	9	1,573
	GRNTRP & INMTRP:LGR	2011	Imnaha_Trap	10	955
	GRNTRP & INMTRP:LGR	2012	Grande_Ronde_Trap	8	1,324
	GRNTRP & INMTRP:LGR	2012	Imnaha_Trap	11	570
	GRNTRP & INMTRP:LGR	2013	Grande_Ronde_Trap	9	1,116
	GRNTRP & INMTRP:LGR	2013	Imnaha_Trap	10	841
	GRNTRP & INMTRP:LGR	2014	Grande_Ronde_Trap	9	1,926
	GRNTRP & INMTRP:LGR	2014	Imnaha_Trap	10	1,962
	GRNTRP & INMTRP:LGR	2015	Grande_Ronde_Trap	9	181
	GRNTRP & INMTRP:LGR	2015	Imnaha_Trap	10	622

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
CH1	GRNTRP & INMTRP:LGR	2016	Grande_Ronde_Trap	10	1,655
	GRNTRP & INMTRP:LGR	2016	Imnaha_Trap	11	1,048
	GRNTRP & INMTRP:LGR	2017	Grande_Ronde_Trap	10	1,375
	GRNTRP & INMTRP:LGR	2017	Imnaha_Trap	10	496
STHD	LGR:LMN	1998	Lower_Granite_Tailrace	15	18,188
	LGR:LMN	1999	Lower_Granite_Tailrace	15	37,783
	LGR:LMN	2000	Lower_Granite_Tailrace	16	24,211
	LGR:LMN	2002	Lower_Granite_Tailrace	12	19,958
	LGR:LMN	2003	Lower_Granite_Tailrace	17	13,729
	LGR:LMN	2004	Lower_Granite_Tailrace	17	19,063
	LGR:LMN	2005	Lower_Granite_Tailrace	12	22,293
	LGR:LMN	2006	Lower_Granite_Tailrace	12	18,797
	LGR:LMN	2007	Lower_Granite_Tailrace	11	5,652
	LGR:LMN	2008	Lower_Granite_Tailrace	11	10,383
	LGR:LMN	2009	Lower_Granite_Tailrace	13	23,979
	LGR:LMN	2010	Lower_Granite_Tailrace	11	1,976
	LGR:LMN	2011	Lower_Granite_Tailrace	16	27,438
	LGR:LMN	2012	Lower_Granite_Tailrace	13	19,329
	LGR:LMN	2013	Lower_Granite_Tailrace	12	5,297
	LGR:LMN	2014	Lower_Granite_Tailrace	14	10,611
	LGR:LMN	2015	Lower_Granite_Tailrace	12	1,359
	LGR:LMN	2016	Lower_Granite_Tailrace	12	14,164
	LGR:LMN	2017	Lower_Granite_Tailrace	14	15,820
STHD	LMN:IHR	2006	Lower_Monumental_Tailrace	10	5,625
	LMN:IHR	2007	Lower_Monumental_Tailrace	11	641
	LMN:IHR	2008	Lower_Monumental_Tailrace	12	3,638
	LMN:IHR	2009	Lower_Monumental_Tailrace	13	6,731
	LMN:IHR	2010	Lower_Monumental_Tailrace	9	643
	LMN:IHR	2011	Lower_Monumental_Tailrace	13	7,578
	LMN:IHR	2012	Lower_Monumental_Tailrace	11	3,978
	LMN:IHR	2013	Lower_Monumental_Tailrace	10	1,203
	LMN:IHR	2014	Lower_Monumental_Tailrace	13	1,701
	LMN:IHR	2015	Lower_Monumental_Tailrace	6	102
	LMN:IHR	2016	Lower_Monumental_Tailrace	9	1,322
	LMN:IHR	2017	Lower_Monumental_Tailrace	13	2,030
STHD	LMN & IHR:MCN	1998	Lower_Monumental_Tailrace	12	2,837
	LMN & IHR:MCN	1999	Lower_Monumental_Tailrace	15	7,751
	LMN & IHR:MCN	2000	Lower_Monumental_Tailrace	14	4,181
	LMN & IHR:MCN	2002	Lower_Monumental_Tailrace	10	2,263
	LMN & IHR:MCN	2003	Lower_Monumental_Tailrace	12	2,046
	LMN & IHR:MCN	2004	Lower_Monumental_Tailrace	16	1,858
	LMN & IHR:MCN	2005	Lower_Monumental_Tailrace	8	4,524
	LMN & IHR:MCN	2005	Ice_Harbor_Tailrace	7	583
	LMN & IHR:MCN	2006	Lower_Monumental_Tailrace	10	4,770
	LMN & IHR:MCN	2006	Ice_Harbor_Tailrace	10	2,174
	LMN & IHR:MCN	2007	Lower_Monumental_Tailrace	11	1,664

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
STHD	LMN & IHR:MCN	2007	Ice_Harbor_Tailrace	9	431
	LMN & IHR:MCN	2008	Lower_Monumental_Tailrace	12	2,952
	LMN & IHR:MCN	2008	Ice_Harbor_Tailrace	11	2,027
	LMN & IHR:MCN	2009	Lower_Monumental_Tailrace	13	8,844
	LMN & IHR:MCN	2009	Ice_Harbor_Tailrace	12	4,252
	LMN & IHR:MCN	2010	Lower_Monumental_Tailrace	9	657
	LMN & IHR:MCN	2010	Ice_Harbor_Tailrace	12	1,215
	LMN & IHR:MCN	2011	Lower_Monumental_Tailrace	13	5,678
	LMN & IHR:MCN	2011	Ice_Harbor_Tailrace	13	2,370
	LMN & IHR:MCN	2012	Lower_Monumental_Tailrace	11	3,051
	LMN & IHR:MCN	2012	Ice_Harbor_Tailrace	11	1,866
	LMN & IHR:MCN	2013	Lower_Monumental_Tailrace	10	1,111
	LMN & IHR:MCN	2013	Ice_Harbor_Tailrace	12	865
	LMN & IHR:MCN	2014	Lower_Monumental_Tailrace	12	1,465
	LMN & IHR:MCN	2014	Ice_Harbor_Tailrace	10	1,066
	LMN & IHR:MCN	2015	Lower_Monumental_Tailrace	6	269
	LMN & IHR:MCN	2015	Ice_Harbor_Tailrace	9	343
	LMN & IHR:MCN	2016	Lower_Monumental_Tailrace	9	3,450
	LMN & IHR:MCN	2016	Ice_Harbor_Tailrace	10	1,125
	LMN & IHR:MCN	2017	Lower_Monumental_Tailrace	13	1,601
	LMN & IHR:MCN	2017	Ice_Harbor_Tailrace	13	604
STHD	MCN:BON	1998	McNary_Tailrace	9	203
	MCN:BON	1999	McNary_Tailrace	13	2,358
	MCN:BON	2000	McNary_Tailrace	11	1,650
	MCN:BON	2002	McNary_Tailrace	11	1,124
	MCN:BON	2003	McNary_Tailrace	12	1,231
	MCN:BON	2004	McNary_Tailrace	11	103
	MCN:BON	2005	McNary_Tailrace	6	151
	MCN:BON	2006	McNary_Tailrace	10	784
	MCN:BON	2007	McNary_Tailrace	9	723
	MCN:BON	2008	McNary_Tailrace	12	2,087
	MCN:BON	2009	McNary_Tailrace	13	4,253
	MCN:BON	2010	McNary_Tailrace	11	3,880
	MCN:BON	2011	McNary_Tailrace	12	1,398
	MCN:BON	2012	McNary_Tailrace	11	757
	MCN:BON	2013	McNary_Tailrace	11	1,613
	MCN:BON	2014	McNary_Tailrace	11	1,293
	MCN:BON	2015	McNary_Tailrace	12	2,617
	MCN:BON	2016	McNary_Tailrace	12	3,705
	MCN:BON	2017	McNary_Tailrace	12	568
STHD	SNKTRP:LGR	1998	Snake_River_Trap	9	2,856
	SNKTRP:LGR	1999	Snake_River_Trap	10	1,449
	SNKTRP:LGR	2000	Snake_River_Trap	9	2,711
	SNKTRP:LGR	2001	Snake_River_Trap	6	2,702
	SNKTRP:LGR	2002	Snake_River_Trap	11	1,839
	SNKTRP:LGR	2003	Snake_River_Trap	10	1,679

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
STHD	SNKTRP:LGR	2004	Snake_River_Trap	11	4,955
	SNKTRP:LGR	2005	Snake_River_Trap	10	3,184
	SNKTRP:LGR	2006	Snake_River_Trap	8	900
	SNKTRP:LGR	2007	Snake_River_Trap	9	1,024
	SNKTRP:LGR	2008	Snake_River_Trap	8	1,377
	SNKTRP:LGR	2009	Snake_River_Trap	9	2,038
	SNKTRP:LGR	2010	Snake_River_Trap	7	1,062
	SNKTRP:LGR	2011	Snake_River_Trap	7	979
	SNKTRP:LGR	2012	Snake_River_Trap	8	662
	SNKTRP:LGR	2013	Snake_River_Trap	8	813
	SNKTRP:LGR	2014	Snake_River_Trap	7	957
	SNKTRP:LGR	2015	Snake_River_Trap	9	506
	SNKTRP:LGR	2016	Snake_River_Trap	9	1,607
STHD	GRNTRP & INMTRP:LGR	1998	Imnaha_Trap	12	3,143
	GRNTRP & INMTRP:LGR	1999	Imnaha_Trap	12	2,630
	GRNTRP & INMTRP:LGR	2000	Imnaha_Trap	13	5,515
	GRNTRP & INMTRP:LGR	2001	Imnaha_Trap	10	5,062
	GRNTRP & INMTRP:LGR	2002	Imnaha_Trap	12	1,424
	GRNTRP & INMTRP:LGR	2003	Grande_Ronde_Trap	10	875
	GRNTRP & INMTRP:LGR	2003	Imnaha_Trap	12	3,079
	GRNTRP & INMTRP:LGR	2004	Grande_Ronde_Trap	10	1,584
	GRNTRP & INMTRP:LGR	2004	Imnaha_Trap	14	6,637
	GRNTRP & INMTRP:LGR	2005	Grande_Ronde_Trap	8	1,408
	GRNTRP & INMTRP:LGR	2005	Imnaha_Trap	13	5,965
	GRNTRP & INMTRP:LGR	2006	Grande_Ronde_Trap	9	1,582
	GRNTRP & INMTRP:LGR	2006	Imnaha_Trap	11	1,287
	GRNTRP & INMTRP:LGR	2007	Grande_Ronde_Trap	7	371
	GRNTRP & INMTRP:LGR	2007	Imnaha_Trap	11	2,009
	GRNTRP & INMTRP:LGR	2008	Grande_Ronde_Trap	8	1,239
	GRNTRP & INMTRP:LGR	2008	Imnaha_Trap	10	755
	GRNTRP & INMTRP:LGR	2009	Grande_Ronde_Trap	7	2,204
	GRNTRP & INMTRP:LGR	2009	Imnaha_Trap	13	1,836
	GRNTRP & INMTRP:LGR	2010	Grande_Ronde_Trap	6	666
	GRNTRP & INMTRP:LGR	2010	Imnaha_Trap	13	1,299
	GRNTRP & INMTRP:LGR	2011	Grande_Ronde_Trap	9	1,286
	GRNTRP & INMTRP:LGR	2011	Imnaha_Trap	10	779
	GRNTRP & INMTRP:LGR	2012	Grande_Ronde_Trap	8	547
	GRNTRP & INMTRP:LGR	2012	Imnaha_Trap	11	1,613
	GRNTRP & INMTRP:LGR	2013	Grande_Ronde_Trap	8	702
	GRNTRP & INMTRP:LGR	2013	Imnaha_Trap	10	1,683
	GRNTRP & INMTRP:LGR	2014	Grande_Ronde_Trap	9	1,160
	GRNTRP & INMTRP:LGR	2014	Imnaha_Trap	13	2,159
	GRNTRP & INMTRP:LGR	2015	Grande_Ronde_Trap	6	102
	GRNTRP & INMTRP:LGR	2015	Imnaha_Trap	10	614
	GRNTRP & INMTRP:LGR	2016	Grande_Ronde_Trap	8	1,193
	GRNTRP & INMTRP:LGR	2016	Imnaha_Trap	11	1,463

Species	Calibration Reach	Year	Release Site	# Cohorts	# Fish
STHD	GRNTRP & INMTRP:LGR	2017	Grande_Ronde_Trap	8	1,231
	GRNTRP & INMTRP:LGR	2017	Imnaha_Trap	10	686

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Appendix 2: Calibration of Models for Migration Rate and Survival

Here we describe the statistical models for survival and for migration rates and describe how these submodels are fit to data using COMPASS. We also provide fitted model parameters and model diagnostics.

Model calibration is the process of parameter estimation for the functional relationships that drive the fish behavioral processes (reservoir survival relationship and migration rate relationship) within the passage model. Note that the PIT tag data are also used to estimate FGE and SPE relationships at some dams, but this is not part of the iterative calibration routine. The goal of the calibration routines is to ensure that model output (predicted survival and passage timing) represents the PIT-tag data as closely as possible. Accordingly, the calibration routine operates by repeatedly running the model with an optimization routine comparing model output to PIT-tag data (Figure A2.1-1). The optimization routines adjust the free model parameters (those being fit to the data) such that the fit is optimized. COMPASS is run on a yearly basis and is supplied with data files reflecting river conditions, PIT-tag release timing and numbers, reach survival estimates, and dam operations during the year.

A2.1 Calibration of Migration Rate Models

Statistical Model for Migration Rates

We use estimates of mean migration rates from PIT tagged fish (see Appendix 1) as data in the migration rate models. We assume that the mean migration rate r_i for cohort *i* follows one of the functional forms described in Section 2.4 that is constructed of covariate values and regression parameters. We assume the observed migration rate, y_i, for cohort *i* follows a normal distribution with mean equal to and variance equal to the estimated variance of the estimated migration rate $\hat{\sigma}_i^2$:

$$y_i \sim \mathrm{N}(r_i, \hat{\sigma}_i^2)$$

Calibration Methods for Migration Rates

The calibration fitting routine for the migration rate models uses the Marquardt optimization method (Press et al. 1994), with derivatives calculated numerically using a finite difference method (Gill et al 1981), to find the parameter set that results in the minimum weighted sum of squared differences between the observed and model-predicted outcome values. The weighted sum of squares (*SS*) is calculated as:

$$SS = \sum_{i=1}^{Y} \sum_{j=1}^{C_i} \sum_{k=1}^{R} w_{ijk} \left(y_{ijk} - \hat{y}_{ijk}\right)^2$$

where *i* indexes the year, *Y* is the total number of years, *j* indexes the cohort, C_i is the total number of cohorts in year *i*, *k* indexes the river segment, *R* is the total number of river segments, *w* is the weight, *y* is the observed migration rate estimate, and $\hat{y}$ is the model predicted migration rate which is a function of the regression parameters. Here the weights are the inverse of the estimated variances of the estimated migration rates. The fitting routine stops when the absolute value of the difference in sum-of-squares between the last and current iteration is < 0.005.

The migration rate model also requires a parameter for the rate of spread. We estimate this parameter as the weighted mean of the maximum likelihood estimates for the rates of spread (calculated analytically) where the weights are proportional to the number of fish in each release group.

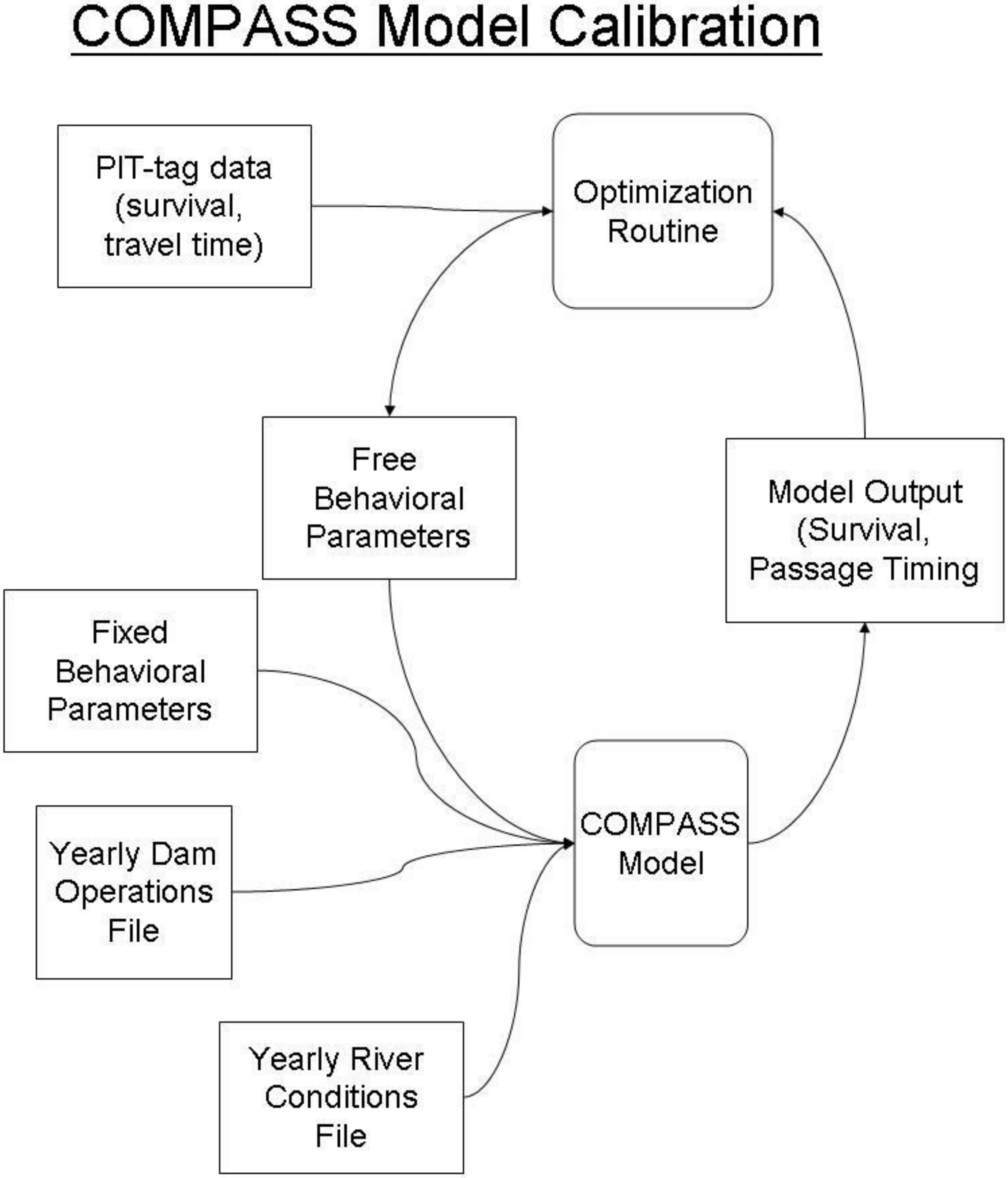

Figure A2.1-1. Schematic diagram of the combined model calibration routine for survival and migration rate.

A2.2 Calibration of Reservoir Survival Models

Statistical Model for Survival

The functional relationships for survival previously described in Section 2.2 of the main documentation provide a deterministic expected value of survival for a particular group of fish in a particular segment. To fit the model parameters to data, we need a probabilistic model to describe the uncertainty in the data generation process. To do this we need to account for the conditional sampling variability in the CJS survival estimates as well as random process uncertainty that is not accounted for by the functional survival model (see Appendix 1 for description of CJS estimates).

Let y_i be the CJS survival estimate for release group i and let ϕ_i be the unknown true survival for that group. We assume the unknown cohort survival follows a Beta distribution with mean S_i, equal to the survival value predicted by the functional form produced by the covariates and the model parameters (see Section 2.2) and precision parameter τ:

$$\phi_i \sim \text{Beta}(S_i, \tau)$$

Note that for a standard $\text{Beta}(\alpha, \beta)$ distribution we have $\alpha = S\tau$ and $\beta = (1 - S)\tau$. It follows that $\text{E}[\phi_i] = S_i$ and $\text{Var}[\phi_i] = \frac{S_i(1-S_i)}{\tau+1}$. Further, we assume that conditional on the unknown cohort survival, the “observed” CJS survival estimates follow a log-normal distribution with mean η_i and variance σ_i^2:

$$y_i \mid \phi_i \sim \text{LogNormal}(\eta_i, \sigma_i^2)$$

Here η_i and σ_i^2 are the true but unknown mean and sampling variance on the log scale. The η_i and σ_i^2 are both functions of the true coefficient of variation, which can be approximated by the estimated coefficient of variation:

$$\nu_i^2 = \frac{\text{Var}[y_i|\phi_i]}{\phi_i^2} \approx \frac{\widehat{\text{Var}}[y_i|\phi_i]}{y_i^2}$$

It follows that

$$\eta_i = \ln\left(\frac{\phi_i^2}{\sqrt{1 + \nu_i^2}}\right)$$

and

$$\sigma_i^2 = \ln(1 + \nu_i^2)$$

This model formulation allows the CJS estimates to go above 1.0 due to sampling variation but constrains the unknown cohort survival to be in the interval [0.0, 1.0].

The ϕ_i in these models can be considered random effects and need to be integrated out of the complete likelihood to form a marginal likelihood. The individual marginal likelihood component for cohort *i* can be written as

$$p(y_i \mid \boldsymbol{\theta}) = \int_0^1 p(y_i \mid \phi_i, \boldsymbol{\theta}) p(\phi_i \mid \boldsymbol{\theta}) \, d\phi_i$$

where $\boldsymbol{\theta}$ are the other parameters in the survival model, $p(y_i \mid \phi_i, \boldsymbol{\theta})$ is the complete likelihood, and $p(\phi_i \mid \boldsymbol{\theta}) = \text{Beta}(S_i, \tau)$.

Calibration Methods for Survival

For the reservoir survival relationships, we compare model-predicted log of project survival (dam + reservoir) to the observed log survival estimates (CJS estimates). In doing so, we fix the dam survival parameters, which are based on independent data, and allow the reservoir survival parameters to vary. This has the effect of partitioning the project survival into dam and reservoir survival components.

We use a custom calibration routine developed in R that maximizes the log-likelihood of the model parameters given the data, where the likelihood is the product of the individual marginal likelihood components described above. We use numerical integration to integrate over the survival random effects.

We ran the travel time and survival calibrations iteratively in a sequence starting with a travel time model calibration followed by a survival model calibration until both models converge on their optimal parameter sets. The best fit parameters from the latest travel time run are fed into the next survival run, and then the best fits from that survival run are fed into the next travel time run and so on. Within each run all the parameter values for all functional relationships in the passage model are held fixed except for those of the model component being calibrated (either travel time or survival). The following steps occur within each calibration run:

Data Analysis and Model Selection

As mentioned above, we typically start with a full model, and then remove terms that do not contribute significantly to model fit. We used Akaike's Information Criterion (AIC) for selecting among alternative models (Burnham and Anderson 2002). The AIC balances better model fit (as measured by the likelihood function) with penalties for the number of parameters estimated from the data. The lower the AIC, the better the model fit. In contrast to other model selection criteria (e.g., likelihood ratio test), AIC can be used to compare non-nested models.

In the current build of COMPASS, only one spill variable is available for use in both survival and migration rate models. Because spill at the downstream dam is often highly significant in migration rate models, we configured COMPASS to use downstream spill as the predictor variable. However, as described above, mechanistically we expect survival to be related to upstream spill, not downstream spill. After initial testing of downstream spill as a potential determinant of survival, we determined that downstream spill is not likely to have a mechanistic relationship with survival. We therefore excluded models containing the spill parameter from the model selection process. In the future, we intend to modify COMPASS so that downstream spill and upstream spill are both available to the migration rate and survival models.

We fitted survival models using the predation terms described above (see Section 2.2 of the main text) and found multiple models with significant relationships between survival and the density-dependent mortality function. However, models with this function perform poorly prospectively; these models are highly sensitive to the background smolt density, especially near the beginning and end of the migration period when that density is low. While we have estimates of background smolt density for historical years, we lack a way to predict this density in the context of a prospective scenario. Since models with the predation terms active are likely to be driven more by assumptions about what the background smolt density will be rather than by management actions in prospective scenarios, we excluded models with the predation terms from the calibration process.

We imposed the following constraints on model selection: (1) if a quadratic term was included, the corresponding linear term was also included; (2) if a time-exposure variable was included, then an intercept term involving time was included (β_{t0}); (3) if a distance-exposure variable was included, then an intercept term involving distance was included (β_{d0}). Also, to protect against over-fitting, we imposed the following requirement: if during the model selection routine we encountered a coefficient whose sign was not consistent with the mechanisms outlined above, we did not consider the model. For example, if the coefficient for flow was negative, implying a negative relationship between survival and flow, we did not consider this model.

Since the Snake and Columbia rivers are physically different, we developed separate reservoir survival relationships for each river. To do this, we first estimated survival parameters for the lower river (McNary to Bonneville). Then, when we estimated parameters for the upper river, we applied the lower river parameters to McNary reservoir (Snake/Columbia River confluence to McNary Dam) and fit the upper river parameters from Lower Granite Dam to the confluence based on survival estimates from Lower Granite Dam to McNary Dam.

We also fitted reservoir survival models to the Snake River above Lower Granite Dam. The goal of this fitting process was to generate a survival model for the free-flowing portion of the middle Snake River above Lower Granite Pool. We first estimated survival parameters for Lower Granite Pool using data from fish tagged at the Snake River trap, which lies near the head of Lower Granite Pool. Then, when we estimated survival for the middle Snake River, we applied these fitted parameters to Lower Granite Pool and fitted survival parameters for the reaches above Lower Granite Pool using survival estimates from fish tagged at the Grande Ronde River trap and the Imnaha River trap. We also considered using data from fish tagged at the Salmon River trap; however, upon investigating the PIT survival data we found that fish from the Salmon River trap have slightly higher mean survival than fish from the Imnaha Trap despite having a longer migration to Lower Granite Dam. This unusual pattern in the data has the potential to result in model overfitting, so we excluded the Salmon River trap from the calibration dataset.

We calculated a weighted R^2 for each model fit. Although no consensus exists on how to calculate R^2 in cases of no intercept, we applied the following calculation:

$$R^2 = 1 - \frac{\sum_{i=1}^{N} w_i \cdot d_i^{\,2}}{\sum_{i=1}^{N} w_i \cdot (S_i - \bar{S})^2}$$

where *i* indexes each group/river segment survival, *N* is total number of group/river segment combinations, *w* is the weight (inverse relative variance), *d* is the deviance between observed and predicted survival, *S* is the observed survival, and $\bar{S}$ is the weighted mean of the observed survivals.

Finally, there is a trend in ecological studies toward recognizing that several alternative models can perform similarly well, and that there may not be a single "best" model (Johnson and Omland 2004). The method of AIC-weights can be used to assess how models perform relative to the "best" model:

$$w_i = \frac{\exp(-\Delta_i / 2)}{\sum_{j=1}^{M} \exp(-\Delta_j / 2)}$$

where *M* is the total number of models considered, and Δ_i is the difference in AIC between model *i* and the one with the lowest AIC (Burnham and Anderson 2002). The denominator normalizes the weights so they sum to 1.0. The weights are sometimes interpreted as estimates of the probability that any particular model is the "best" one among the suite of alternative models considered in the candidate set. We apply these weights to alternative models in Appendix 3.

Results

Details of the best fit models (based on AIC) for the "full" model are provided in Table A2.2-1. Plots of model fits for the full model are provided in Figures A2.2-1,2. All the best fit models for Chinook had the travel time intercept and temperature parameters. One model for Chinook also had flow as a predictor. All the best fit models for steelhead had the travel time intercept and temperature parameters. Diagnostics for these model fits are provided in Appendix 3.

Table A2.2-1. Regression results for survival versus travel time and environmental covariates for Snake River stocks of spring/summer Chinook salmon and steelhead. See text (Equation 5) for definitions of coefficients. Abbreviations: s.e. = standard error; N = sample size (number of cohorts).

Coefficient	**Variables**	**Value**	**s.e.**	**t-value**	**P-value**
Chinook Salmon			*N = 188 AICc = -367.06 R^2 = 0 .854*		
Little Goose Pool to Ice Harbor Tailrace					
β_1	intercept	-6.6474	0.383	-17.33	< 0.0001
β_2	flow	-0.00606	0.00227	-2.67	0.0075
β_4	temperature	0.2358	0.202	11.30	< 0.0001
Chinook Salmon			*N = 132 AICc = 154.83 R^2 = 0.139*		
McNary Pool to Bonneville Pool					
β_1	intercept	-8.6828	2.049	-4.24	< 0.0001
β_4	temperature	0.4051	0.147	2.75	0.0060
Chinook Salmon			*N = 109 AICc = -321.49 R^2 = 0.254*		
Lower Granite Pool					
β_1	intercept	-10.1738	1.582	-6.43	< 0.0001
β_4	temperature	0.4685	0.145	3.23	0.0012
Chinook Salmon			*N = 264 AICc = -577.92 R^2 = 0.669*		
Imnaha & Grande Ronde Traps to the Snake River Trap					
β_1	intercept	-8.7191	0.291	-29.99	< 0.0001
β_4	temperature	0.4409	0.026	16.76	< 0.0001
Steelhead			*N = 168 AICc = -230.93 R^2 = 0.711*		
Little Goose Pool to Ice Harbor Tailrace					
β_1	intercept	-8.3172	0.463	-17.95	< 0.0001
β_4	temperature	0.4031	0.037	10.91	< 0.0001
Steelhead			*N = 56 AICc = -16.25 R^2 = 0.376*		
McNary Pool to Bonneville Pool					
β_1	intercept	-5.2575	1.195	-4.40	< 0.0001

β_4	temperature	0.1900	0.088	2.17	0.0303
Steelhead			*N = 107*	*AICc = -313.78*	*R^2 = 0.414*
Lower Granite Pool					
β_1	intercept	-14.4444	3.229	-4.47	< 0.0001
β_4	temperature	0.8162	0.263	3.10	0.0019
Steelhead			*N = 245*	*AICc = -494.48*	*R^2 = 0.526*
Imnaha & Grande Ronde Traps to the Snake River Trap					
β_1	intercept	-8.8928	0.810	-10.98	< 0.0001
β_4	temperature	0.4084	0.072	5.67	< 0.0001

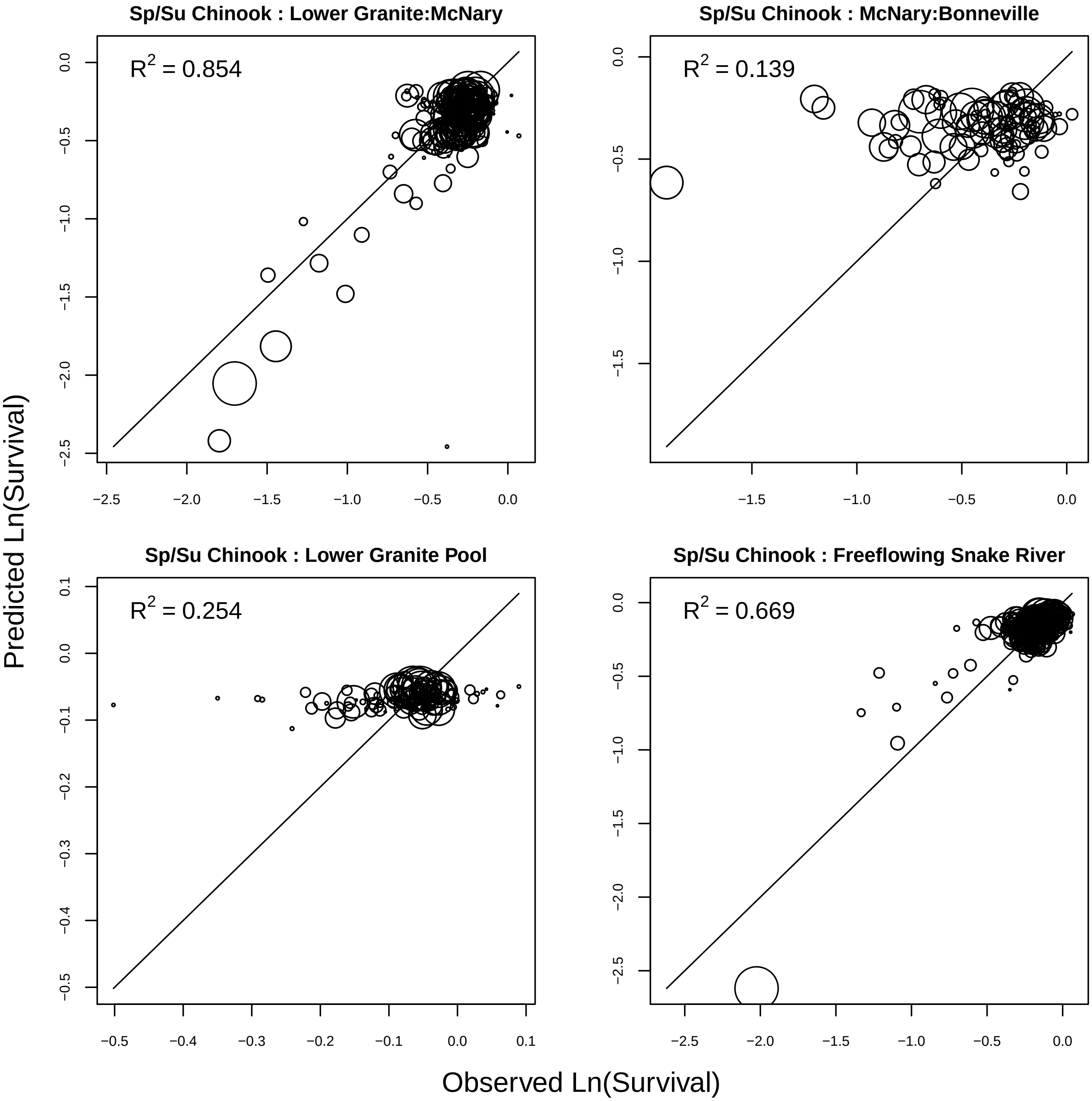

Figure A2.2-1. Log(predicted survival) versus log(observed survival) for Snake River spring/summer Chinook, with survival estimates from all four river reaches. Model fits are based on the models provided in Table A2.2-1. The R^2s provided are weighted by inverse relative variance (see text for formulation). The diameter of each point reflects it weight.

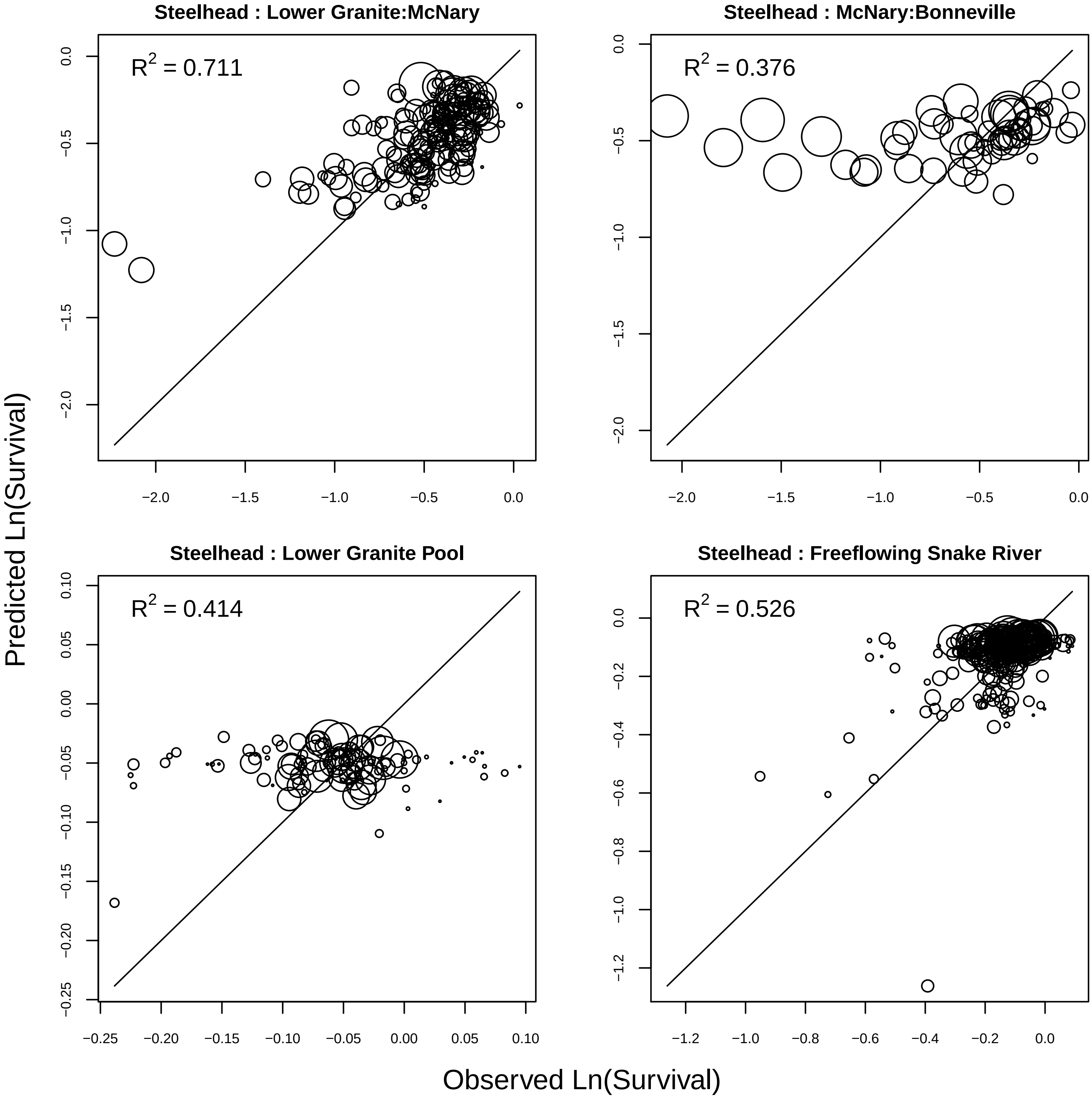

Figure A2.2-2. Log(predicted survival) versus log(observed survival) for Snake River steelhead, with survival estimates from all four river reaches. Model fits are based on the models provided in Table A2.2-1. The R^2s provided are weighted by inverse relative variance (see text for formulation). The diameter of each point reflects it weight.

Calibration Methods for Travel Time

The process for calibrating the migration rate models in COMPASS is similar to the process for calibrating the reservoir mortality models, with one significant exception. We only use data for fish observed at the detection site, meaning that the observed travel times used in calibration are known and there is no need to account for uncertainty in the data or estimate a process variance component.

As with the reservoir survival modeling, we begin with the "full" models presented in Section 2.4 of the main text, and selected the best fit model based on AIC. We compared model-predicted migration rates to PIT-tag data (see Figures A2.2-3 through A2.2-6 and Appendix 3). As with the reservoir survival modeling, we developed separate relationships for the Snake and Columbia Rivers; we also fitted separate migration rate models for Ice Harbor pool and McNary Pool.

As with reservoir mortality, we fitted migration rate models to the Snake River above Lower Granite Dam. We fitted separate migration rate models for the impounded Lower Granite pool and the free-flowing middle Snake River between the Imnaha and Grande Ronde traps and the Snake River trap.

In all cases, water velocity was a significant factor for predicting migration rate (Table A2.2-2). Spill and temperature were also a significant factor for almost all models of both Chinook salmon and steelhead. Seasonal effects were detected in all models for Chinook salmon, but only for models above Lower Granite Dam for steelhead. Plots of predicted versus observed arrival distributions are presented for all models in Appendix 3.

Table A2.2-2. Regression results for fish velocity versus environmental covariates and date in the season. Model 2 (with the seasonal velocity relationship) was used for Chinook and the steelhead models above Lower Granite Dam, and model 1 (linear terms only) for the remaining steelhead models. Models within the hydrosystem are presented before models above the hydrosystem. Abbreviations: s.e. = standard error; N = sample size (number of cohorts).

Coefficient	**Value**	**s.e.**	**t-value**	**P-value**
Chinook Salmon		*N = 203 AICc = 553.63* R^2 *= 0.848*		
Little Goose Pool through Lower Monumental Pool				
β_0	-3.081	0.0357	-86.29	< 0.0001
β_1	2.573	0.307	8.38	< 0.0001
β_2	0.494	0.0161	30.75	< 0.0001

α	0.160	0.0258	6.23	< 0.0001
T_{SEASN}	109.19	1.077	101.40	< 0.0001
β_4	0.377	0.0146	25.83	< 0.0001
Chinook Salmon		*N = 92 AICc = 451.67* R^2 *= 0.722*		
Ice Harbor Pool				
β_0	-14.085	0.749	-18.8	< 0.0001
β_2	0.872	0.168	5.18	< 0.0001
α	0.0179	0.00801	2.24	0.0278
T_{SEASN}	130.35	15.275	8.53	< 0.0001
β_4	1.894	0.127	14.91	< 0.0001
Chinook Salmon		*N = 294 AICc = 1027.73* R^2 *= 0.538*		
McNary Pool				
β_0	0.472	1.023	0.46	0.6451
β_1	7.939	0.445	17.84	< 0.0001
β_2	0.230	0.0365	6.31	< 0.0001
α	0.351	0.179	1.96	0.0507
T_{SEASN}	125.20	1.361	91.93	< 0.0001
β_4	0.562	0.0942	5.96	< 0.0001
Chinook Salmon		*N = 152 AICc = 677.66* R^2 *= 0.680*		
John Day Pool through Bonneville Pool				
β_0	14.951	0.610	24.50	< 0.0001
β_2	0.680	0.0757	8.98	< 0.0001
α	0.0999	0.0207	4.81	0.0278
T_{SEASN}	130.75	2.423	53.97	< 0.0001
Chinook Salmon		*N = 129 AICc = 375.93* R^2 *= 0.726*		

Lower Granite Pool				
β_0	-8.399	0.177	-47.43	< 0.0001
β_1	1.502	0.389	3.86	0.0002
β_2	0.341	0.0076	44.72	< 0.0001
α	0.069	0.0131	5.26	< 0.0001
T_{SEASN}	108.56	3.320	32.70	< 0.0001
β_4	1.014	0.022	45.71	< 0.0001
Chinook Salmon		*N = 317 AICc = 376.40* $R^2 =$ *0.830*		
Imnaha & Grande Ronde Traps to the Snake River Trap				
β_0	-0.885	2.515	-0.35	0.7254
β_2	0.148	0.019	7.64	< 0.0001
α	0.419	0.188	2.23	0.0264
T_{SEASN}	114.36	1.185	96.47	< 0.0001
β_4	0.406	0.274	1.48	0.1391
Steelhead		*N 193 AIC = 651.32* $R^2 =$ *0.833*		
Little Goose Pool through Lower Monumental Pool				
β_0	-15.768	0.409	-38.52	< 0.0001
β_1	1.205	0.0300	40.15	< 0.0001
β_3	2.073	0.620	3.34	0.0010
β_5	0.633	0.0227	27.97	< 0.0001
Steelhead		*N 99 AIC = 517.80* $R^2 =$ *0.757*		
Ice Harbor Pool				
β_0	-21.810	1.180	-18.48	< 0.0001
β_1	2.479	0.0995	24.91	< 0.0001
β_5	0.540	0.0504	10.71	< 0.0001

Steelhead *N 284 AIC = 1040.41* R^2 *= 0.778*

McNary Pool

β_0	-15.004	2.866	-5.24	< 0.0001
β_1	0.577	0.343	1.68	0.0931
β_4	0.148	0.0439	3.37	0.0008
β_5	0.772	0.104	7.44	< 0.0001

Steelhead *N 135 AIC = 661.020* R^2 *= 0.676*

John Day Pool through Bonneville Pool

β_0	-14.944	1.884	-7.93	< 0.0001
β_1	0.388	0.346	1.12	0.2635
β_3	2.707	2.497	1.08	0.2803
β_4	0.105	0.0440	2.39	0.0184
β_5	0.714	0.0896	7.97	< 0.0001

Steelhead *N = 152 AIC = 494.67* R^2 *= 0.886*

Lower Granite Pool

β_0	2.400	0.128	18.80	< 0.0001
β_2	0.746	0.0387	19.26	< 0.0001
α	0.0653	0.0209	3.13	0.0021
T_{SEASN}	88.84	2.012	44.16	< 0.0001
β_4	0.164	0.045	3.63	0.0004
β_7	-4.270	0.349	-12.24	< 0.0001

Steelhead *N = 298 AICc = 1030.05* R^2 *= 0.819*

Imnaha & Grande Ronde Traps to the Snake River Trap

β_0	-15.244	2.757	-5.53	< 0.0001
β_2	0.238	0.0247	9.62	< 0.0001

α	0.261	0.0676	3.87	0.0001
T_{SEASN}	118.85	1.240	95.84	< 0.0001
β_4	1.548	0.271	5.71	< 0.0001

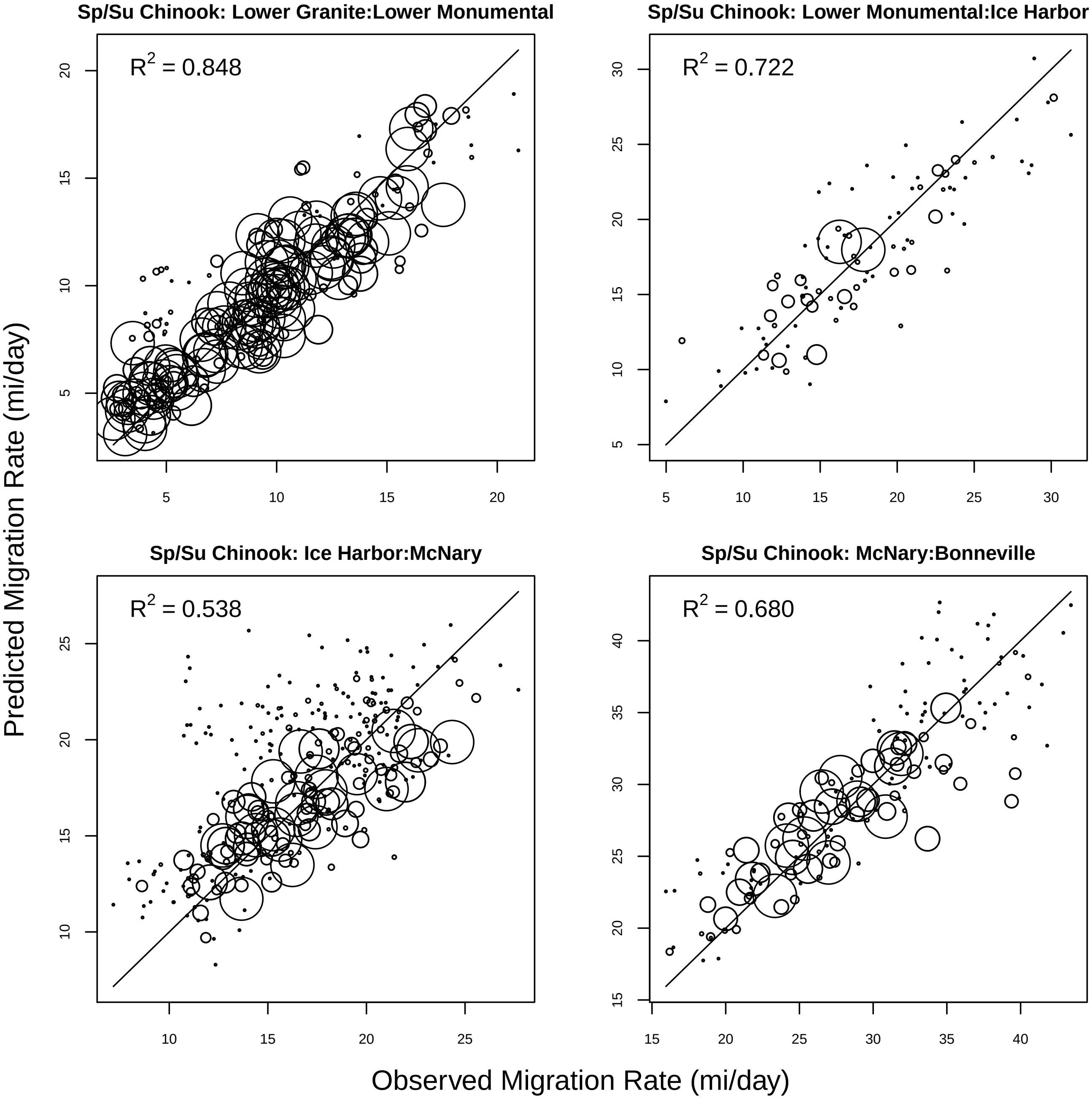

Figure A2.2-3. Predicted migration rate versus observed migration rate for Snake River spring/summer Chinook with migration rates from the river reaches within the hydrosystem from Lower Granite to Bonneville. Model fits are based on the models provided in Table A2-2.2. The R^2s provided are weighted by variance (see text for formulation). The diameter of each point reflects it weight.

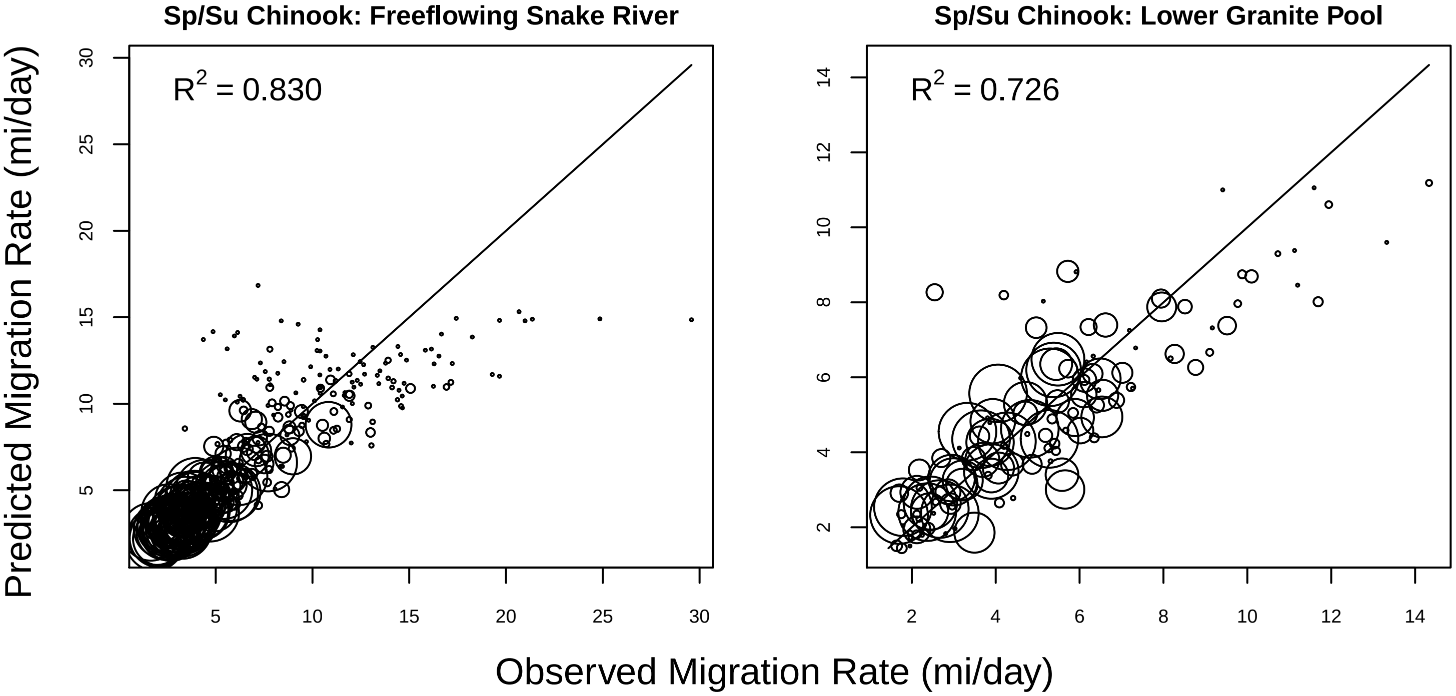

Figure A2.2-4. Predicted migration rate versus observed migration rate for Snake River spring/summer Chinook with migration rates from the Snake River reaches above Lower Granite Dam. Model fits are based on the models provided in Table A2-2.2. The R^2s provided are weighted by variance (see text for formulation). The diameter of each point reflects it weight.

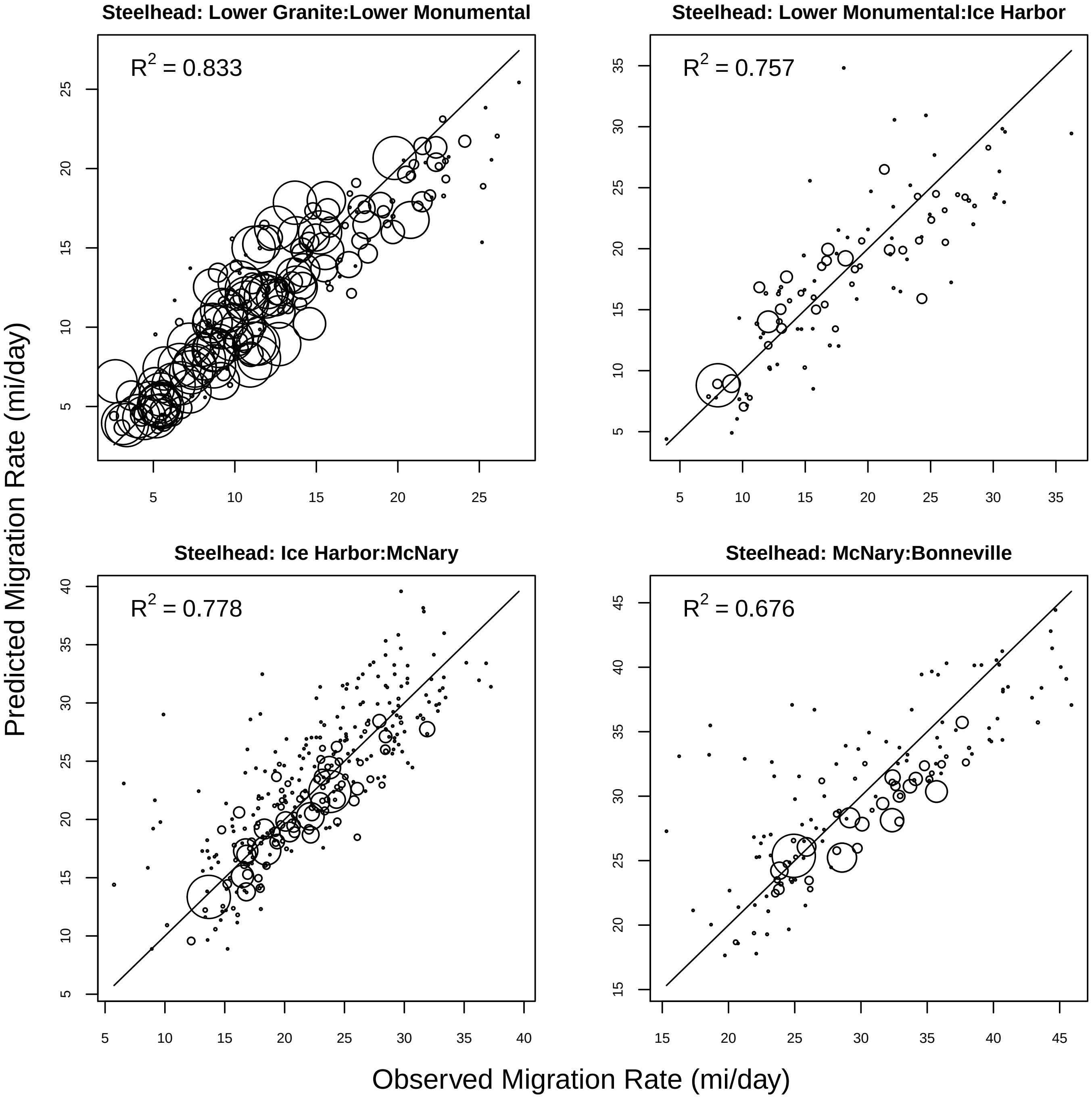

Figure A2.2-5. Predicted migration rate versus observed migration rate for Snake River steelhead with migration rates from the river reaches within the hydrosystem from Lower Granite to Bonneville. Model fits are based on the models provided in Table A2-2.2. The R^2s provided are weighted by variance (see text for formulation). The diameter of each point reflects it weight.

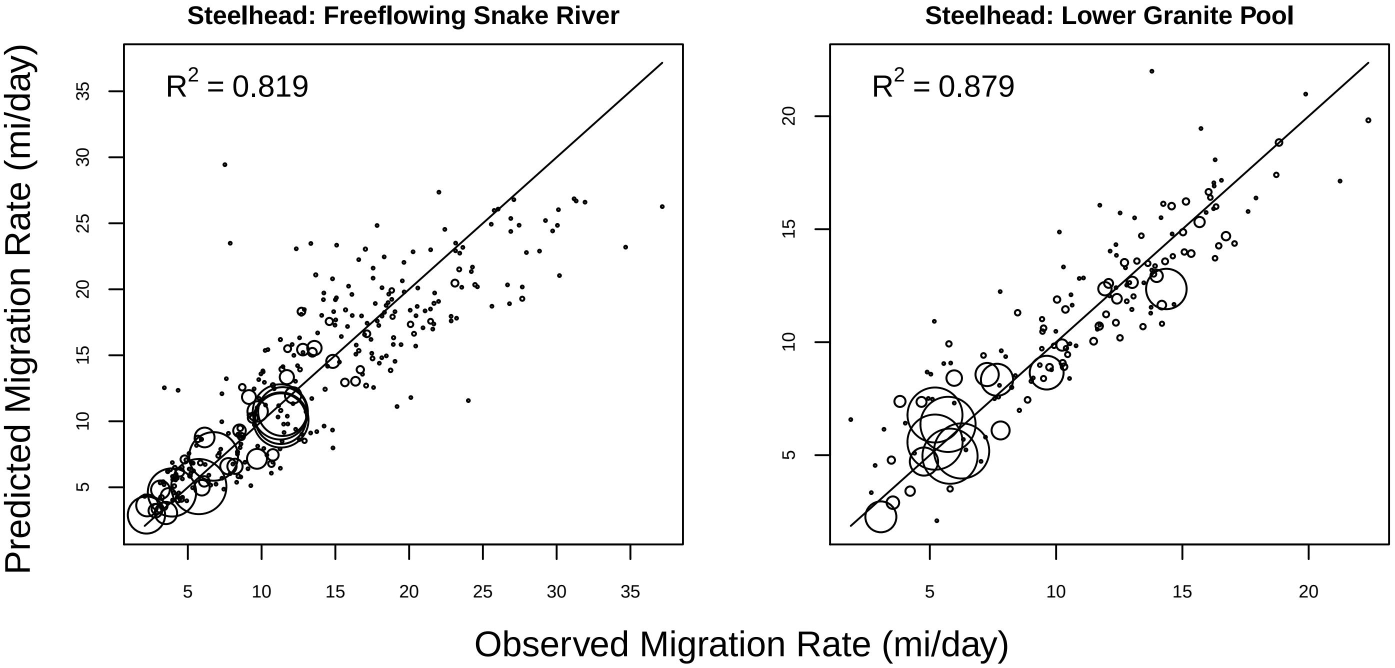

Figure A2.2-6. Predicted migration rate versus observed migration rate for Snake River steelhead with migration rates from the Snake River reaches above Lower Granite Dam. Model fits are based on the models provided in Table A2-2.2. The R^2s provided are weighted by variance (see text for formulation). The diameter of each point reflects it weight.

This Appendix provides detailed diagnostics of the model fit to PIT-tag data. It is separated into the following sections:

Appendix 3-0 – Introduction, Methods, and Discussion for each section

Appendix 3-1 – Analysis of residuals

Appendix 3-2 – Predicted and observed survival probabilities for weekly groups

Appendix 3-3 – Predicted and observed passage distributions

Section 1: Analysis of residuals

In this section, we provide an analysis of residuals for the survival (Figures A3-1 1 through 8) and migration rate models (Figures A3-1 9 through 20). The residuals are based on the best fit models presented in Tables 3 and 4 in the main text. For each model, we created four plots: 1) predicted versus observed estimates (replicated from Figures A2.2-1 through A2.2-6 in Appendix 2); 2) residuals versus observed estimates; 3) residuals versus migration year; and 4) residuals versus river segment.

For the survival model, no apparent bias is revealed by plotting residuals against observed values, year, or river segment (Figures A3-1 1 through 9). Moreover, variance appears relatively homogenous compared to observed values, year, and river segment. It is clear that weighting of data points is not always uniform across years or river segment. This is unavoidable given the nature of the data.

The model fits for survival of cohorts of both species migrating through the lower Columbia River (Figures A3-1 2, A3-1 6) and through Lower Granite Pool (Figures A3-1 3, A3-1 7) are relatively poor, with less variability in the predicted values compared to the observed ones. We believe this is largely due to poor quality data in these river segments (see the plots in section 2 of this appendix). Because of high uncertainty in the observed survival estimates in these reaches, it is difficult to detect a signal.

The plots of predicted versus observed migration rates demonstrate that the model captures a great deal of variability in migration rates (Figures A3-1 9 through 20). The residuals become somewhat more variable as migration rate increase, but this is not surprising because the points have increasing variance (less weight) as migration rate increases. Also, compared to the survival plots, the migration rate residuals exhibit more year to year variability. However, this is not such a concern because of the strong model fits. There is no apparent bias across river segments, and the variance appears relatively homogeneous across river segments. Also, downstream migration rates receive considerable weight.

Section 2: Predicted and observed survival probabilities for weekly groups

To construct these plots, we ran COMPASS with weekly cohorts reflecting those in the PIT-tag database. For each cohort, we predicted survival corresponding to PIT-tag survival estimates. The plots contain model predictions compared to the survival estimates, which are plotted with their 95% confidence intervals (Figures A3-2 1 through 32). Modeled survival estimates are plotted as a line for ease of visibility, but only one cohort was modeled per observed survival estimate.

These plots demonstrate that when data quality is good, the model captures seasonal trends in survival. For example, Chinook survival drops off at the end of the season in some years (1999, 2003, 2004) but not in others (2008, 2014, 2017), and the model captures this.

As mentioned above, the plots demonstrate the poor quality of data in the lower Columbia River and in Lower Granite Pool. Because the confidence intervals are so broad, the model predictions are less variable, which is expected.

Section 3: Predicted and observed passage distributions

In this section, we created model release distributions equivalent to the distribution of PIT-tagged fish. We then compared model-predicted arrival distributions to arrival distributions of PIT-tagged fish (Figures A3-3 1 through 17). In nearly all cases, model-predicted distributions are within a day or two of the observed ones. These plots reveal that COMPASS realistically models the temporal distributions of migrating juvenile salmonids within the hydrosystem. This is important because many management actions (e.g., timing of spill and transportation) have a timing component.

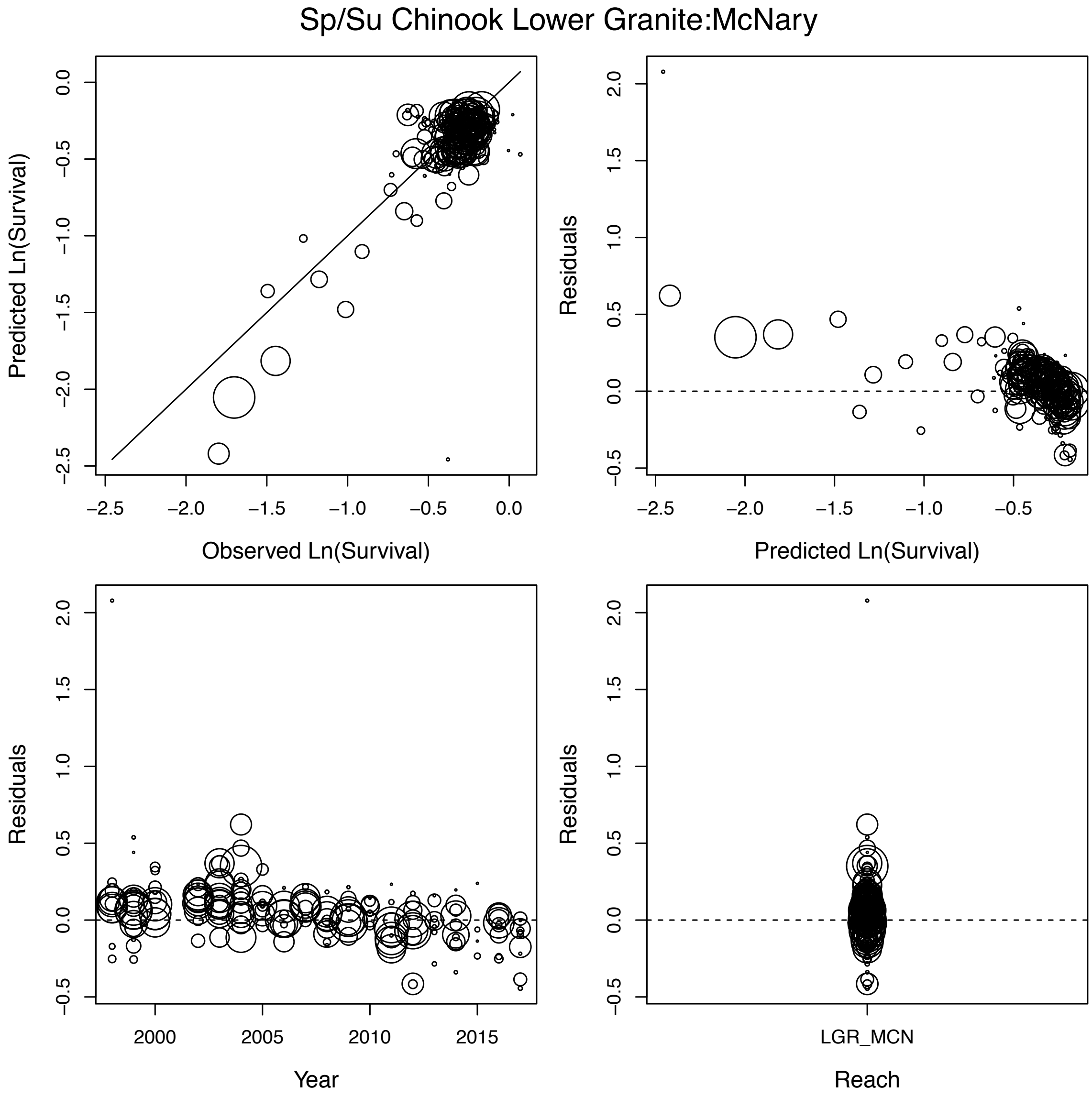

Figure A3-1 1. Diagnostics of predicted survival probabilities for Snake River spring/summer Chinook migrating from Lower Granite to McNary Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LGR = Lower Granite Dam; MCN = McNary Dam.

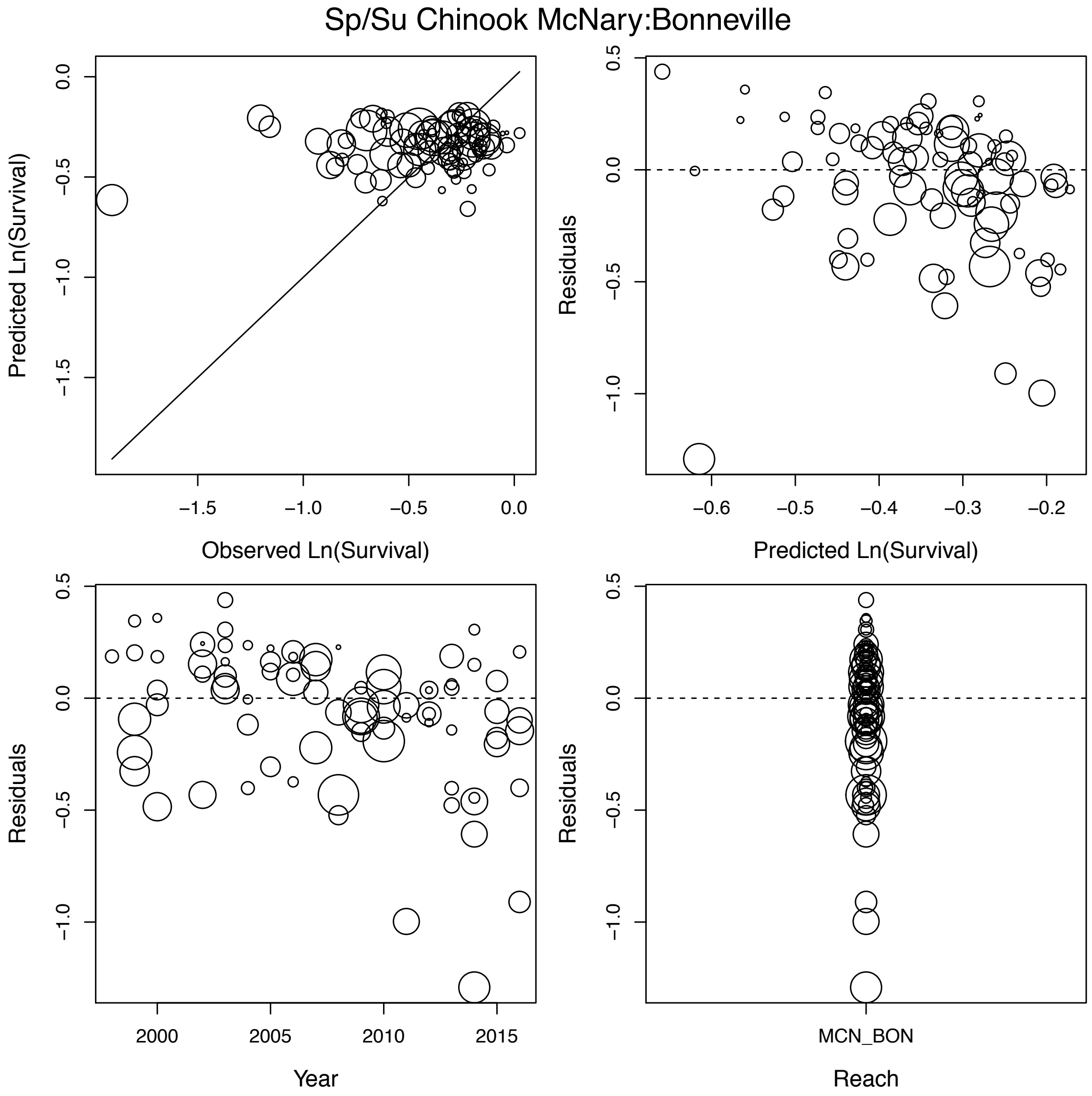

Figure A3-1 2. Diagnostics of predicted survival probabilities for Snake River spring/summer Chinook migrating from McNary Dam to Bonneville Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: MCN = McNary Dam; BON = Bonneville Dam.

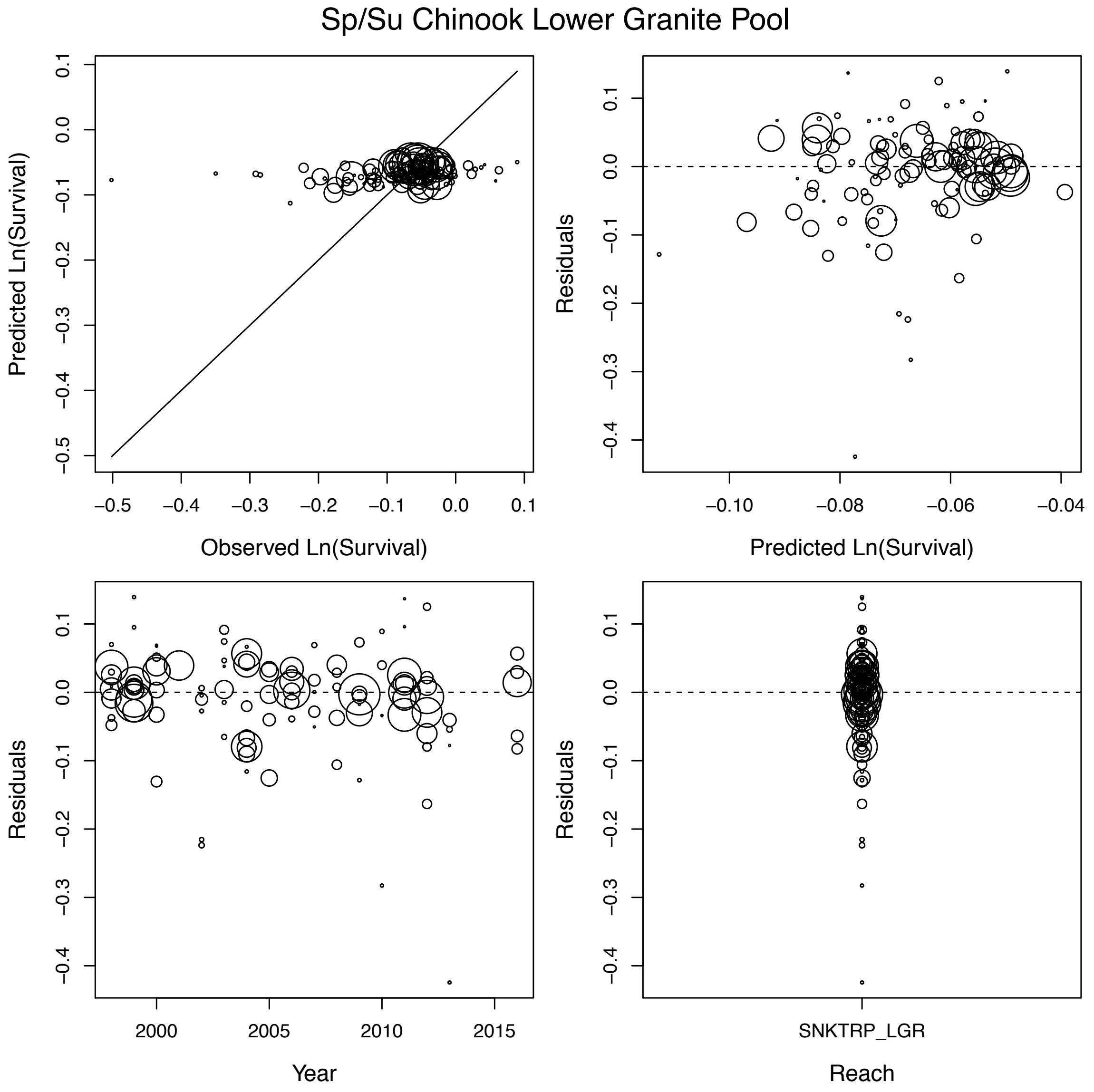

Figure A3-1 3. Diagnostics of predicted survival probabilities for Snake River spring/summer Chinook migrating from the Snake River Trap to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: SNKTRP = Snake River Trap; LGR = Lower Granite Dam.

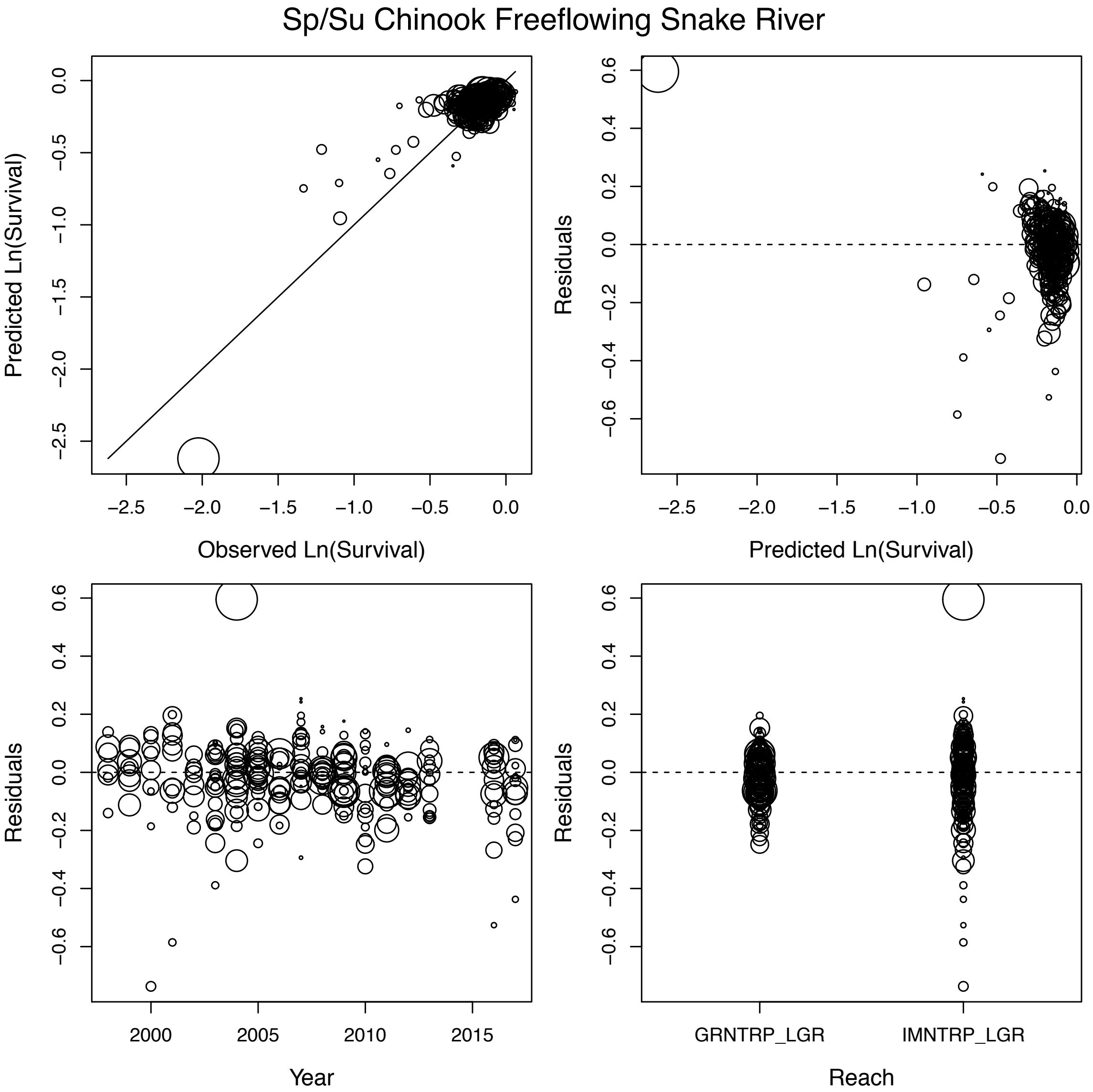

Figure A3-1 4. Diagnostics of predicted survival probabilities for Snake River spring/summer Chinook migrating from the Grande Ronde Trap and Imnaha River Trap to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: GRNTRP = Grande Ronde River Trap; IMNTRP = Imnaha River Trap; LGR = Lower Granite Dam.

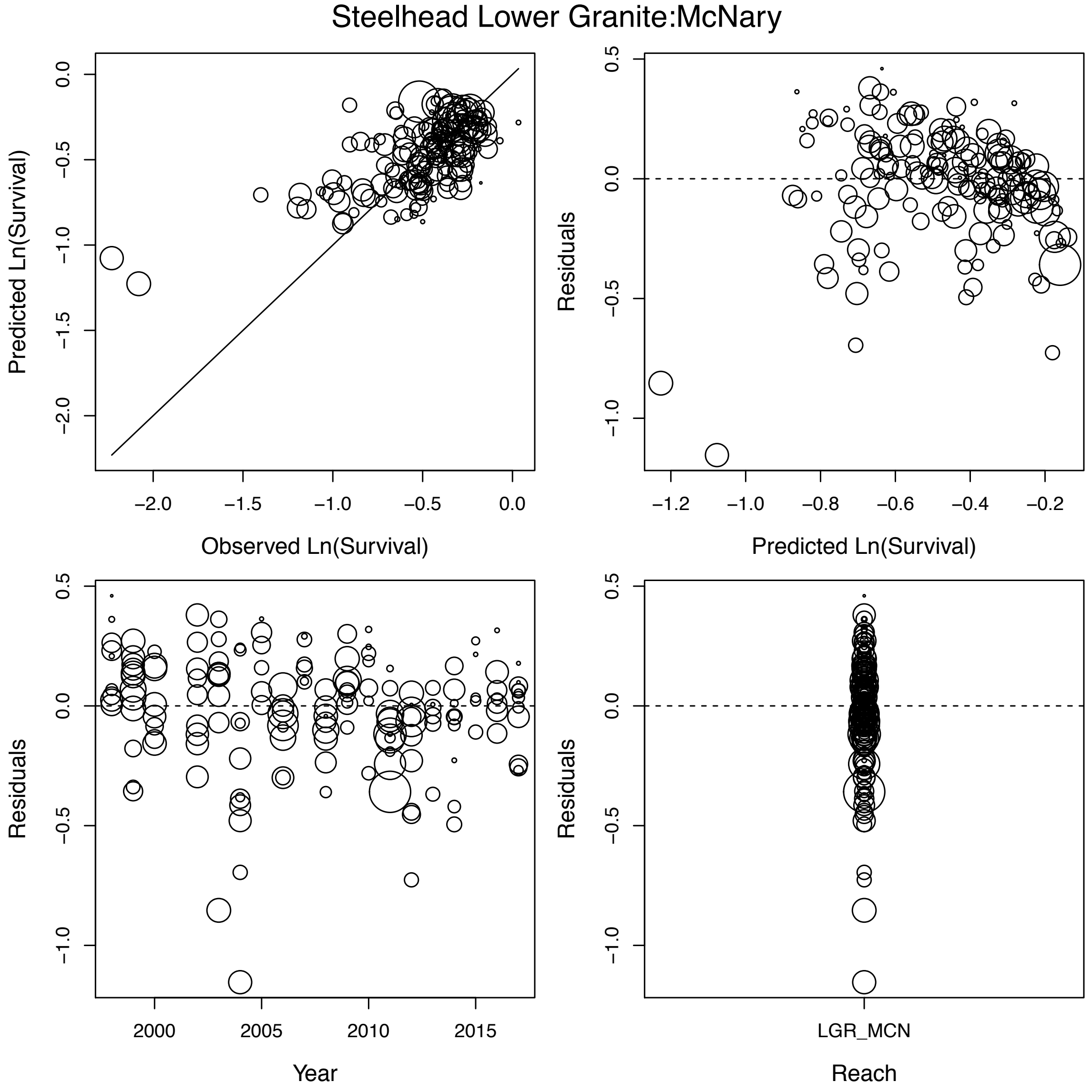

Figure A3-1 5. Diagnostics of predicted survival probabilities for Snake River steelhead migrating from Lower Granite to McNary Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LGR = Lower Granite Dam; MCN = McNary Dam.

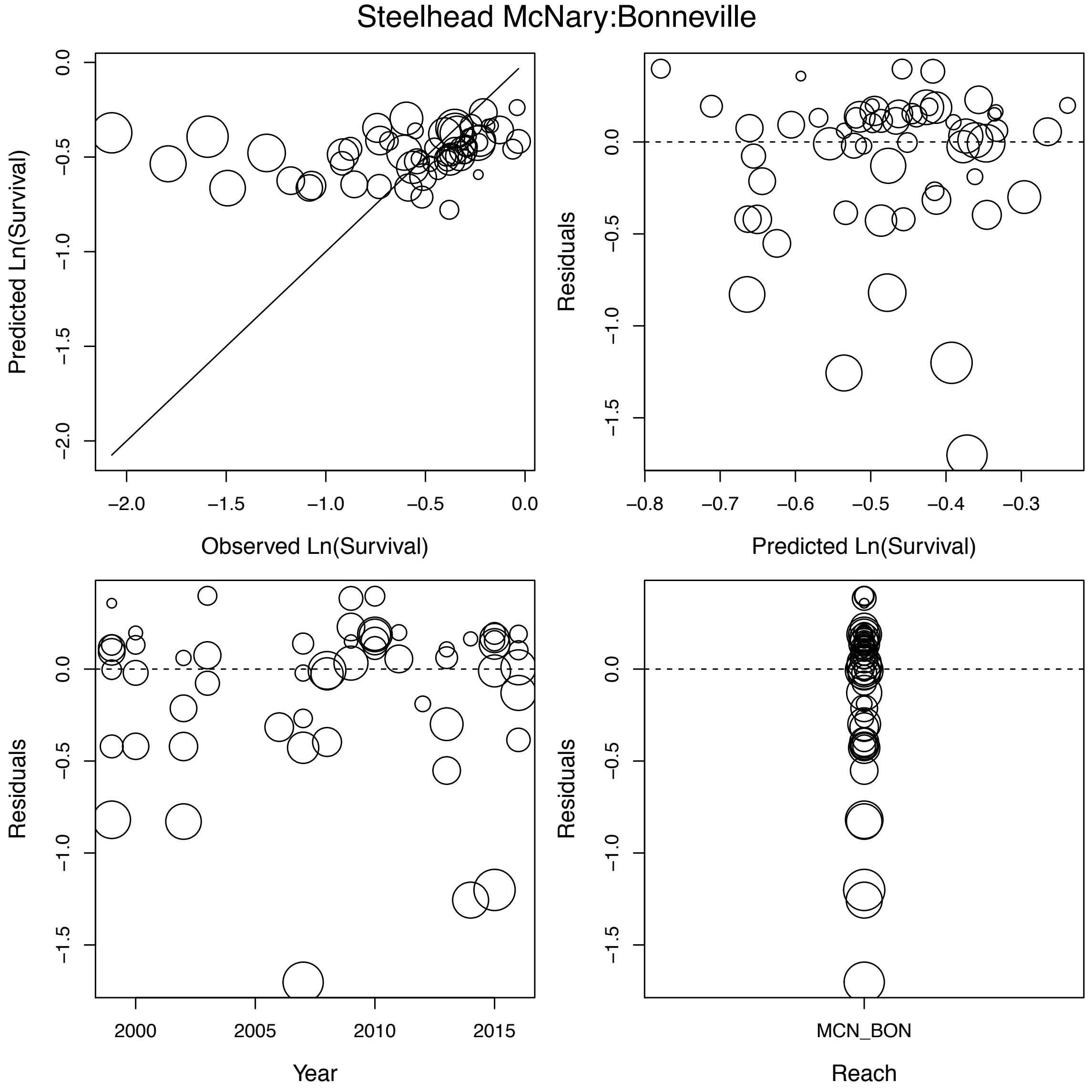

Figure A3-1 6. Diagnostics of predicted survival probabilities for Snake River steelhead migrating from McNary Dam to Bonneville Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: MCN = McNary Dam; BON = Bonneville Dam.

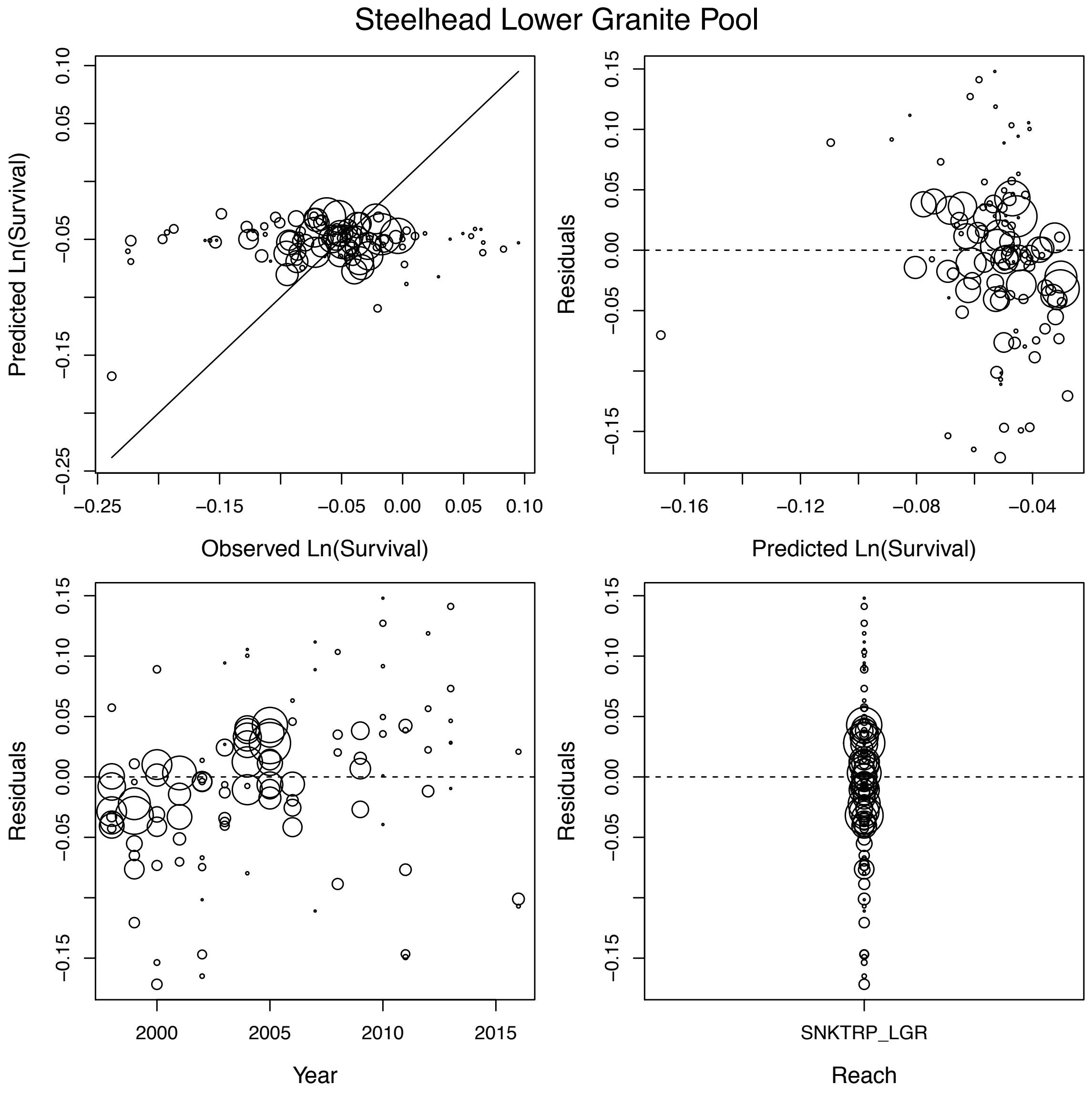

Figure A3-1 7. Diagnostics of predicted survival probabilities for Snake River steelhead migrating from the Snake River Trap to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: SNKTRP = Snake River Trap; LGR = Lower Granite Dam.

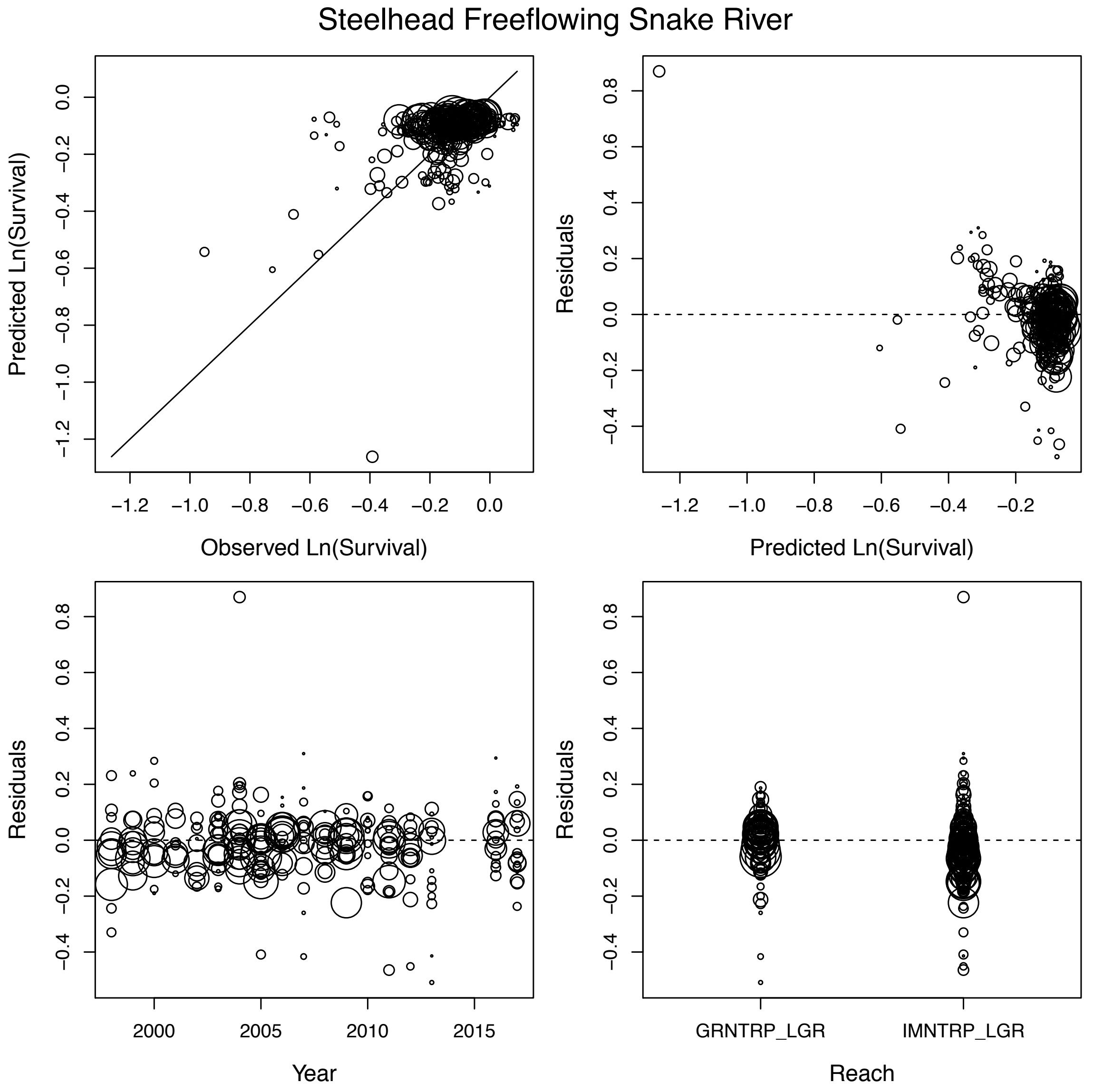

Figure A3-1 8. Diagnostics of predicted survival probabilities for Snake River steelhead migrating from the Grande Ronde Trap and Imnaha River Trap to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: GRNTRP = Grande Ronde River Trap; IMNTRP = Imnaha River Trap; LGR = Lower Granite Dam.

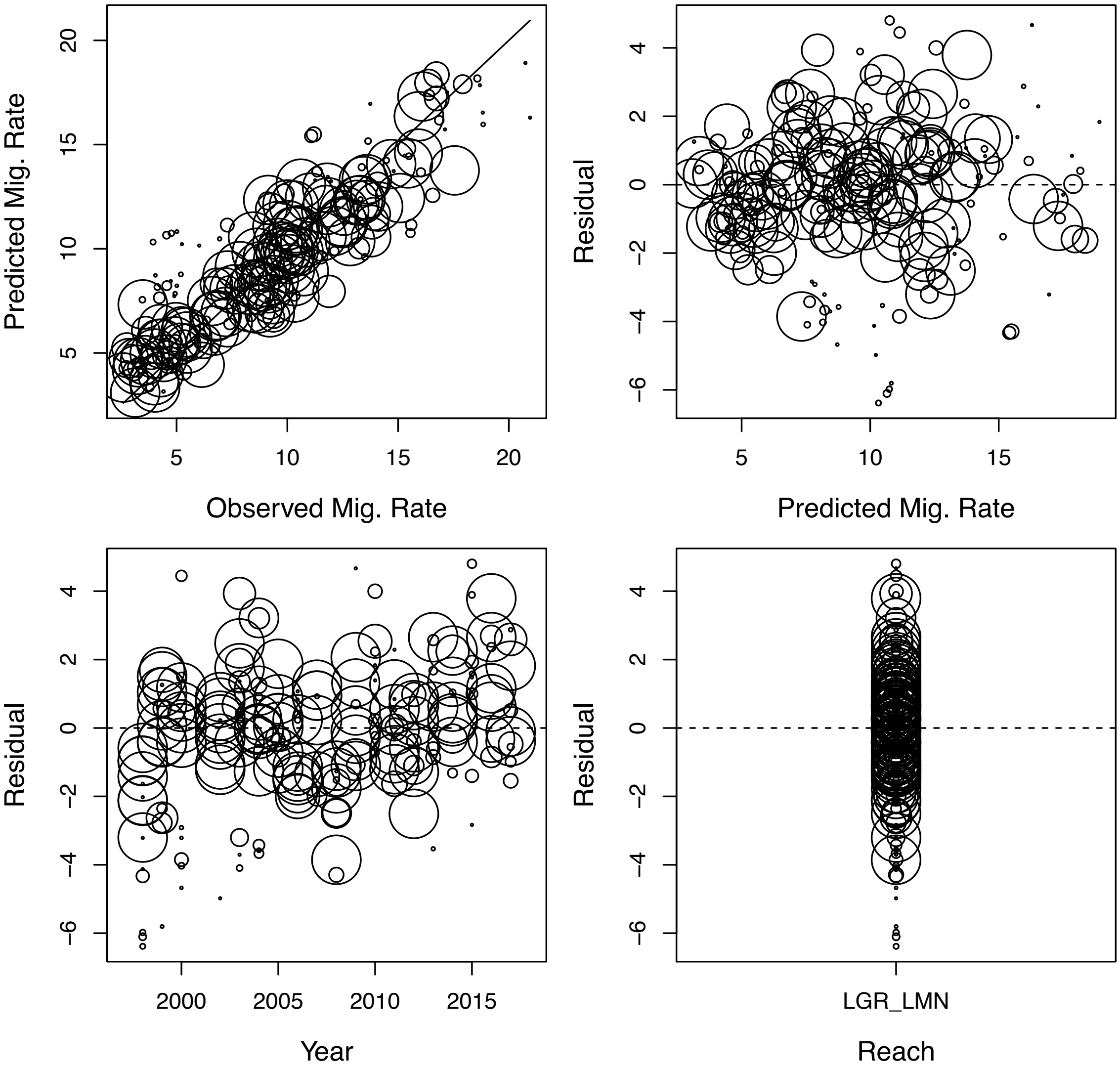

Figure A3-1 9. Diagnostics of predicted migration rates for Snake River spring/summer Chinook migrating from Lower Granite to Lower Monumental Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LGR = Lower Granite Dam; LMN = Lower Monumental Dam.

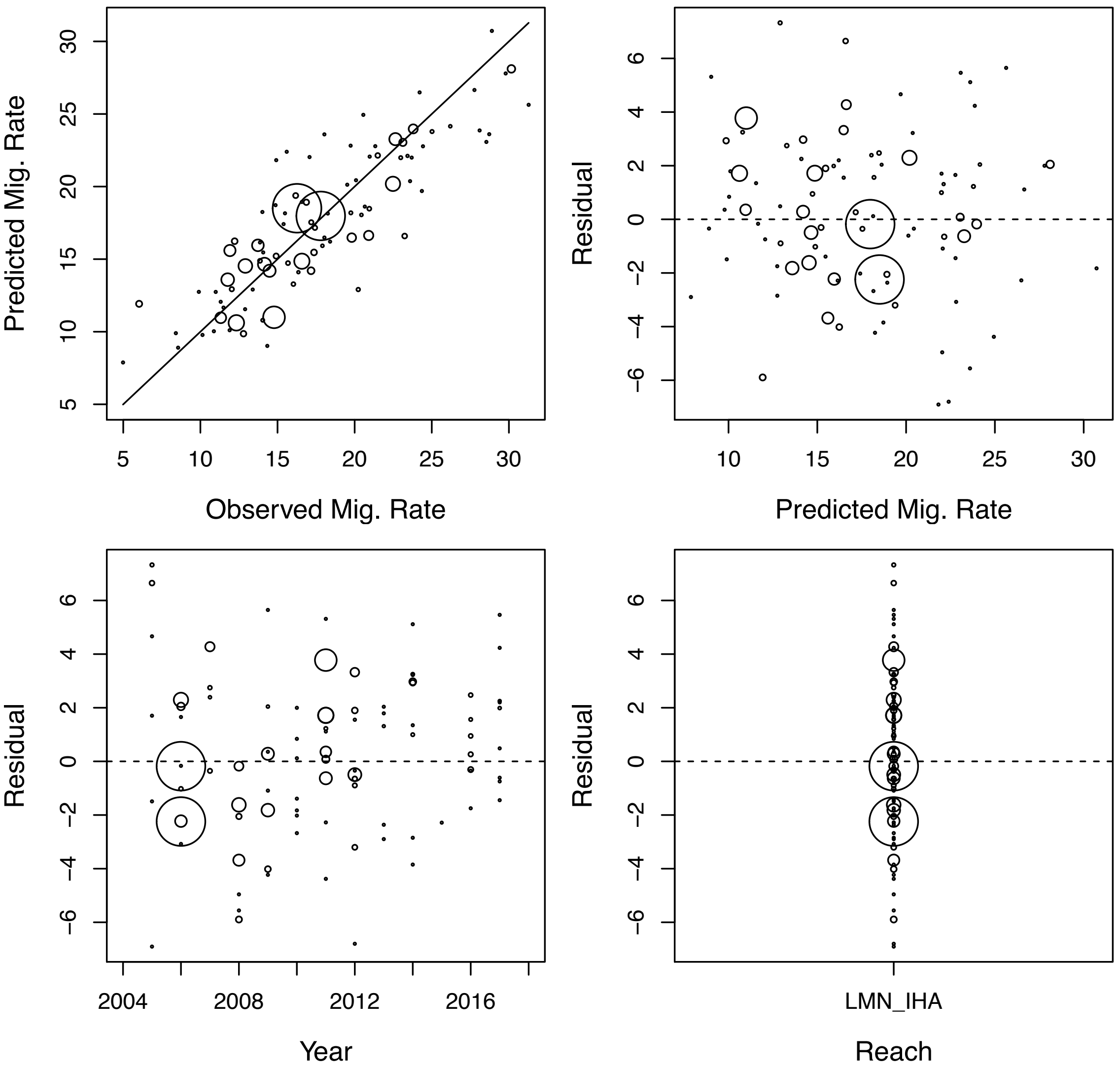

Figure A3-1 10. Diagnostics of predicted migration rates for Snake River spring/summer Chinook migrating from Lower Monumental to Ice Harbor Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LMN = Lower Monumental Dam; IHA = Ice Harbor Dam.

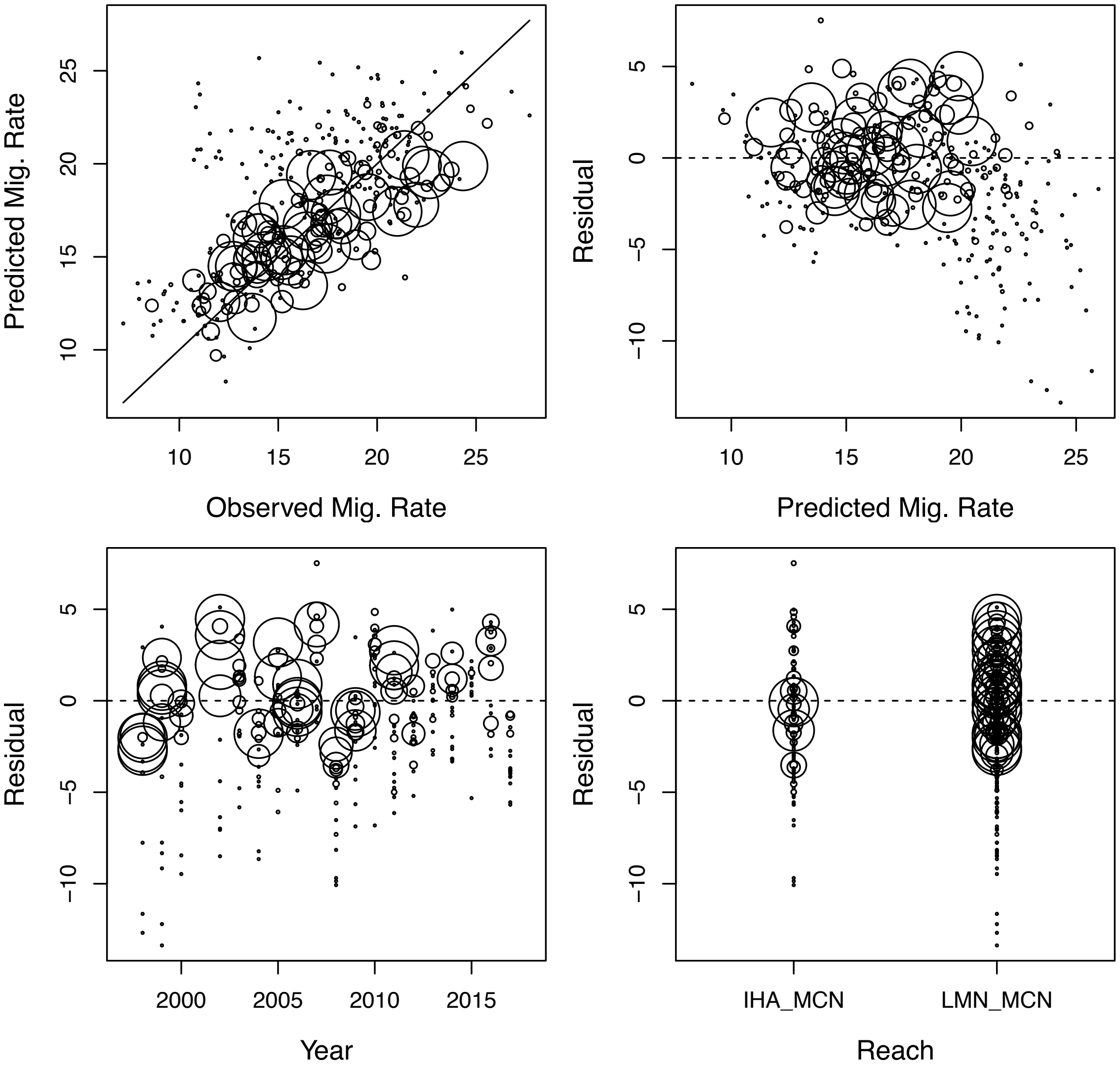

Figure A3-1 11. Diagnostics of predicted migration rates for Snake River spring/summer Chinook migrating from Lower Monumental to McNary Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LMN = Lower Monumental Dam; IHA = Ice Harbor Dam; MCN = McNary Dam.

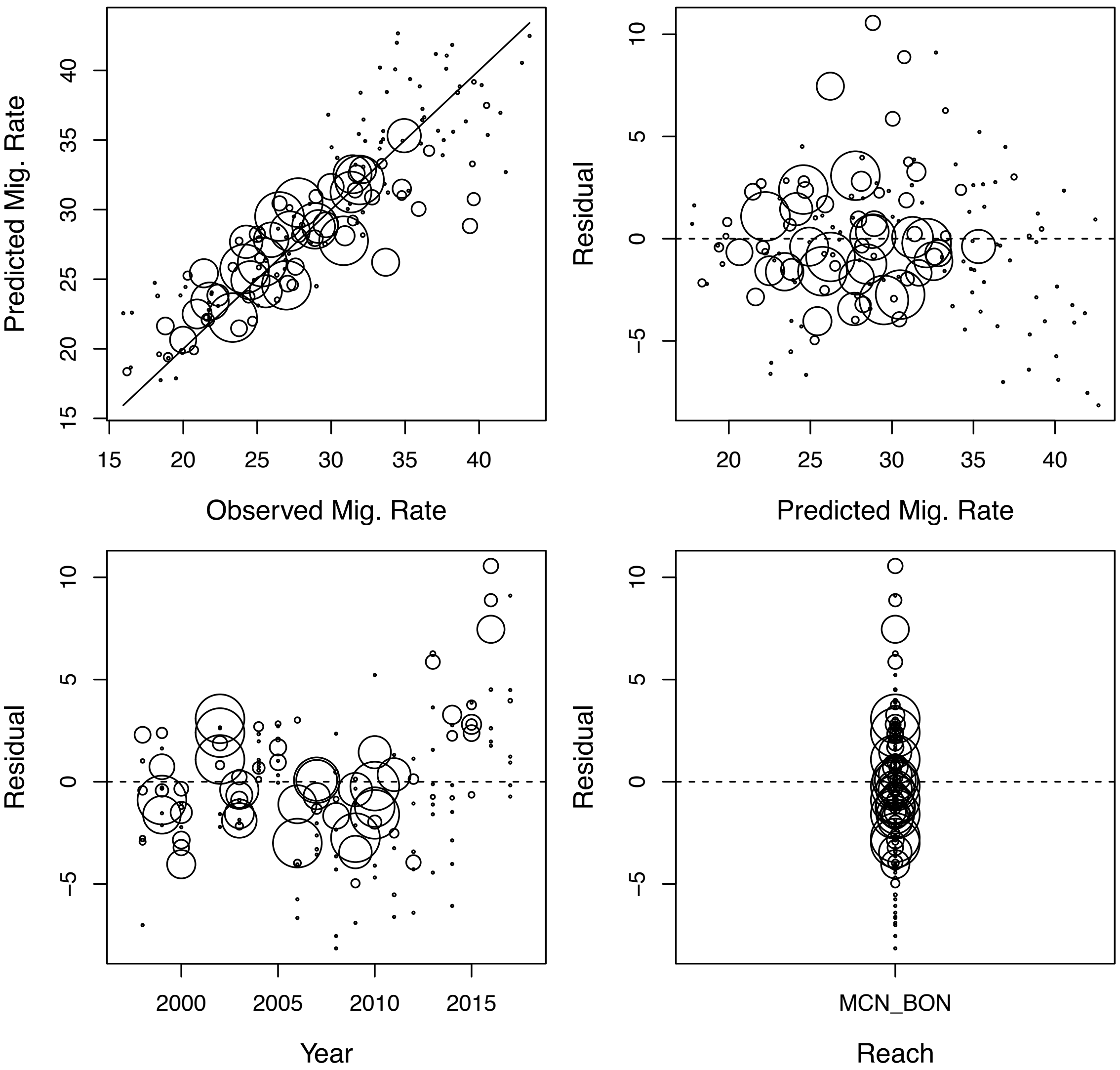

Figure A3-1 12. Diagnostics of predicted migration rates for Snake River spring/summer Chinook migrating from McNary to Bonneville Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: MCN = McNary Dam, BON = Bonneville Dam.

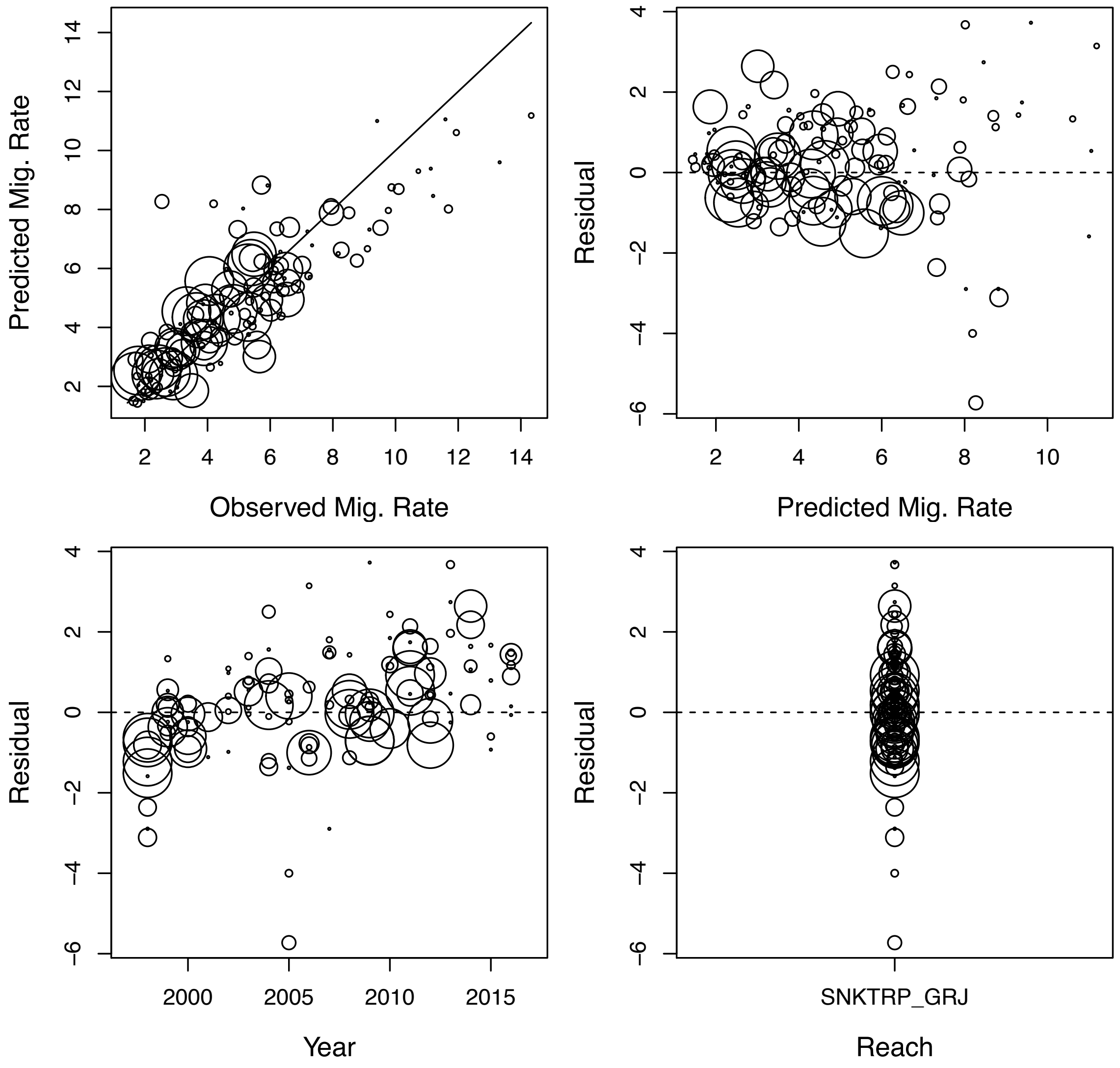

Figure A3-1 13. Diagnostics of predicted migration rates for Snake River spring/summer Chinook migrating from the Snake River trap to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: SNKTRP = Snake River trap, GRJ = Lower Granite Dam.

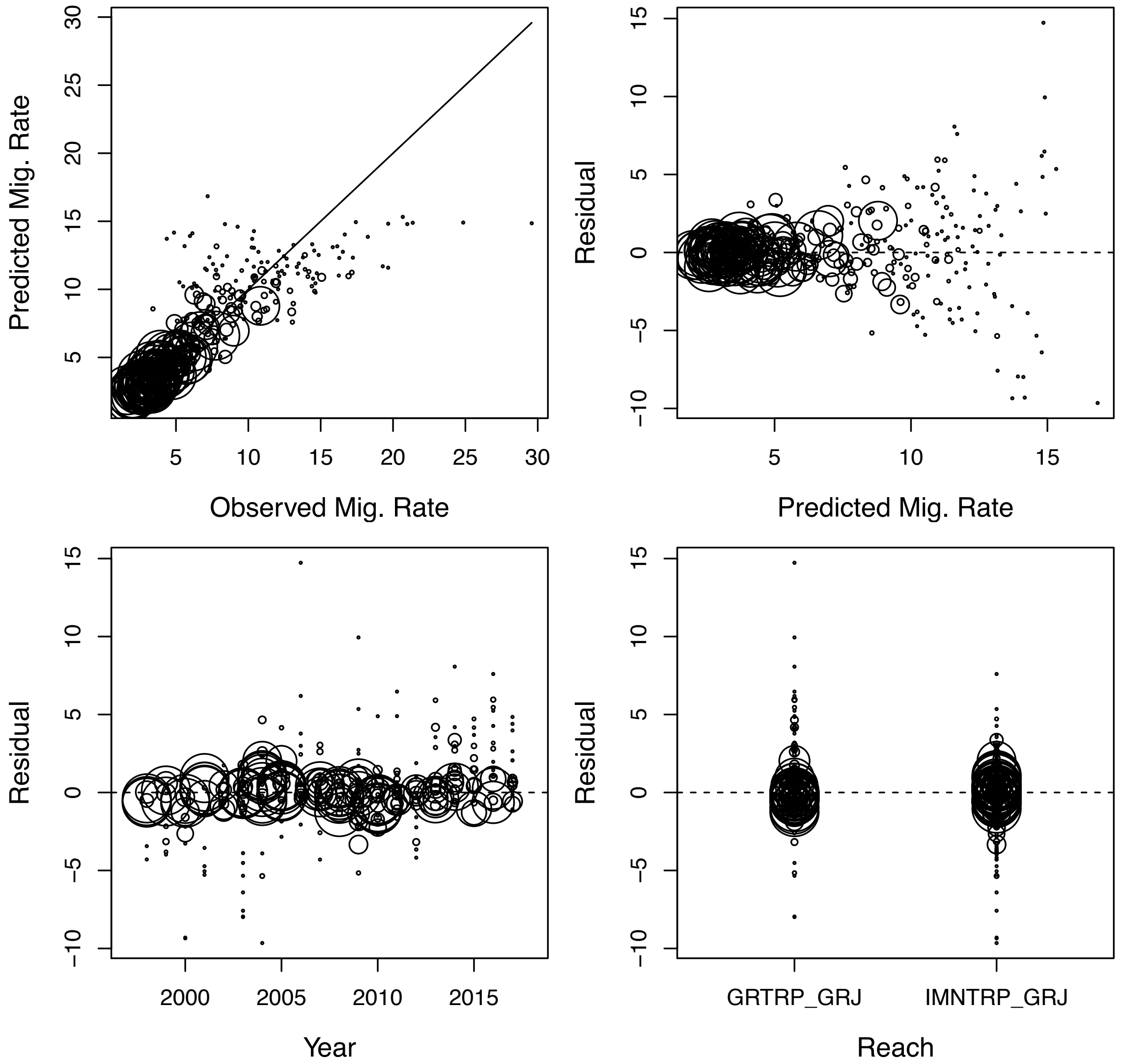

Figure A3-1 14. Diagnostics of predicted migration rates for Snake River spring/summer Chinook migrating from the Grande Ronde River and Imnaha River traps to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: GRNTRP = Grande Ronde River trap; IMNTRP = Imnaha River trap; GRJ = Lower Granite Dam.

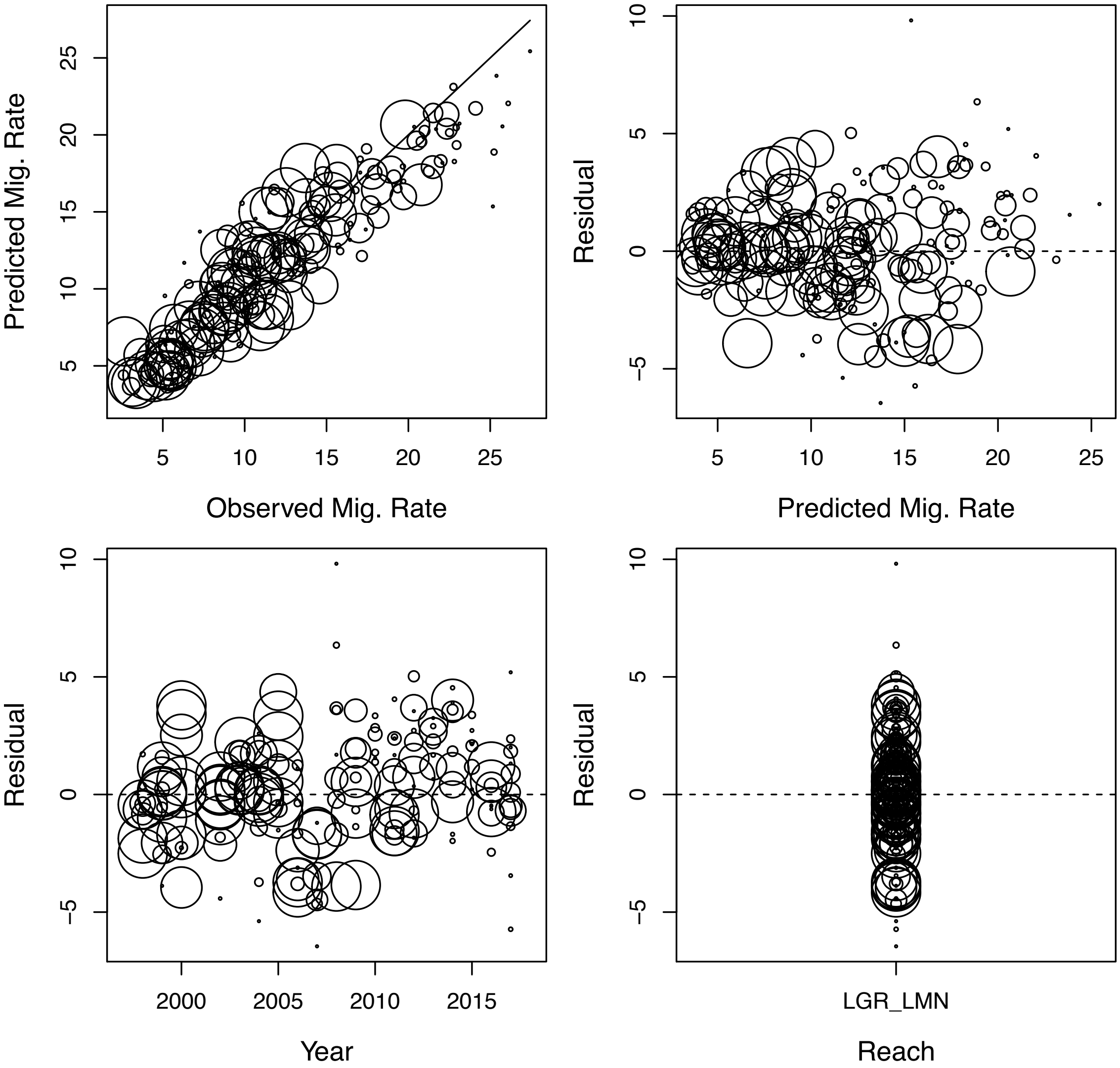

Figure A3-1 15. Diagnostics of predicted migration rates for Snake River steelhead migrating from Lower Granite to Lower Monumental Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LGR = Lower Granite Dam; LMN = Lower Monumental Dam.

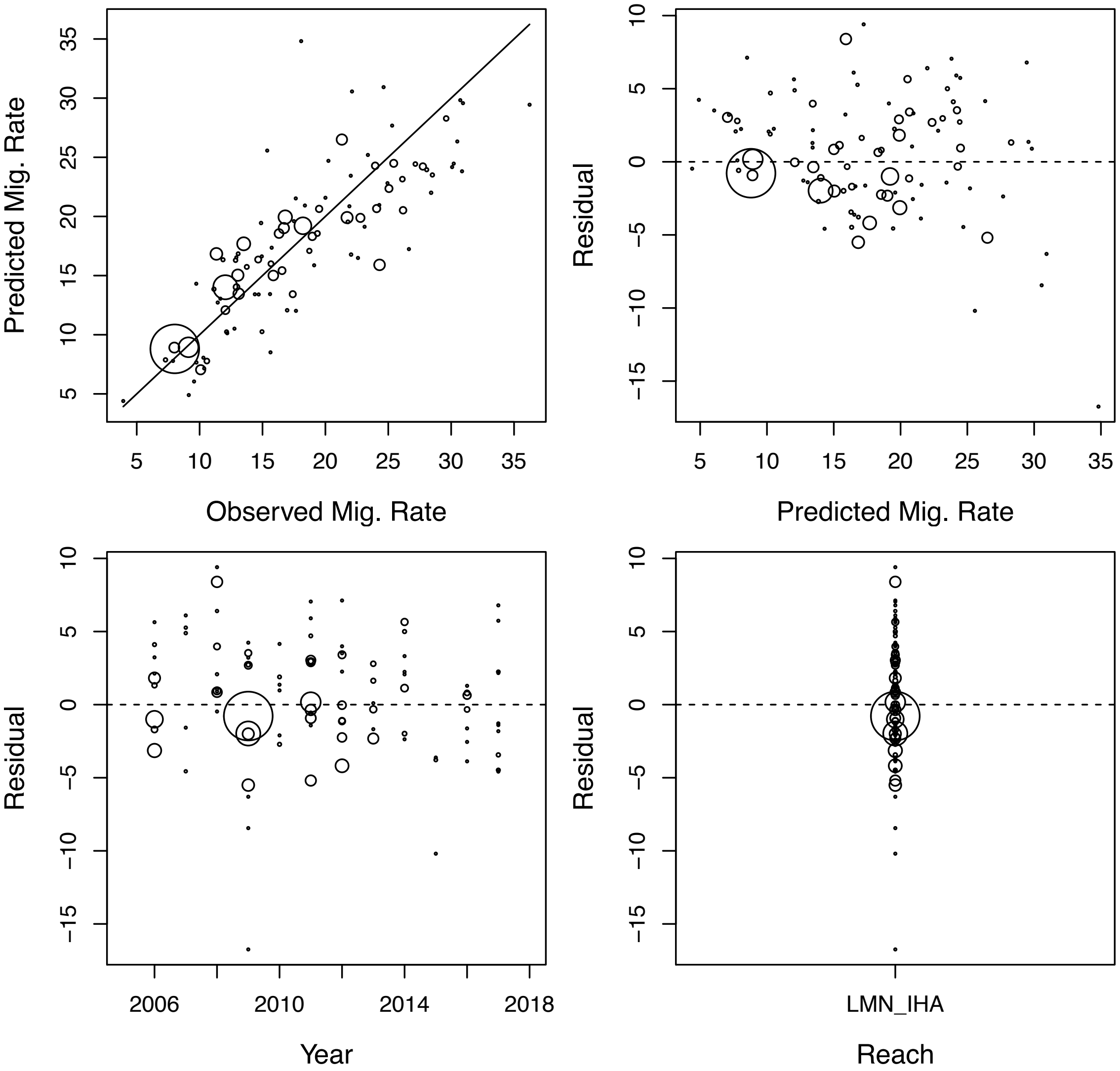

Figure A3-1 16. Diagnostics of predicted migration rates for Snake River steelhead migrating from Lower Monumental to Ice Harbor Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LMN = Lower Monumental Dam; IHA = Ice Harbor Dam.

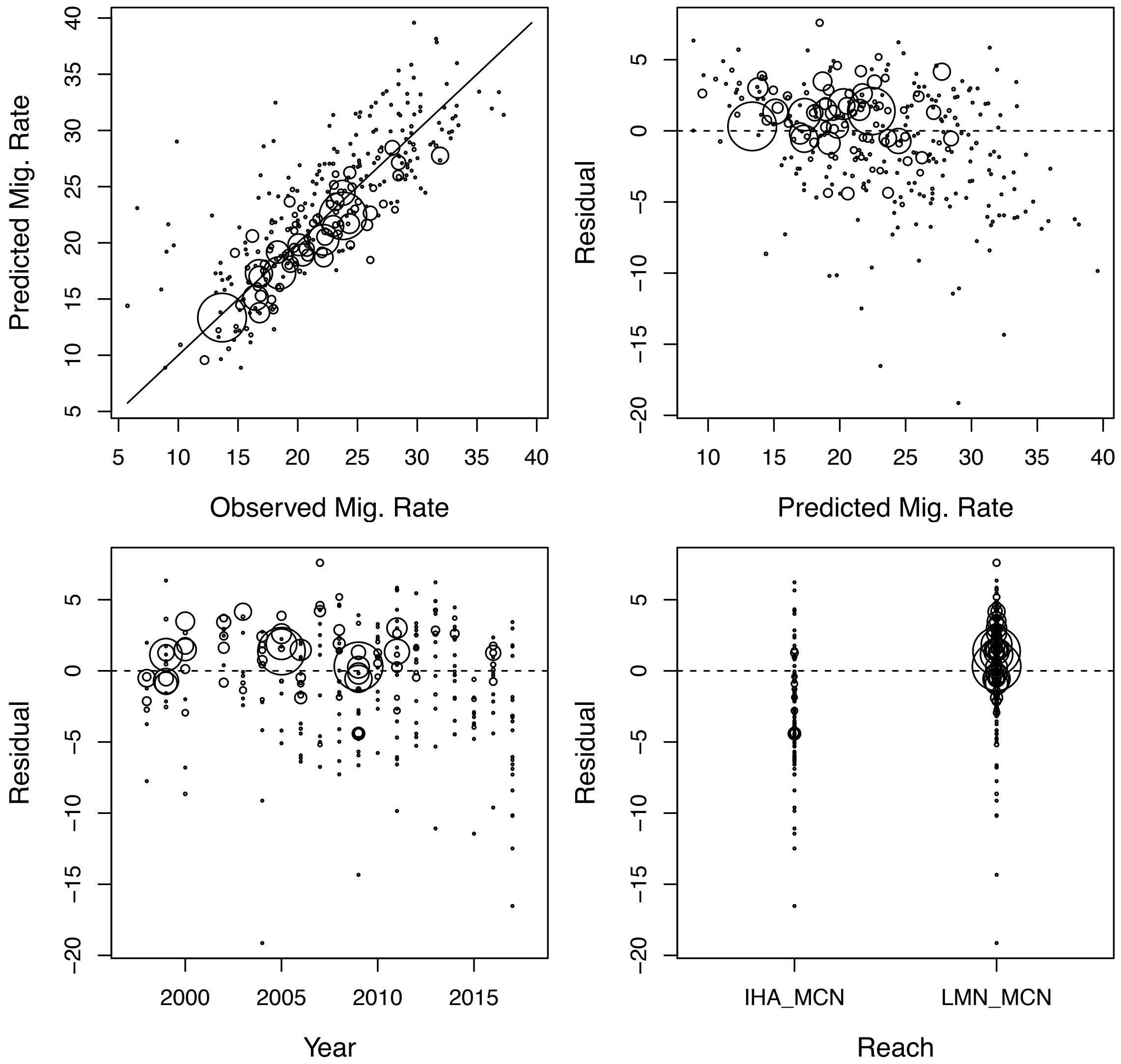

Figure A3-1 17. Diagnostics of predicted migration rates for Snake River steelhead migrating from Lower Monumental to McNary Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: LMN = Lower Monumental Dam; IHA = Ice Harbor Dam; MCN = McNary Dam.

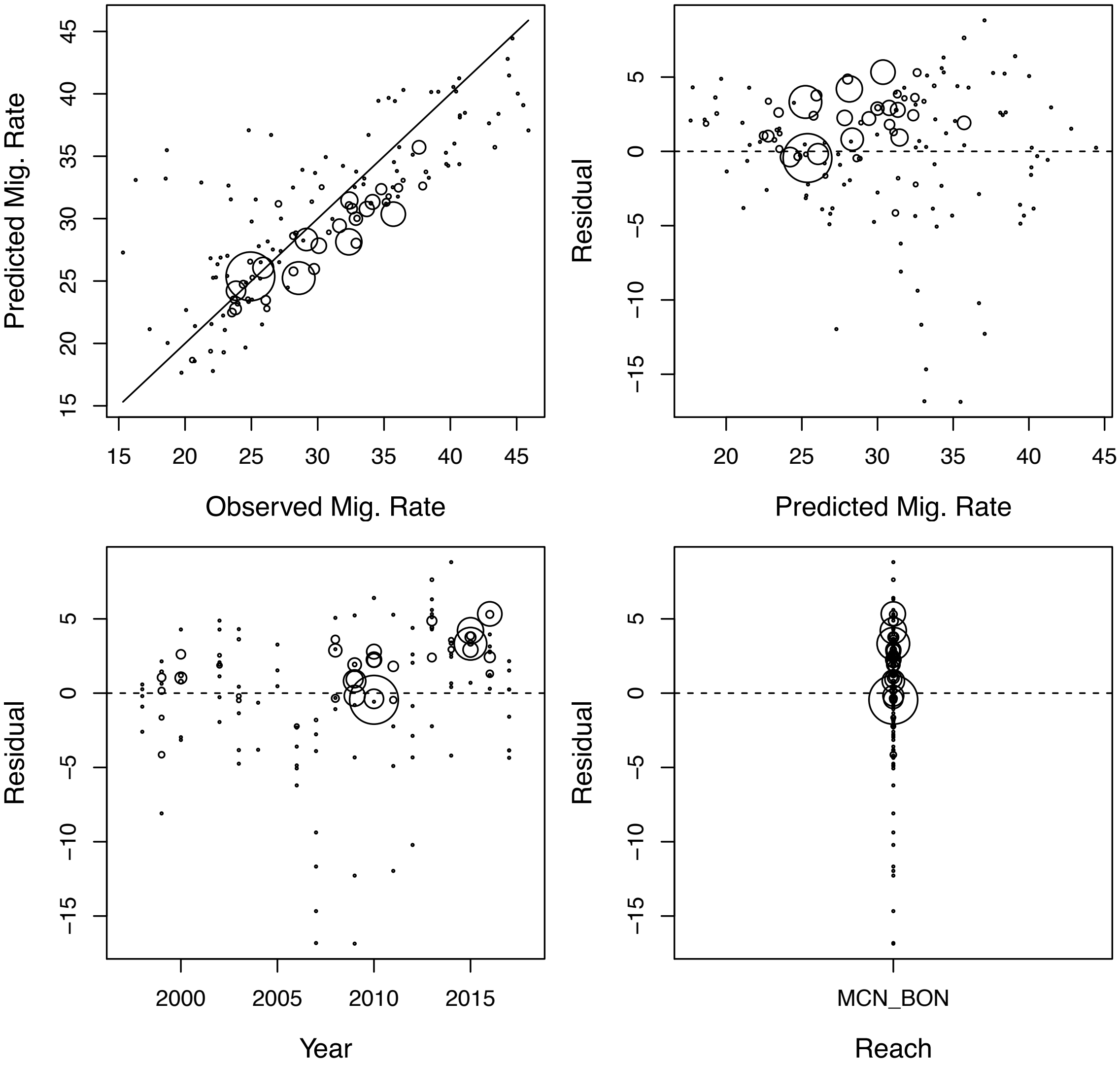

Figure A3-1 18. Diagnostics of predicted migration rates for Snake River steelhead migrating from McNary to Bonneville Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: MCN = McNary Dam, BON = Bonneville Dam.

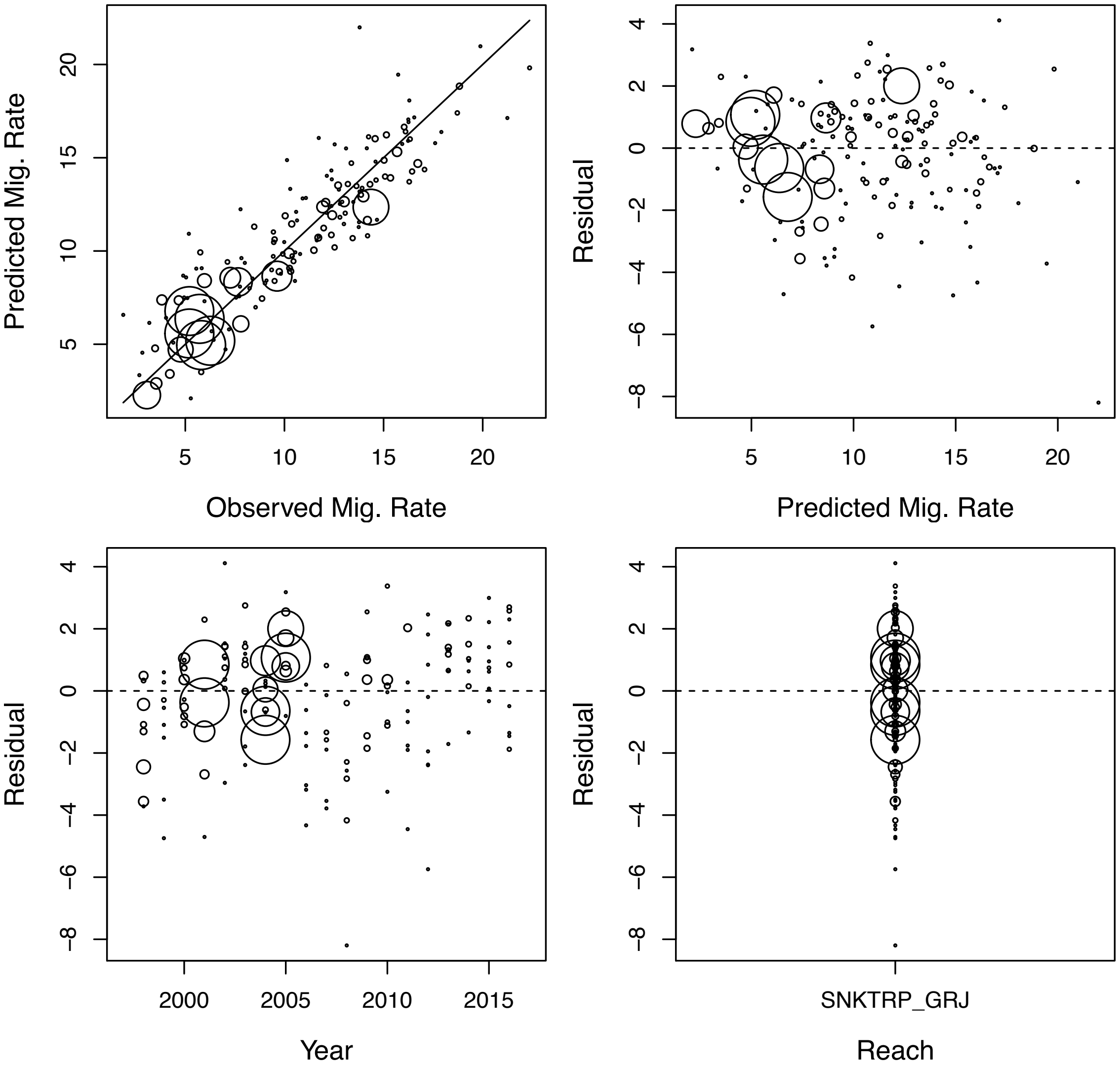

Figure A3-1 19. Diagnostics of predicted migration rates for Snake River steelhead migrating from the Snake River trap to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: SNKTRP = Snake River trap, GRJ = Lower Granite Dam.

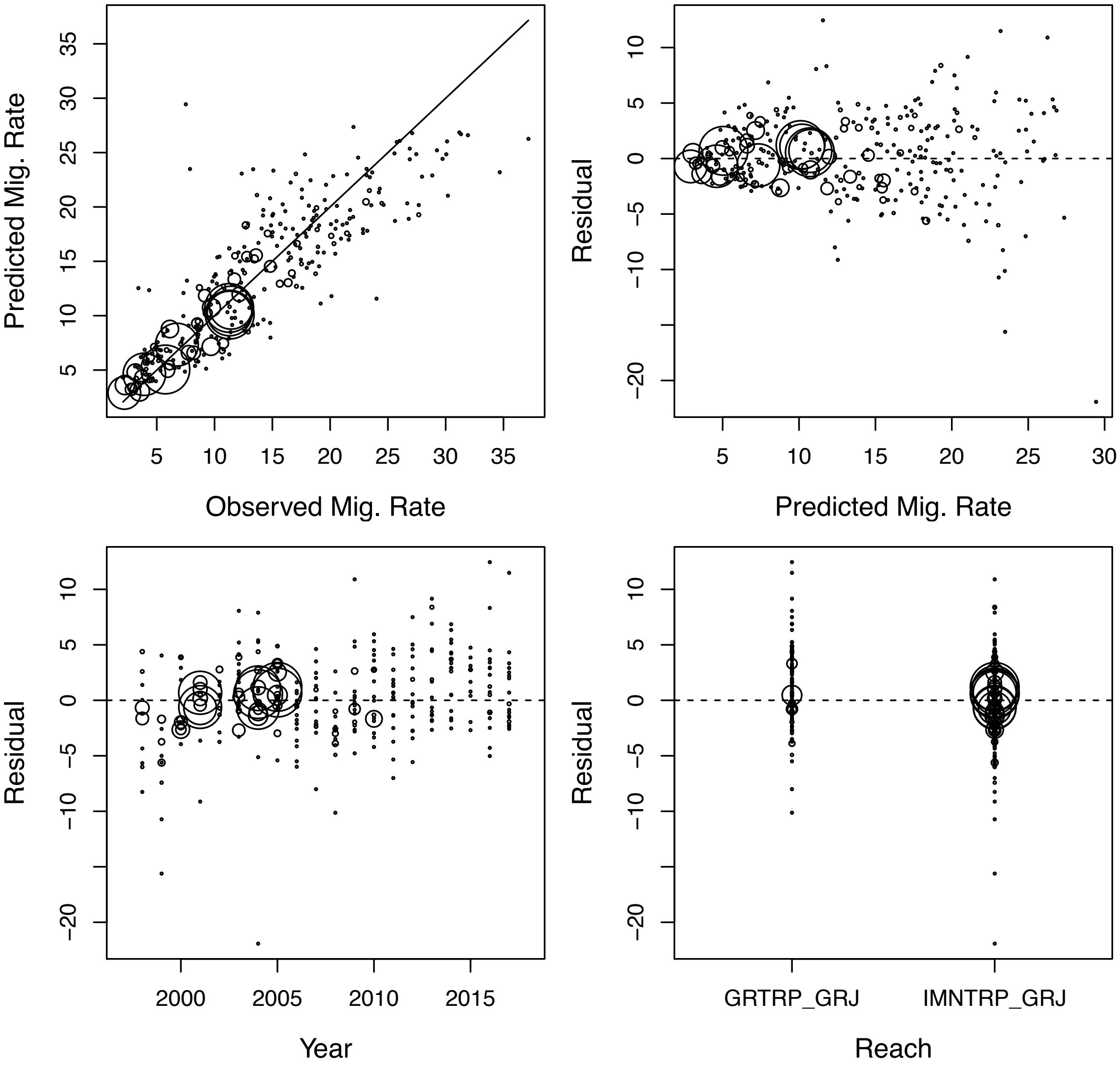

Figure A3-1 20. Diagnostics of predicted migration rates for Snake River steelhead migrating from the Grande Ronde River and Imnaha River traps to Lower Granite Dam. The diameter of the points in the plots reflects the weight assigned to the point. Abbreviations: GRNTRP = Grande Ronde River trap; IMNTRP = Imnaha River trap; GRJ = Lower Granite Dam.

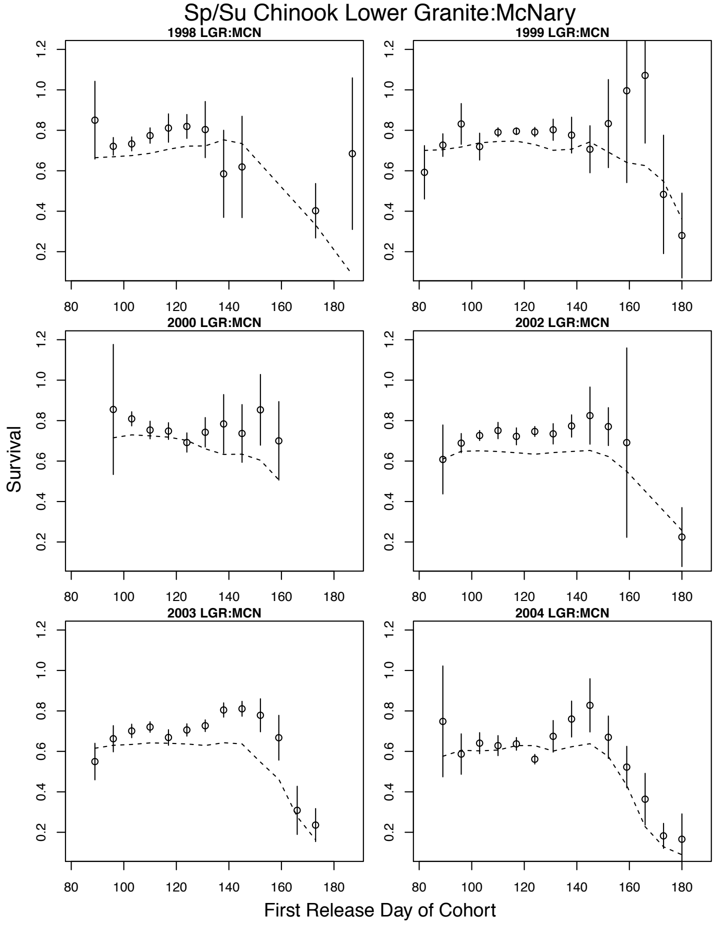

Figure A3-2 1. Survival probabilities for weekly groups of Snake River sp/su Chinook for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

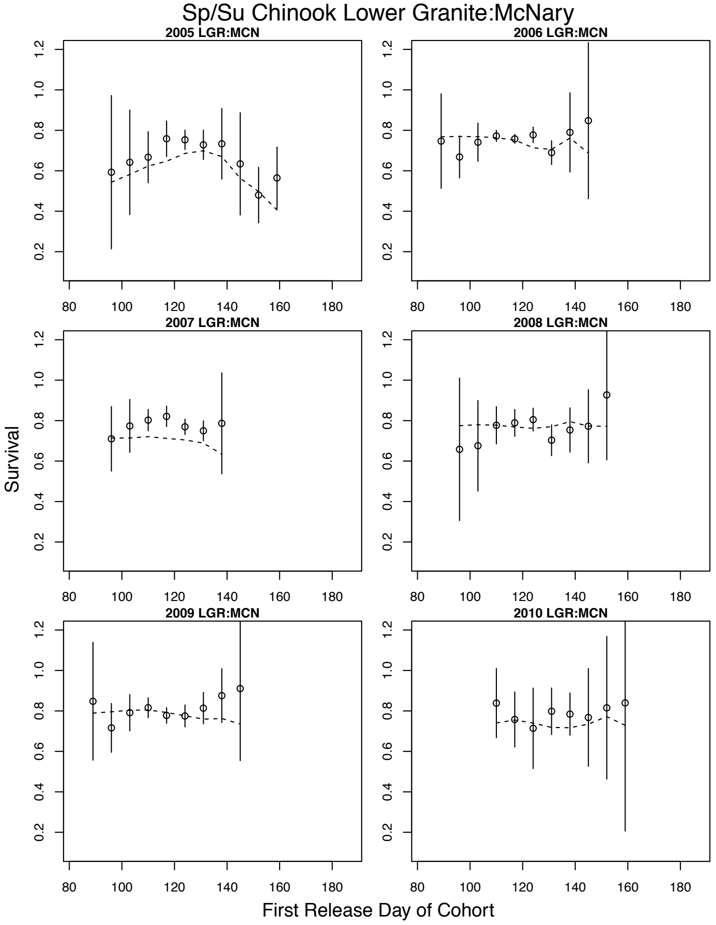

Figure A3-2 2. Survival probabilities for weekly groups of Snake River sp/su Chinook for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

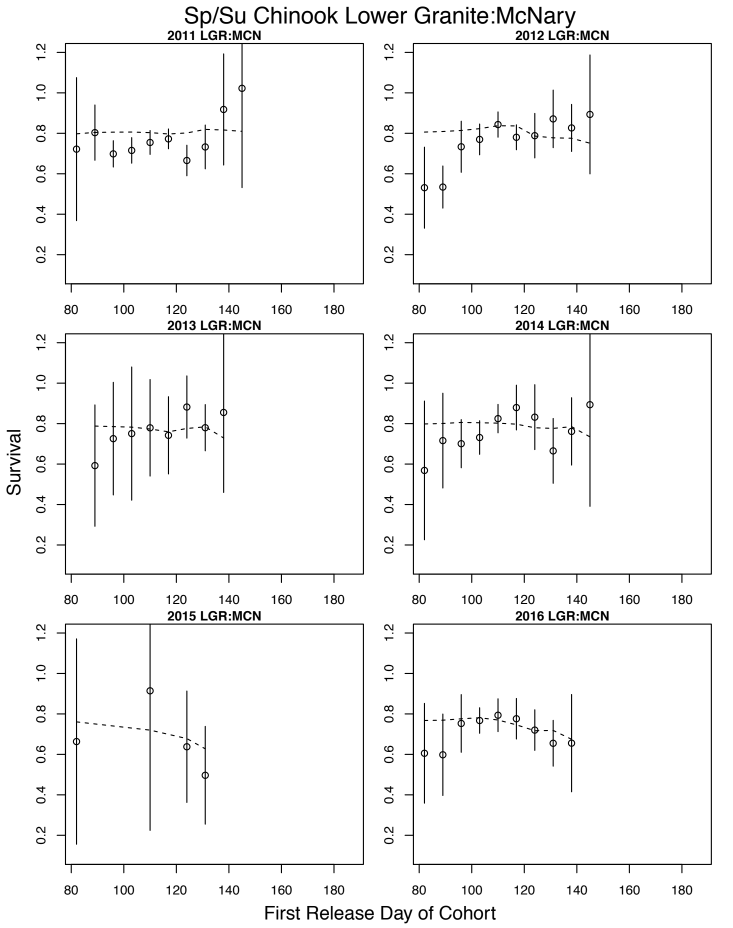

Figure A3-2 3. Survival probabilities for weekly groups of Snake River sp/su Chinook for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

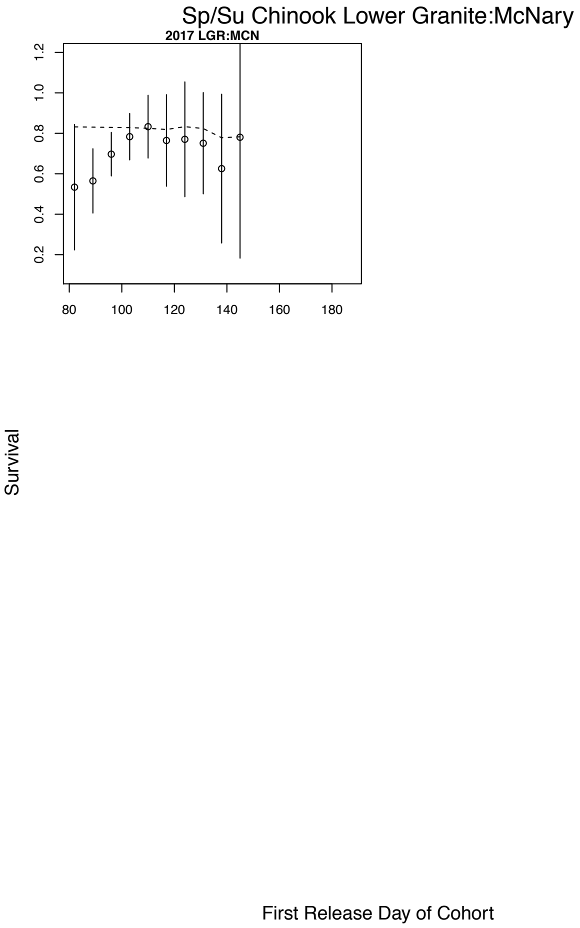

Figure A3-2 4. Survival probabilities for weekly groups of Snake River sp/su Chinook for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

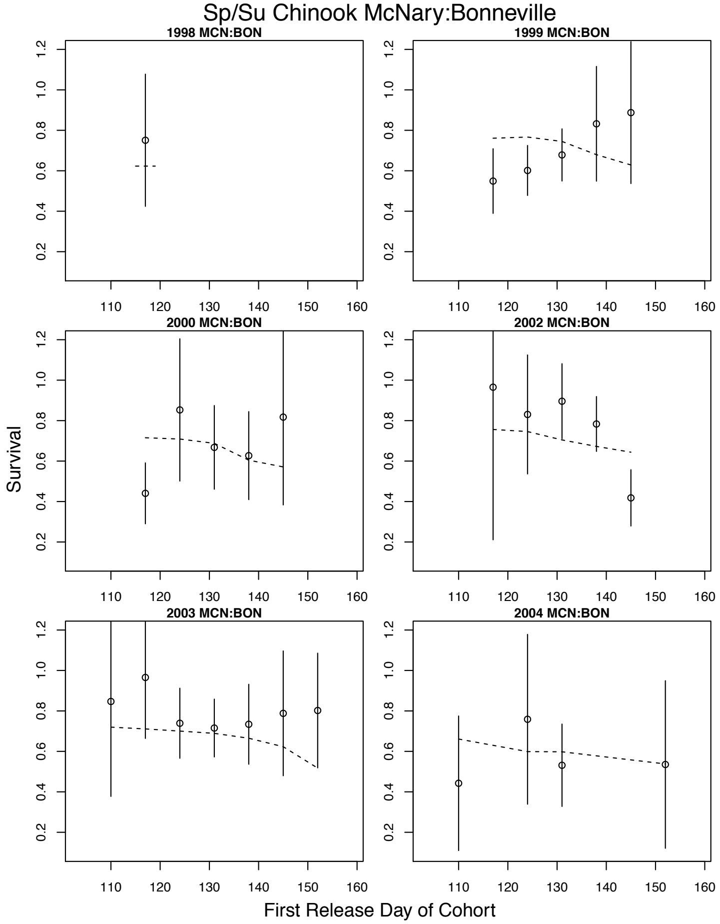

Figure A3-2 5. Survival probabilities for weekly groups of Snake River sp/su Chinook for the MCN to BON river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

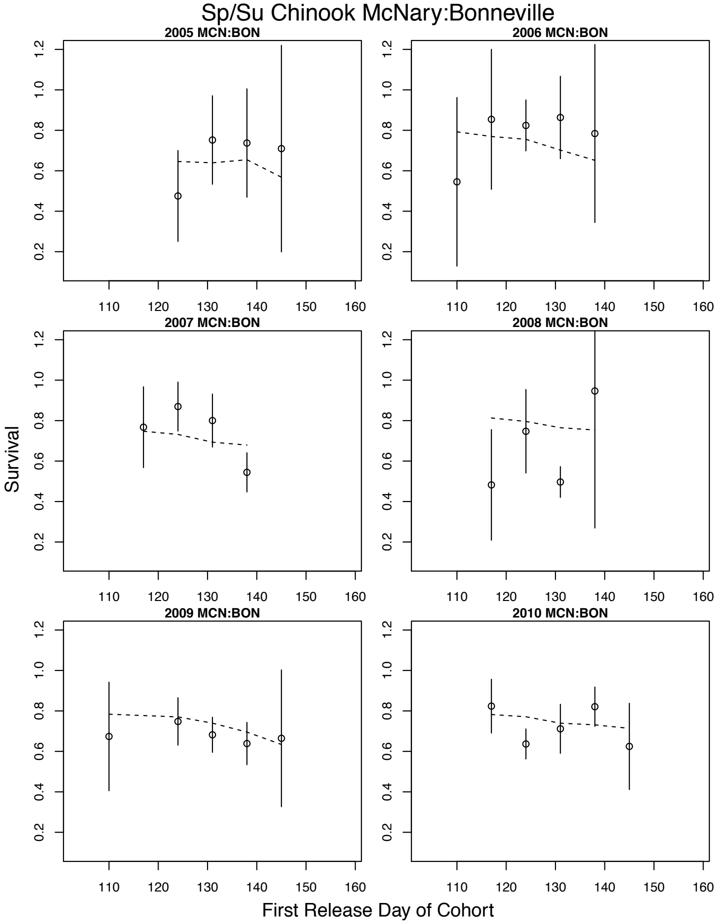

Figure A3-2 6. Survival probabilities for weekly groups of Snake River sp/su Chinook for the MCN to BON river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

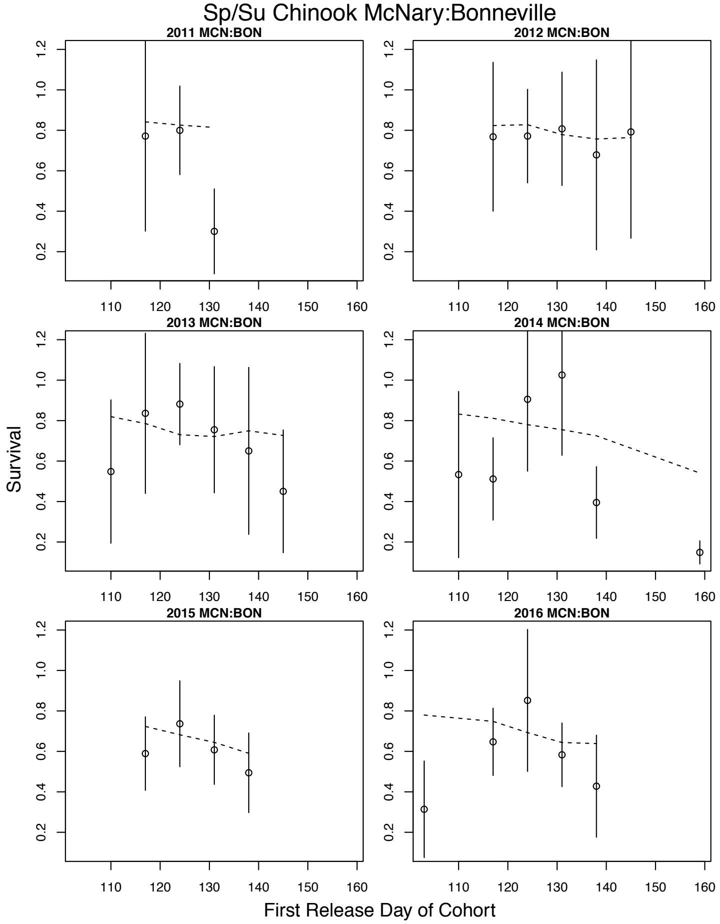

Figure A3-2 7. Survival probabilities for weekly groups of Snake River sp/su Chinook for the MCN to BON river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

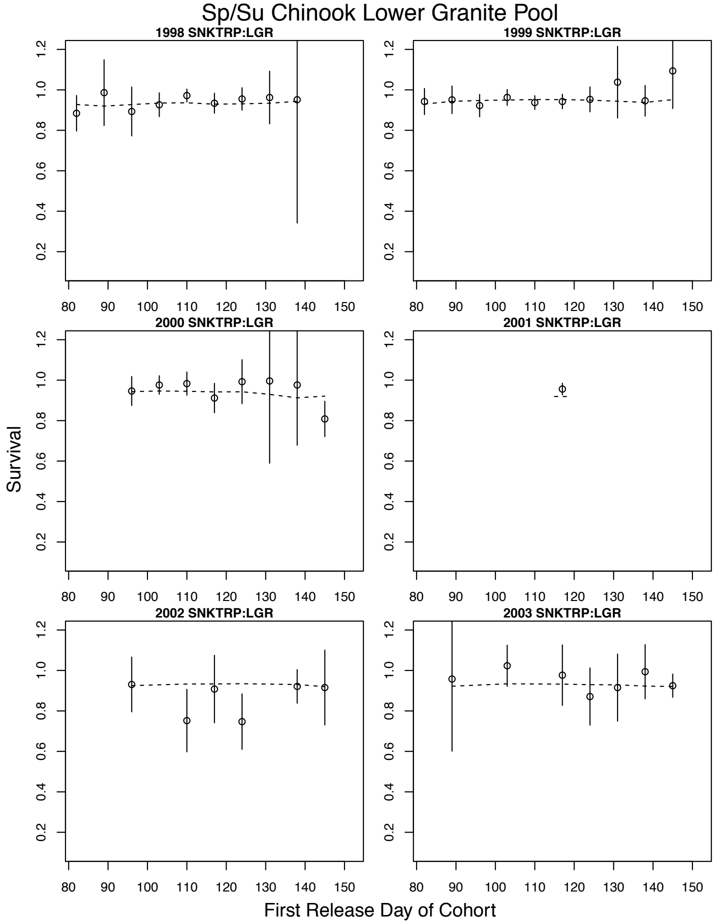

Figure A3-2 8. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Snake River Trap to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

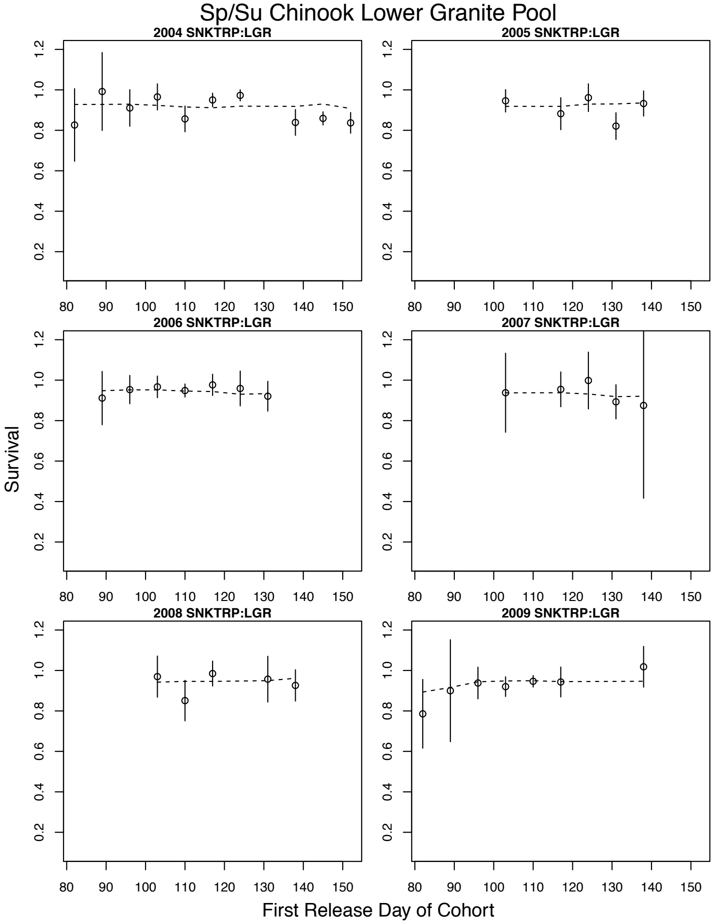

Figure A3-2 9. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Snake River Trap to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

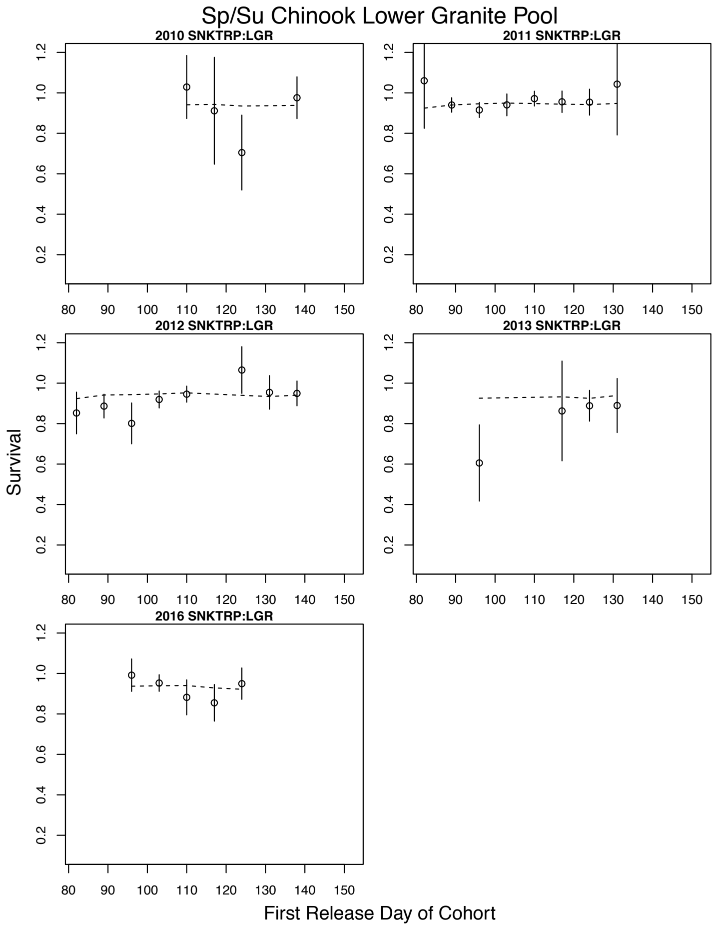

Figure A3-2 10. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Snake River Trap to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

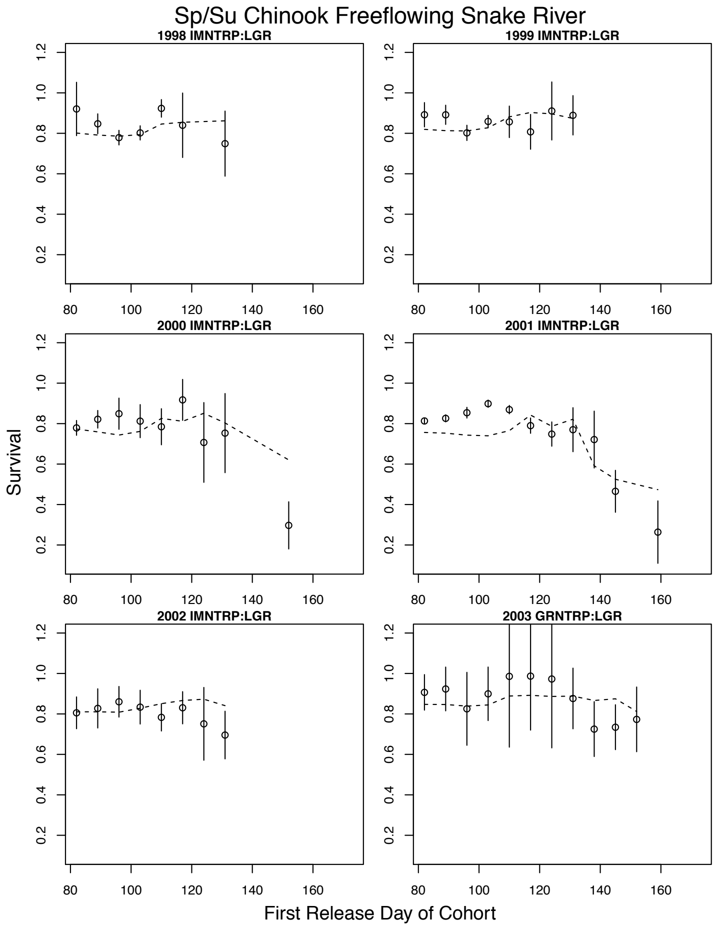

Figure A3-2 11. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

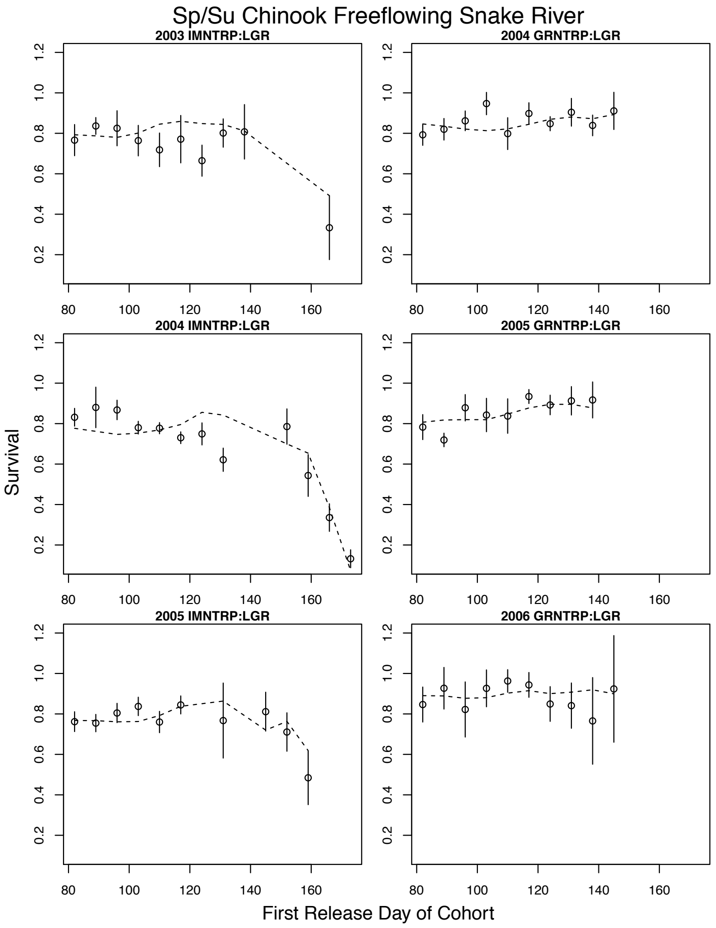

Figure A3-2 12. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

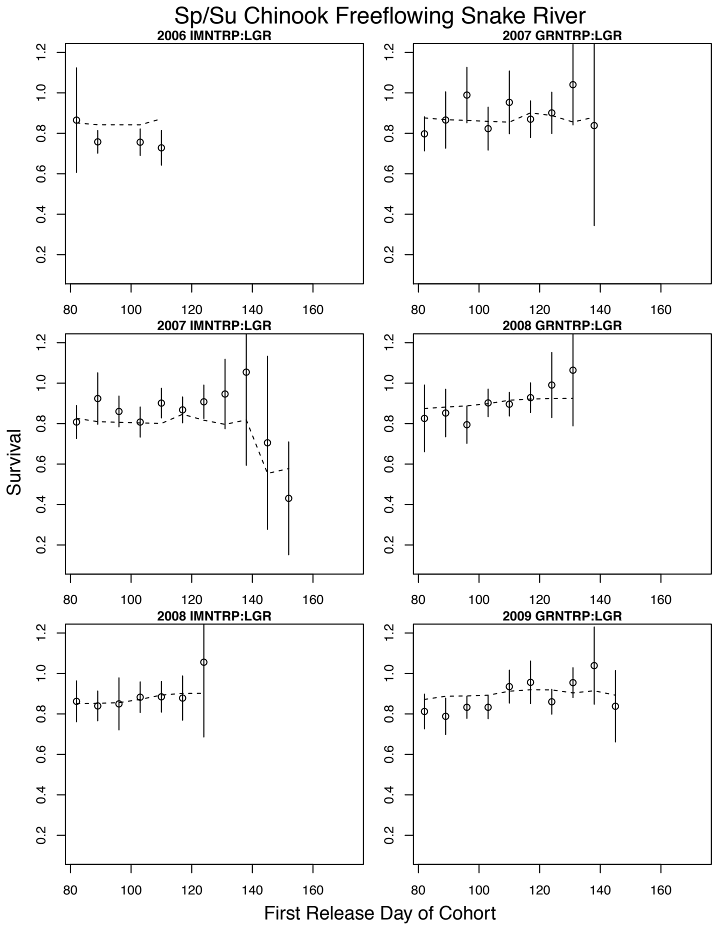

Figure A3-2 13. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

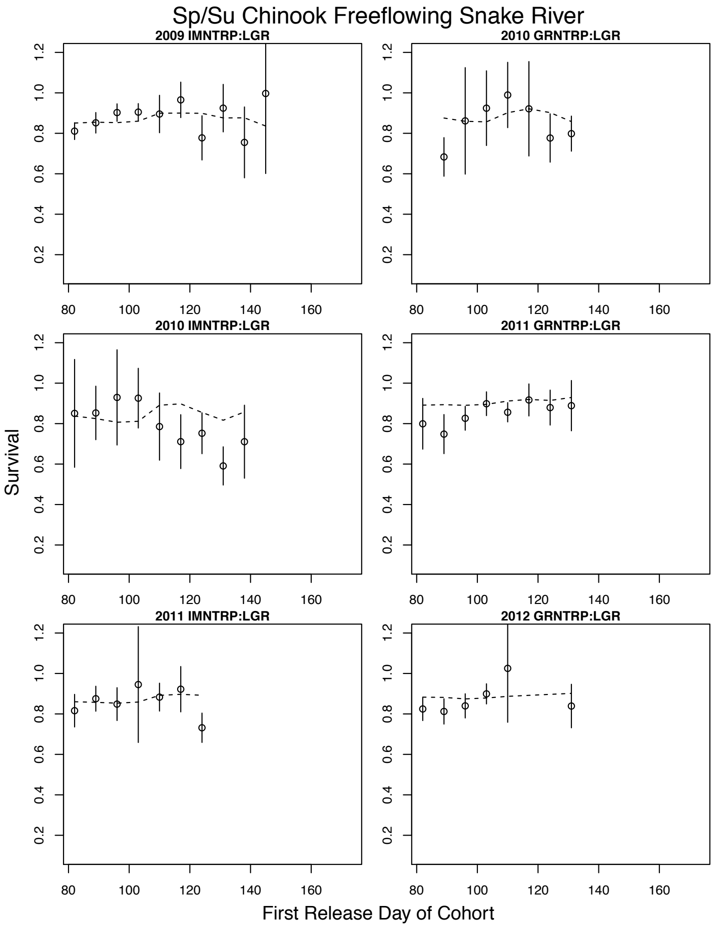

Figure A3-2 14. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

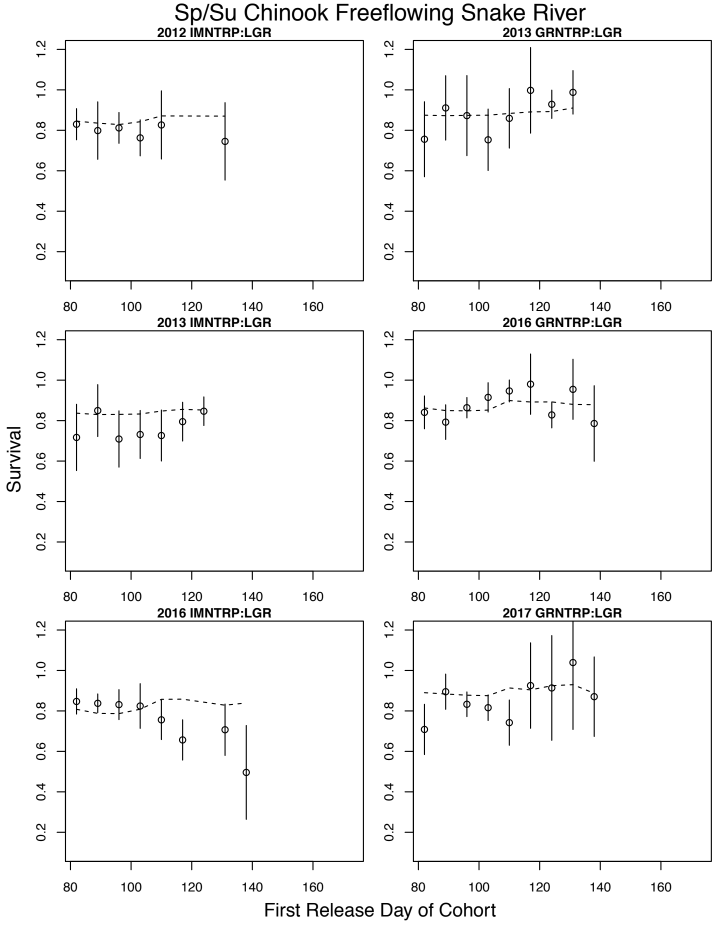

Figure A3-2 15. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

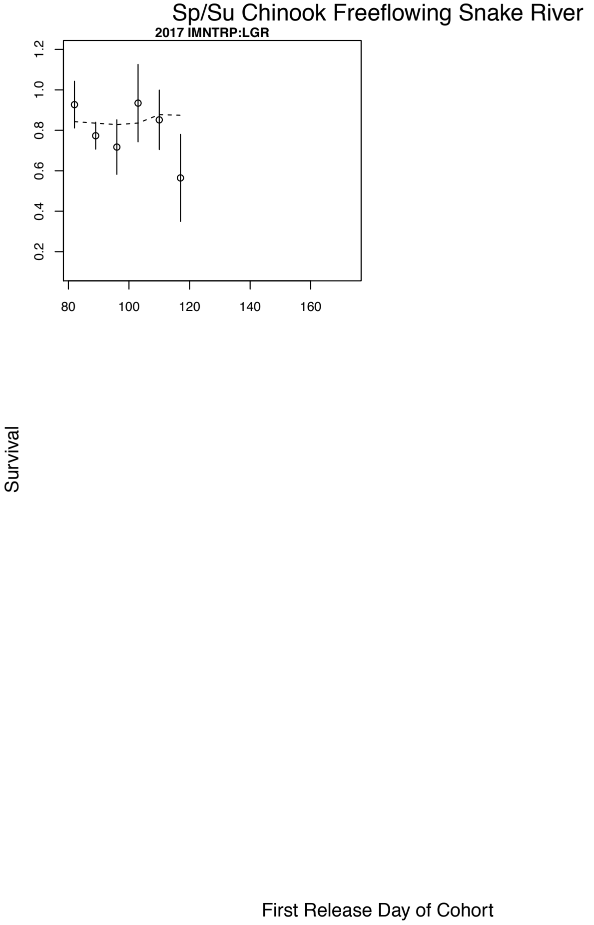

Figure A3-2 16. Survival probabilities for weekly groups of Snake River sp/su Chinook from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

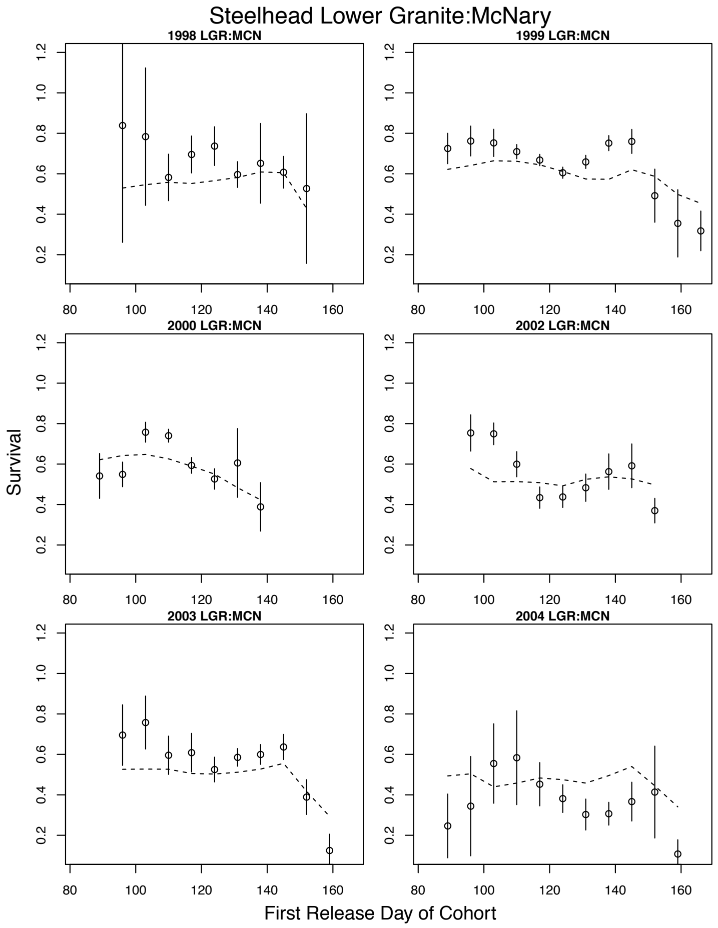

Figure A3-2 17. Survival probabilities for weekly groups of Snake River steelhead for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

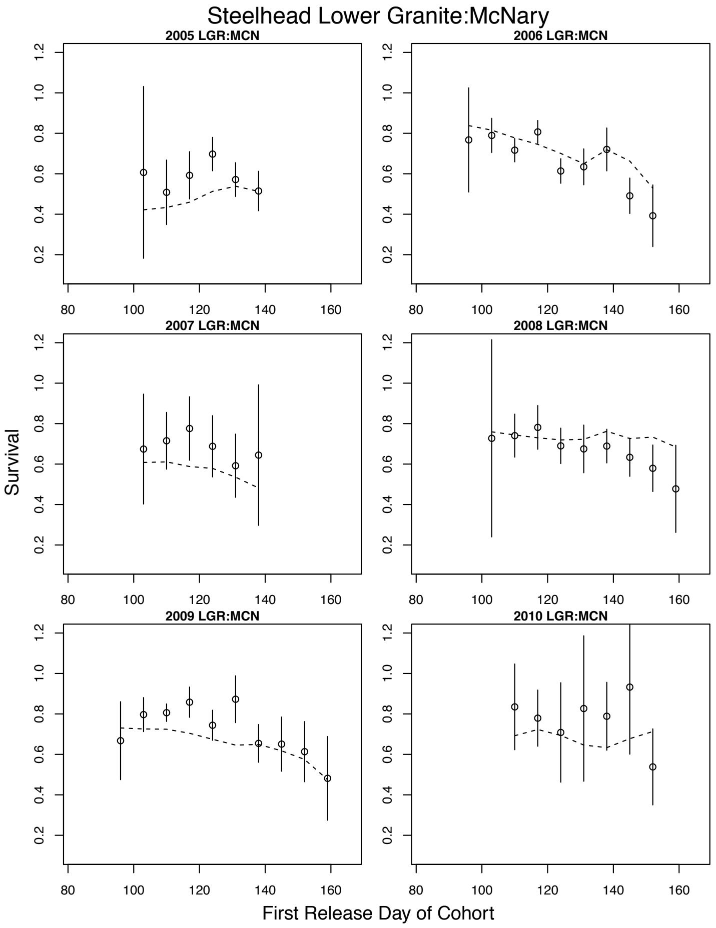

Figure A3-2 18. Survival probabilities for weekly groups of Snake River steelhead for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

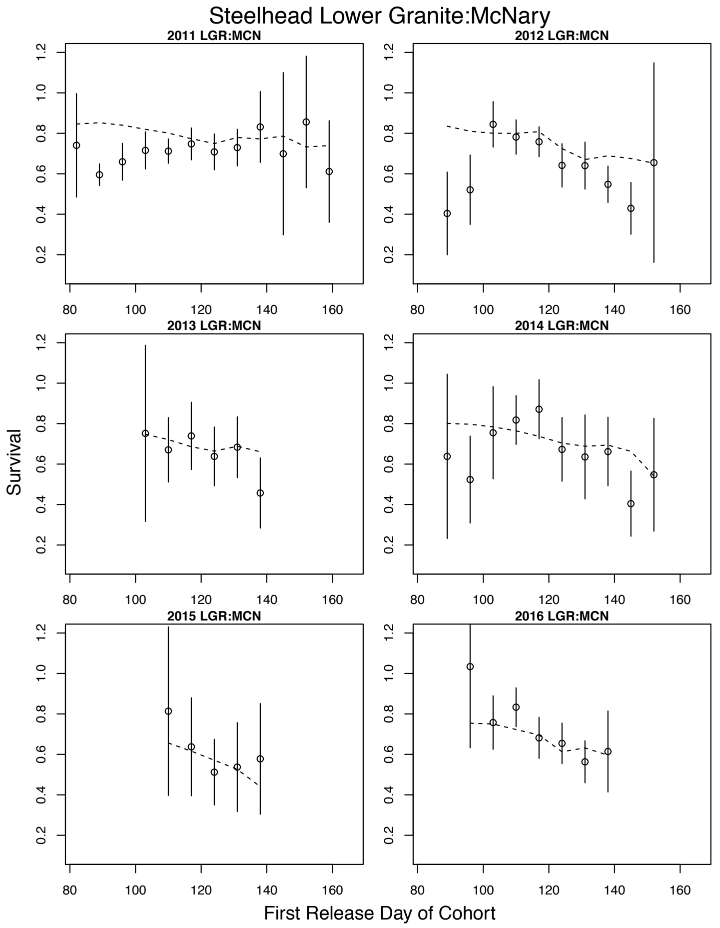

Figure A3-2 19. Survival probabilities for weekly groups of Snake River steelhead for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

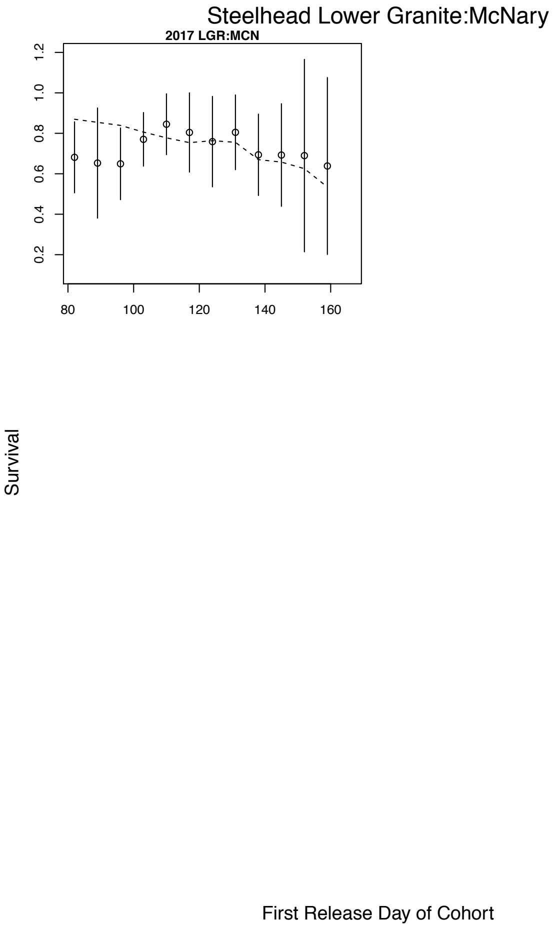

Figure A3-2 20. Survival probabilities for weekly groups of Snake River steelhead for the LGR to MCN river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

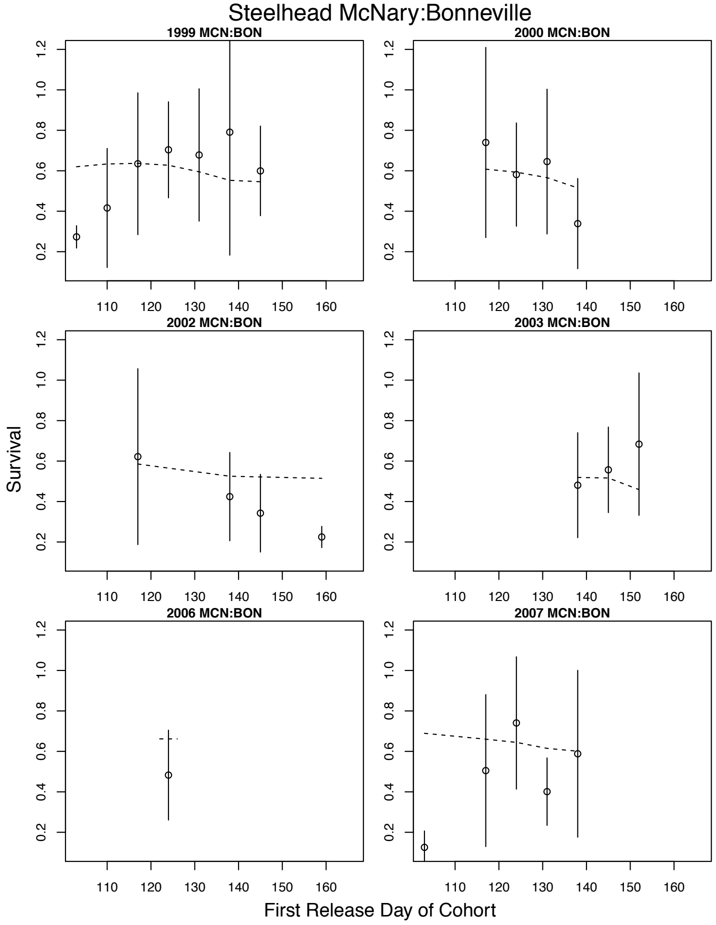

Figure A3-2 21. Survival probabilities for weekly groups of Snake River steelhead for the MCN to BON river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

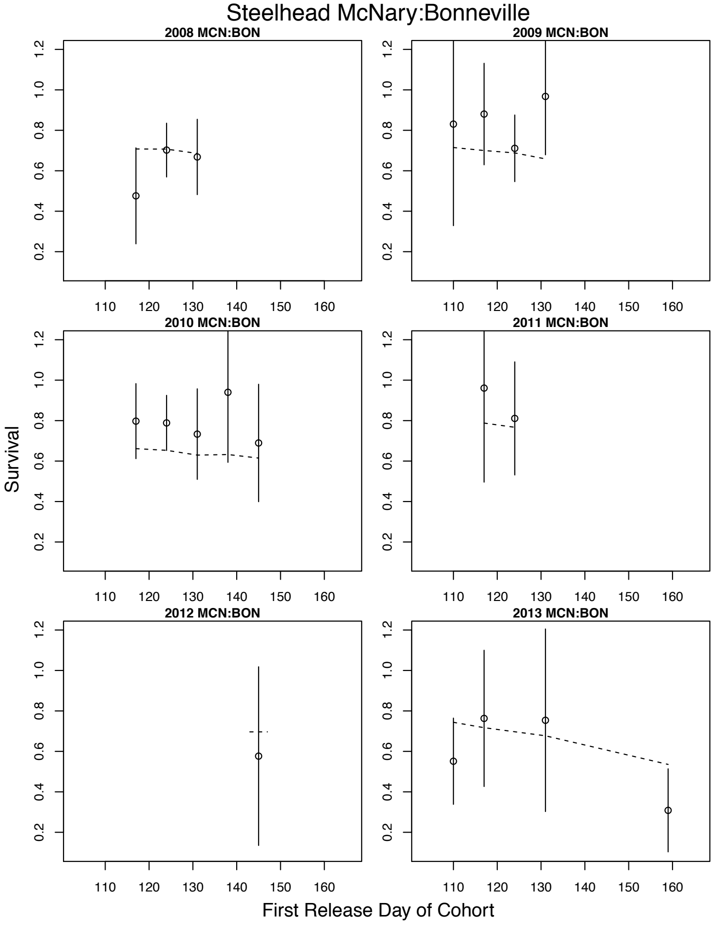

Figure A3-2 22. Survival probabilities for weekly groups of Snake River steelhead for the MCN to BON river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

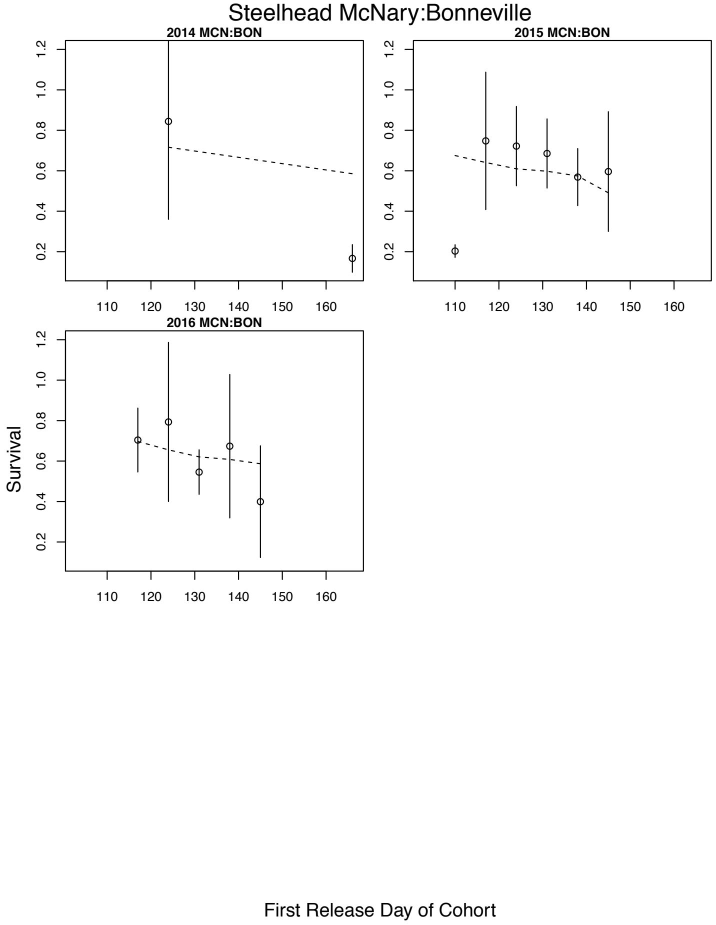

Figure A3-2 23. Survival probabilities for weekly groups of Snake River steelhead for the MCN to BON river segment in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

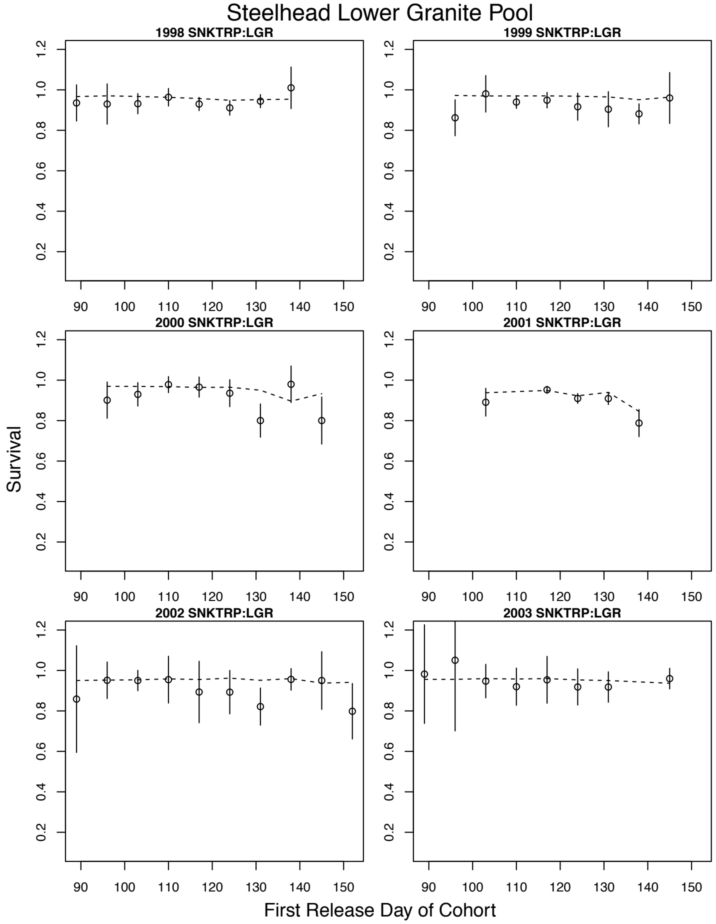

Figure A3-2 24. Survival probabilities for weekly groups of Snake River steelhead from the Snake River Trap to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

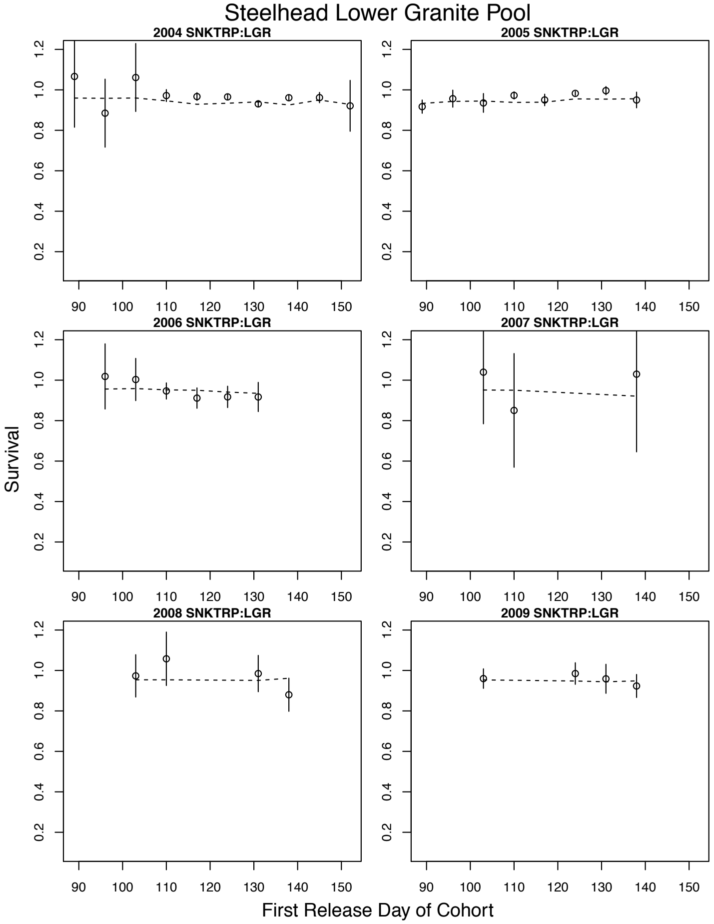

Figure A3-2 25. Survival probabilities for weekly groups of Snake River steelhead from the Snake River Trap to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

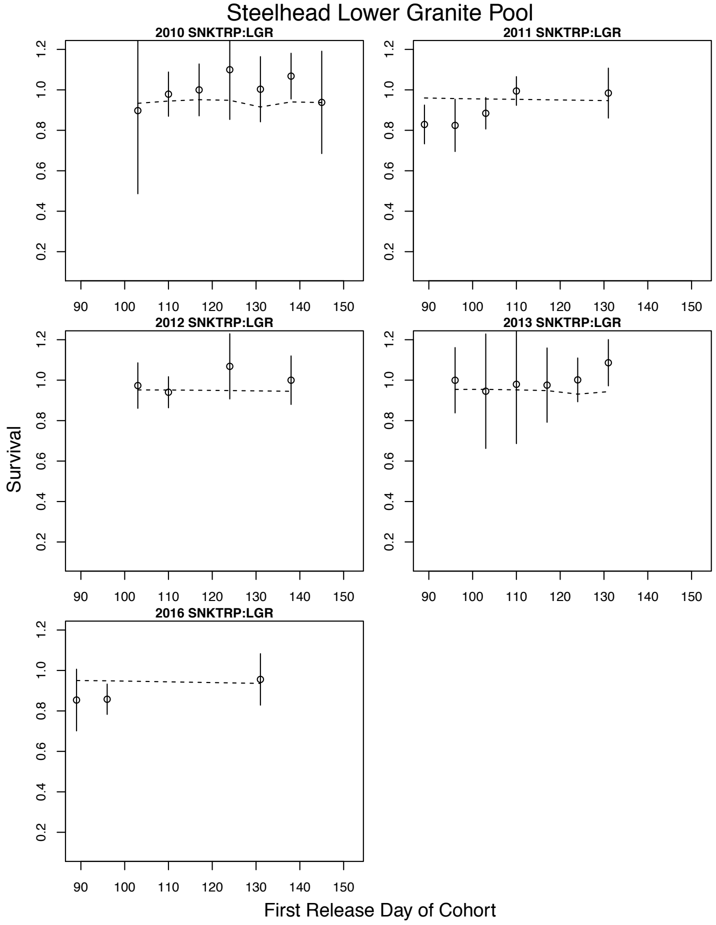

Figure A3-2 26. Survival probabilities for weekly groups of Snake River steelhead from the Snake River Trap to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

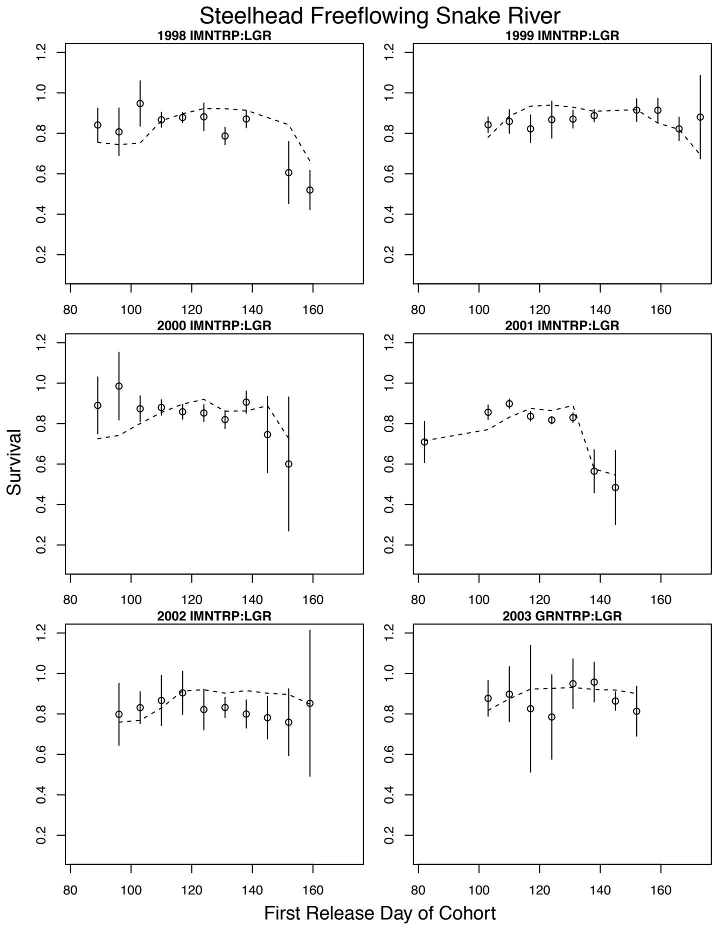

Figure A3-2 27. Survival probabilities for weekly groups of Snake River steelhead from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

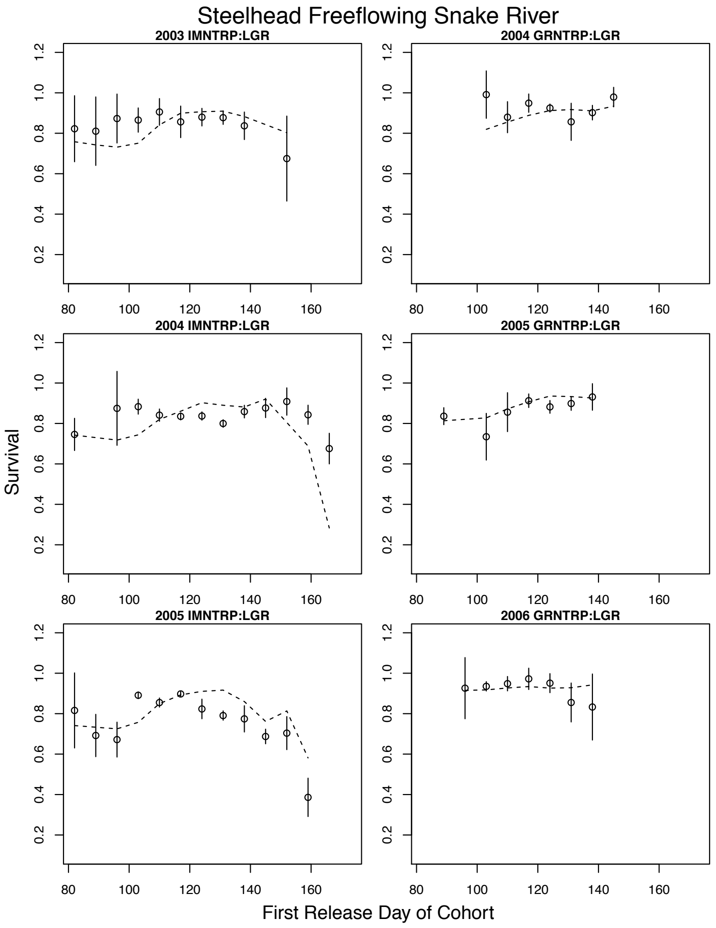

Figure A3-2 28. Survival probabilities for weekly groups of Snake River steelhead from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

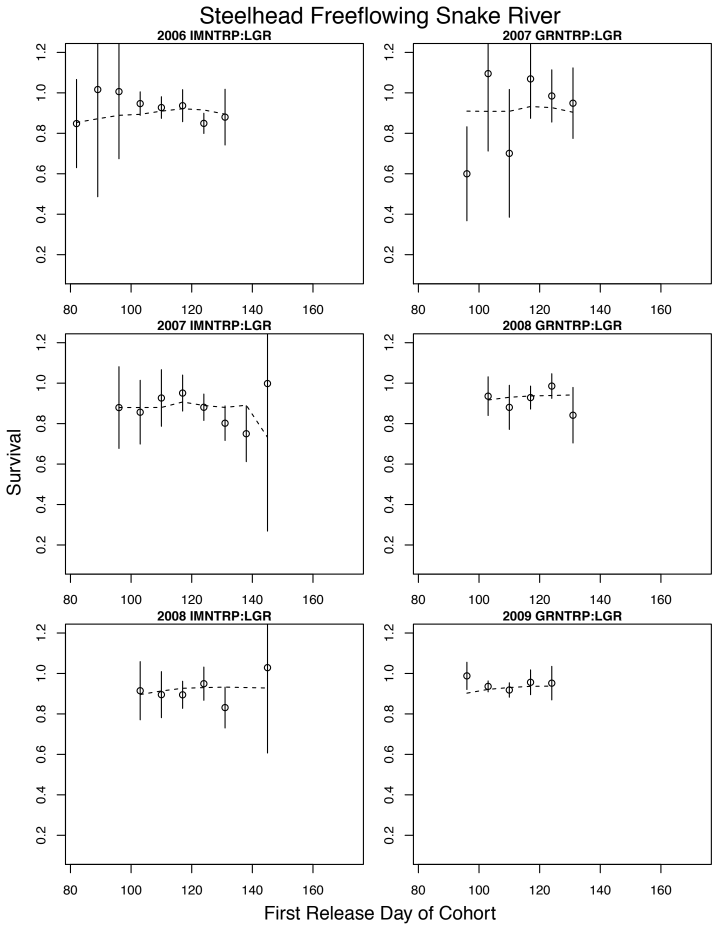

Figure A3-2 29. Survival probabilities for weekly groups of Snake River steelhead from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

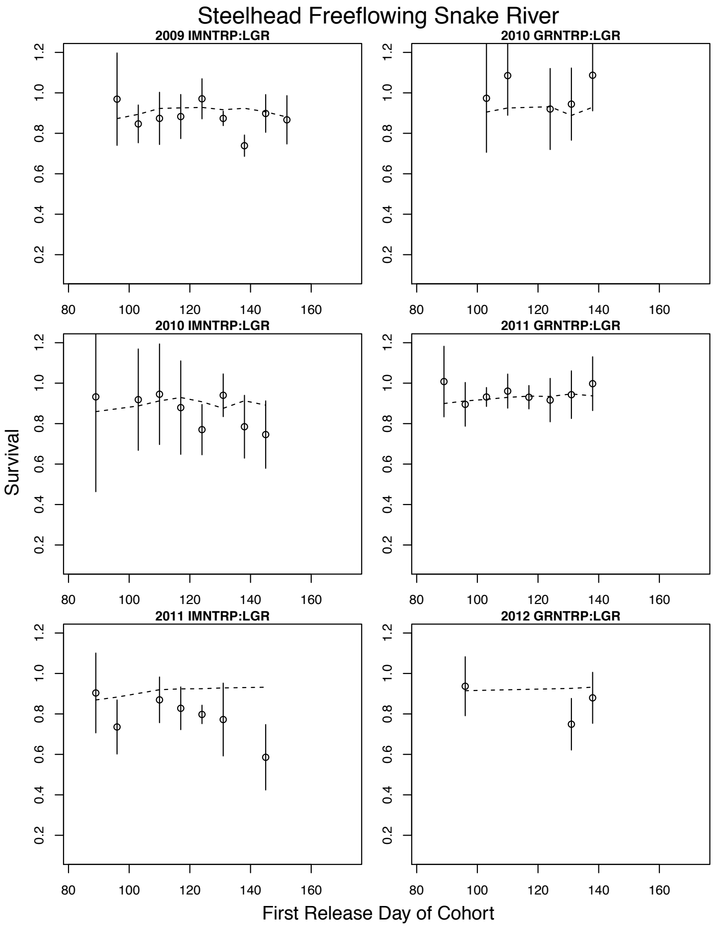

Figure A3-2 30. Survival probabilities for weekly groups of Snake River steelhead from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

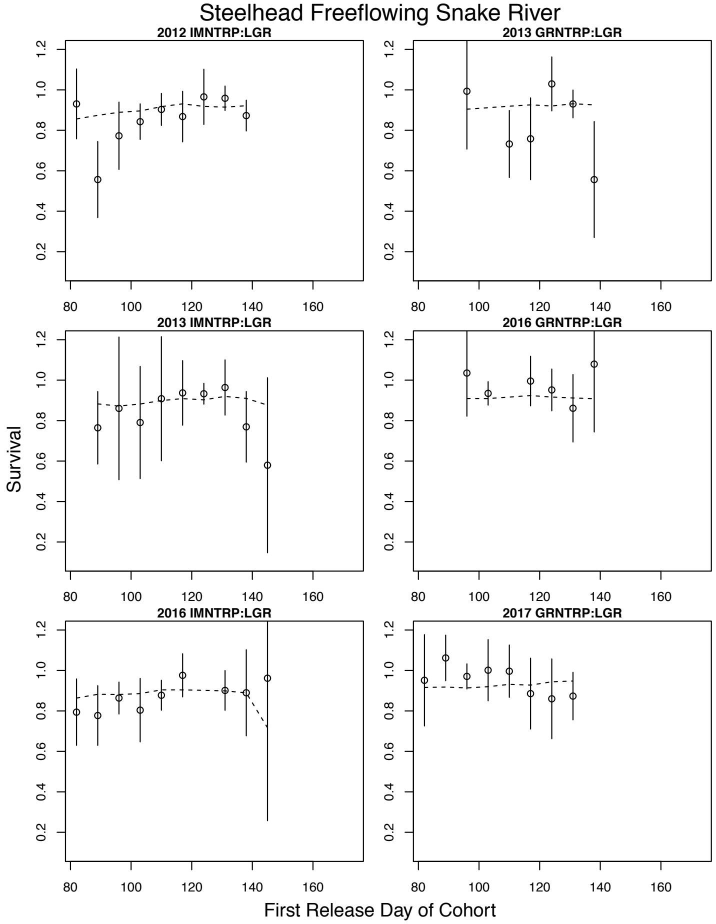

Figure A3-2 31. Survival probabilities for weekly groups of Snake River steelhead from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

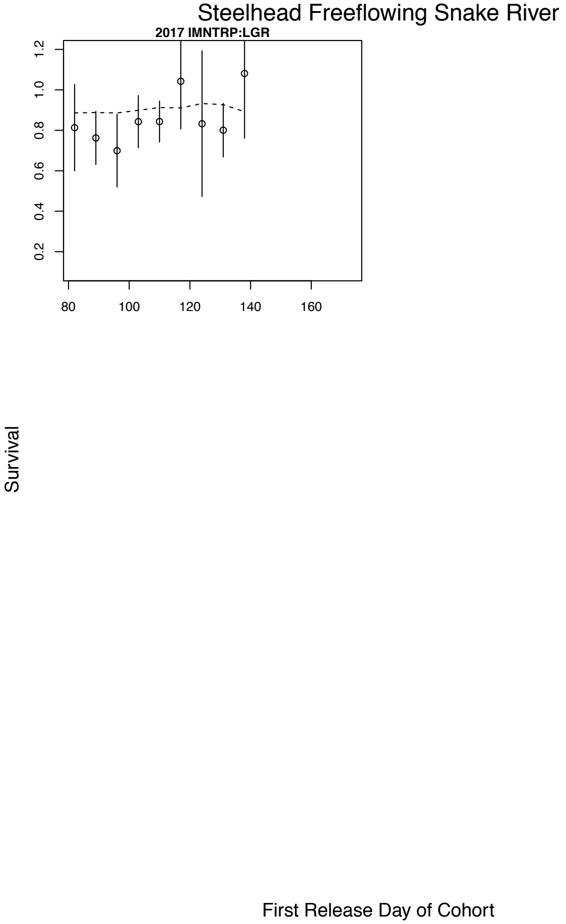

Figure A3-2 32. Survival probabilities for weekly groups of Snake River steelhead from the Grande Ronde River and Imnaha River traps to LGR in various years. The dashed line represent COMPASS model predictions. Points represent PITtag estimate, and the vertical line represent the 95% CI.

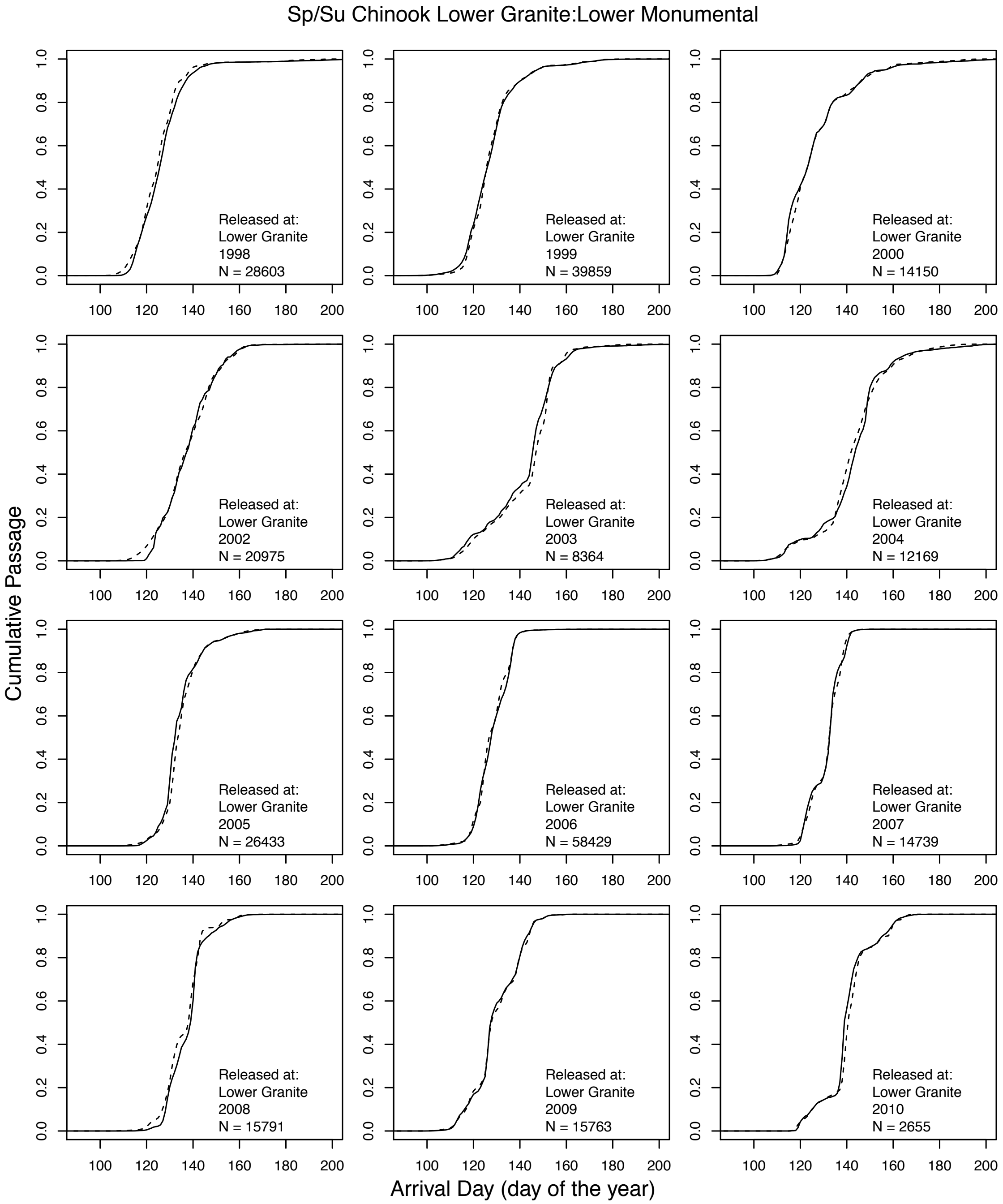

Figure A3-3 1. Predicted (dashed line) versus observed (solid line) passage distribution at Lower Monumental Dam for Snake River spring/summer Chinook grouped at Lower Granite Dam. N refers to the number of observed fish.

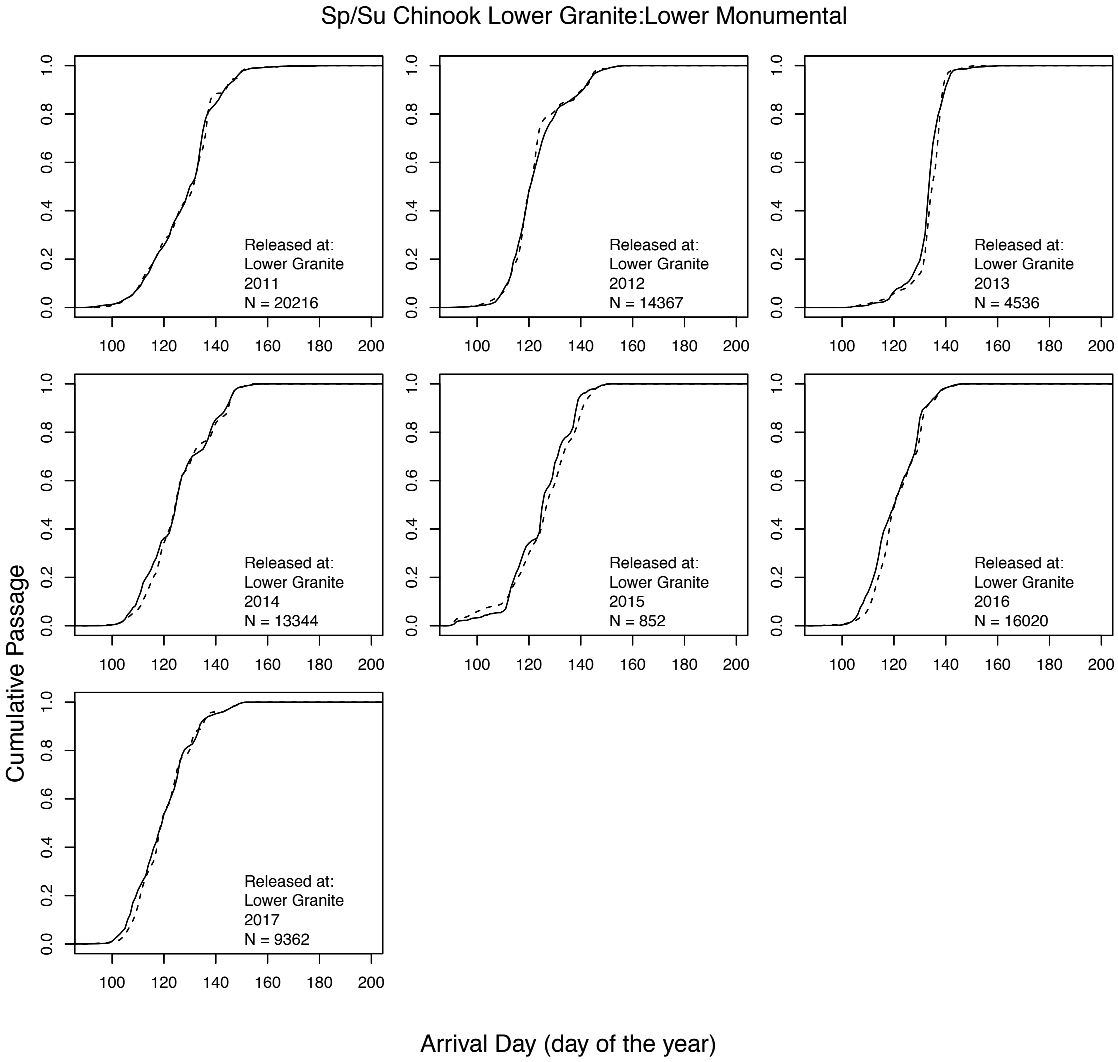

Figure A3-3 2. Predicted (dashed line) versus observed (solid line) passage distribution at Lower Monumental Dam for Snake River spring/summer Chinook grouped at Lower Granite Dam. N refers to the number of observed fish.

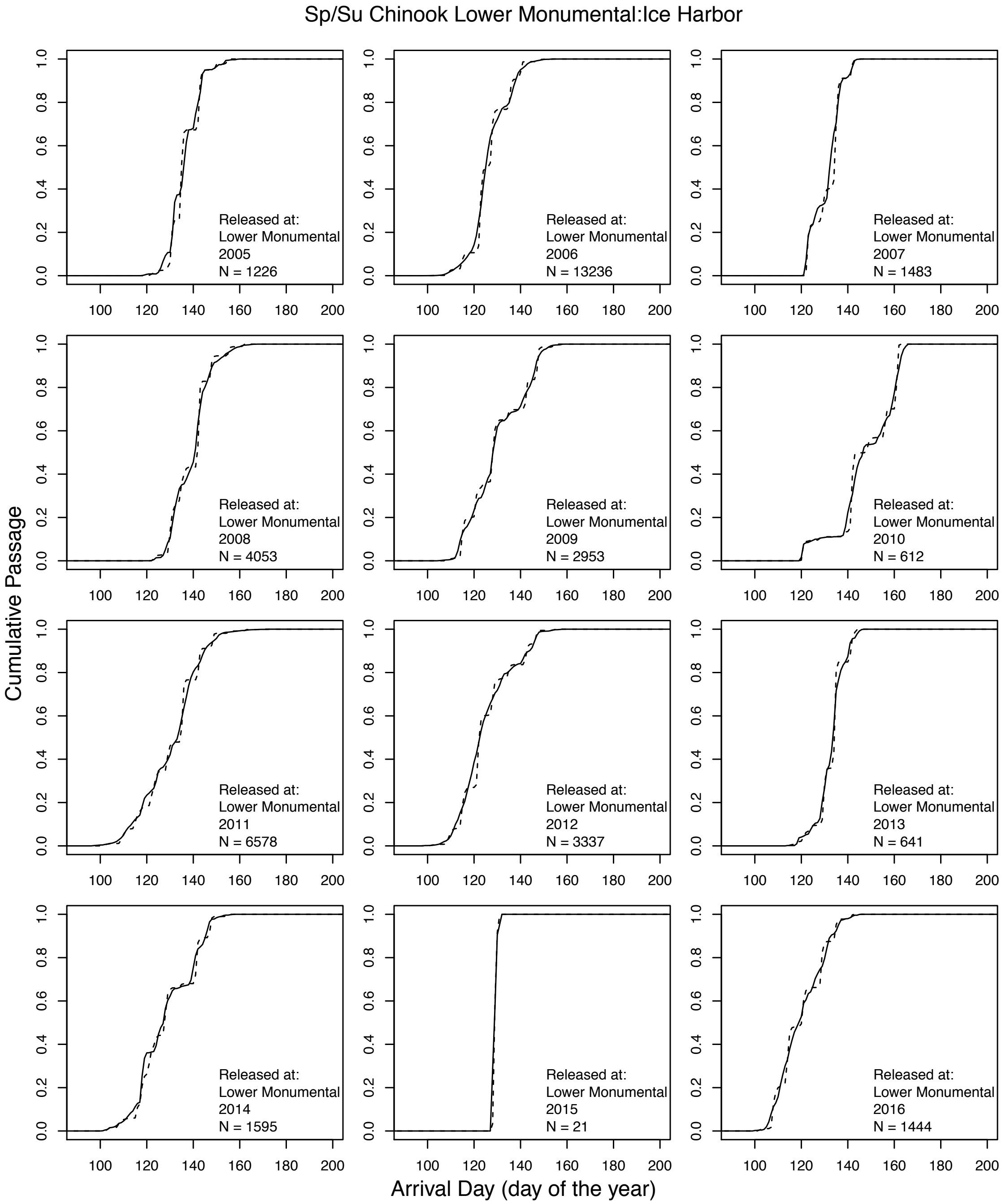

Figure A3-3 3. Predicted (dashed line) versus observed (solid line) passage distribution at Ice Harbor Dam for Snake River spring/summer Chinook grouped at Lower Monumental Dam. N refers to the number of observed fish.

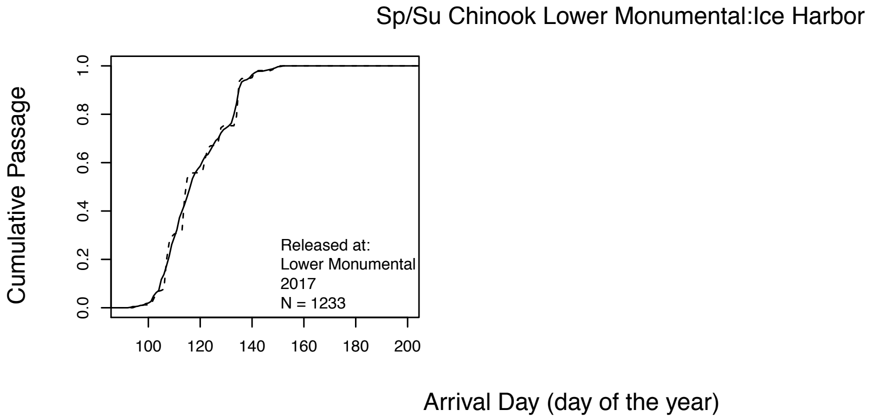

Figure A3-3 4. Predicted (dashed line) versus observed (solid line) passage distribution at Ice Harbor Dam for Snake River spring/summer Chinook grouped at Lower Monumental Dam. N refers to the number of observed fish.

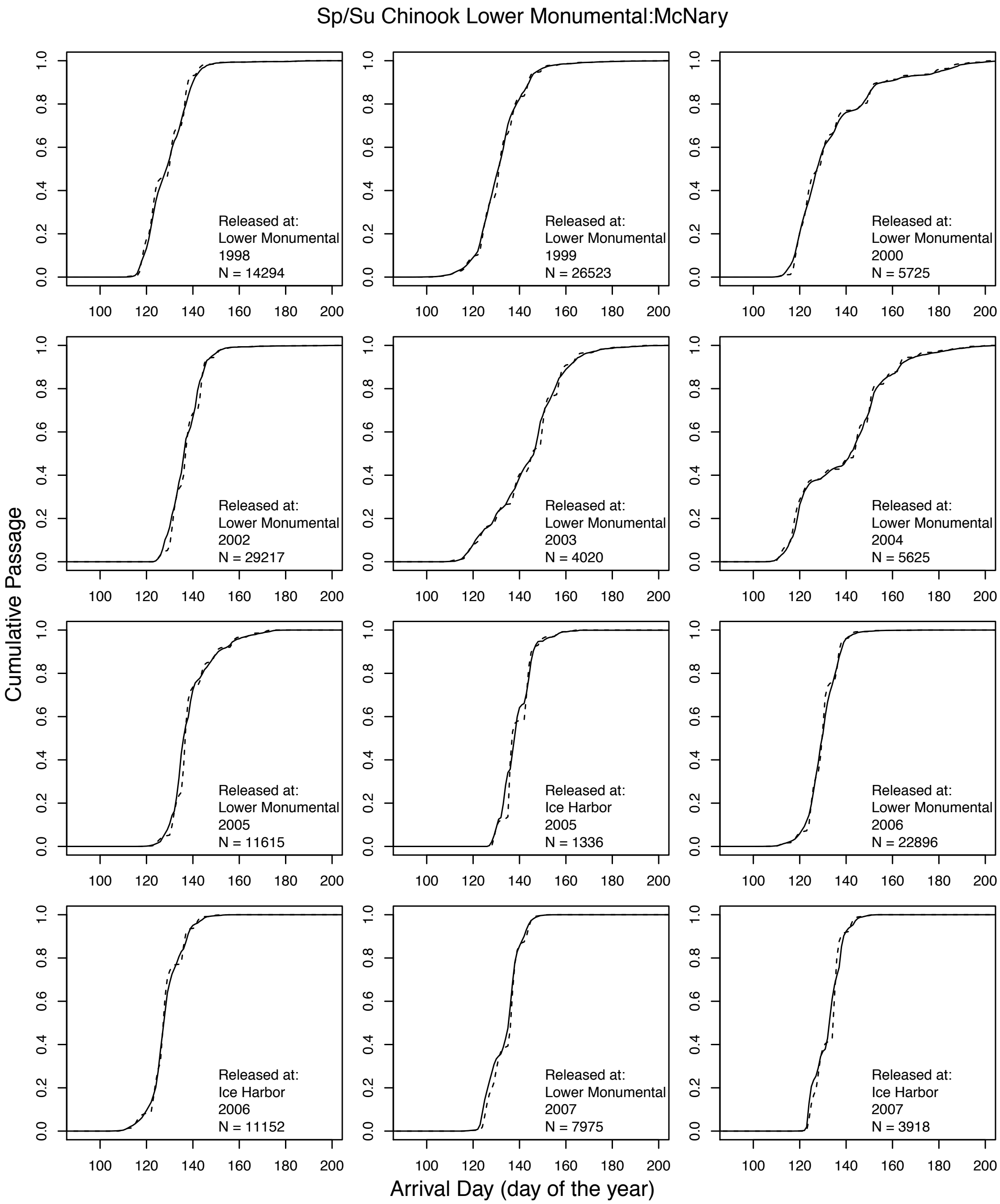

Figure A3-3 5. Predicted (dashed line) versus observed (solid line) passage distribution at McNary Dam for Snake River spring/summer Chinook grouped at either Lower Monumental Dam or Ice Harbor Dam. N refers to the number of observed fish.

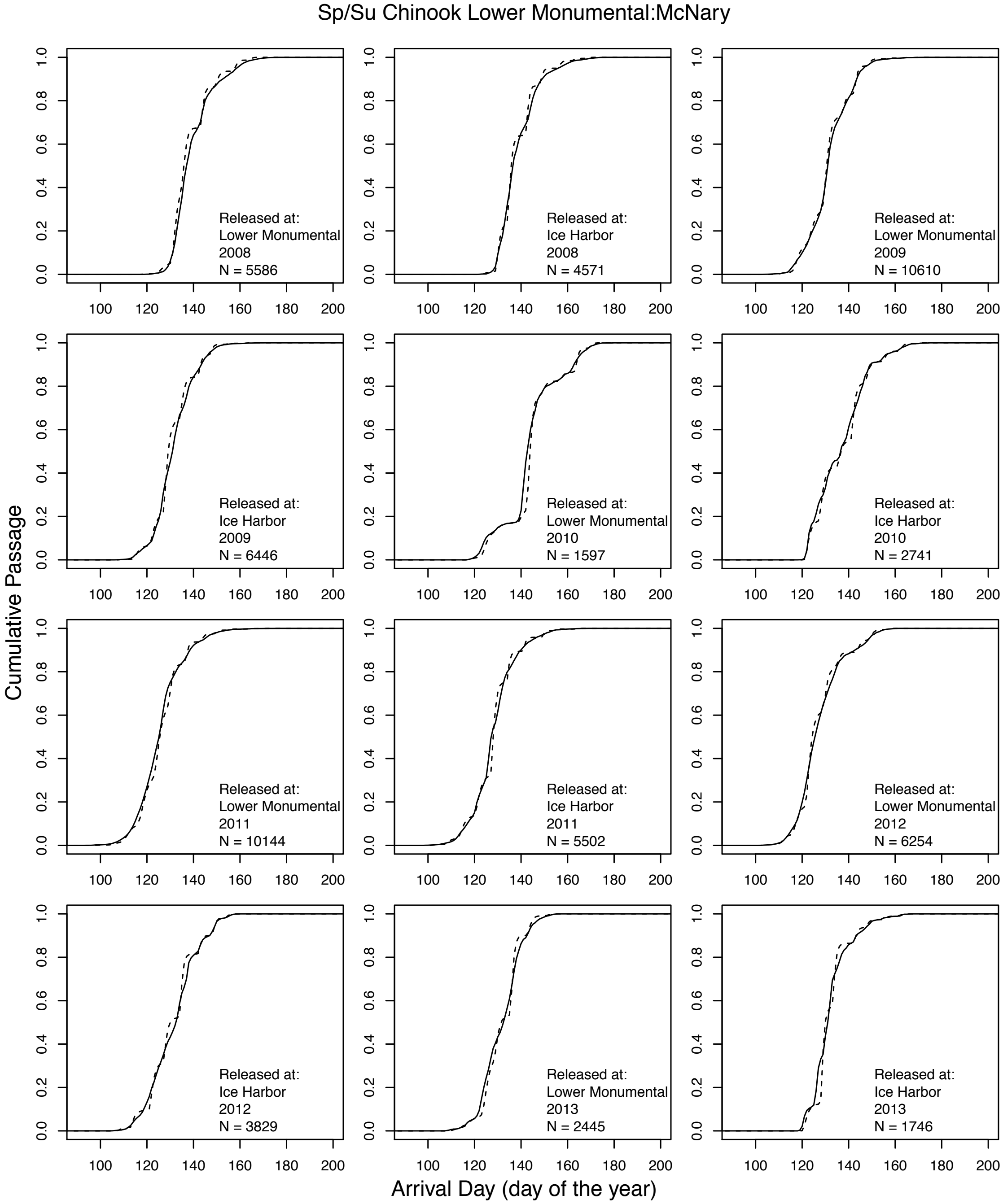

Figure A3-3 6. Predicted (dashed line) versus observed (solid line) passage distribution at McNary Dam for Snake River spring/summer Chinook grouped at either Lower Monumental Dam or Ice Harbor Dam. N refers to the number of observed fish.

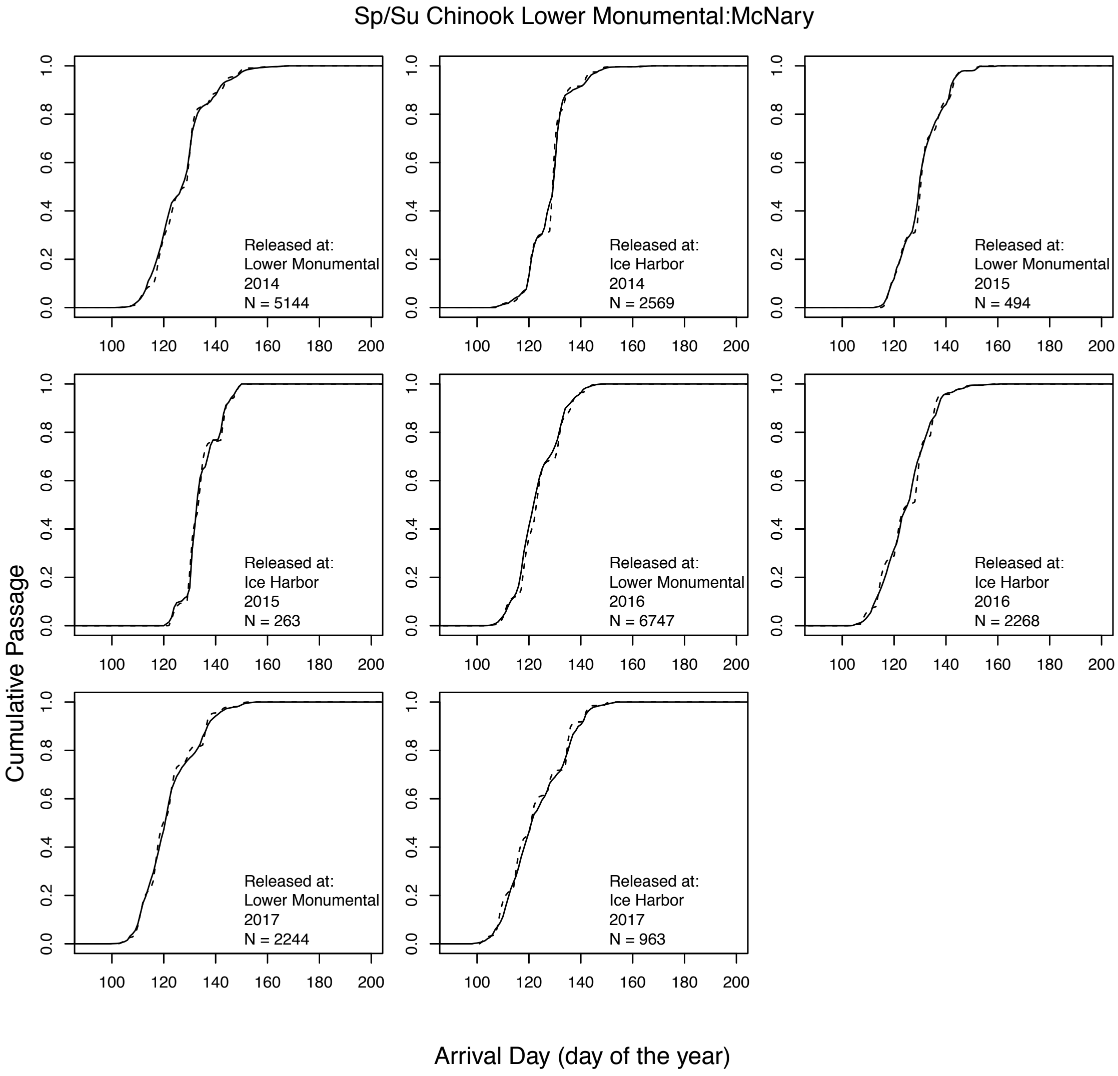

Figure A3-3 7. Predicted (dashed line) versus observed (solid line) passage distribution at McNary Dam for Snake River spring/summer Chinook grouped at either Lower Monumental Dam or Ice Harbor Dam. N refers to the number of observed fish.

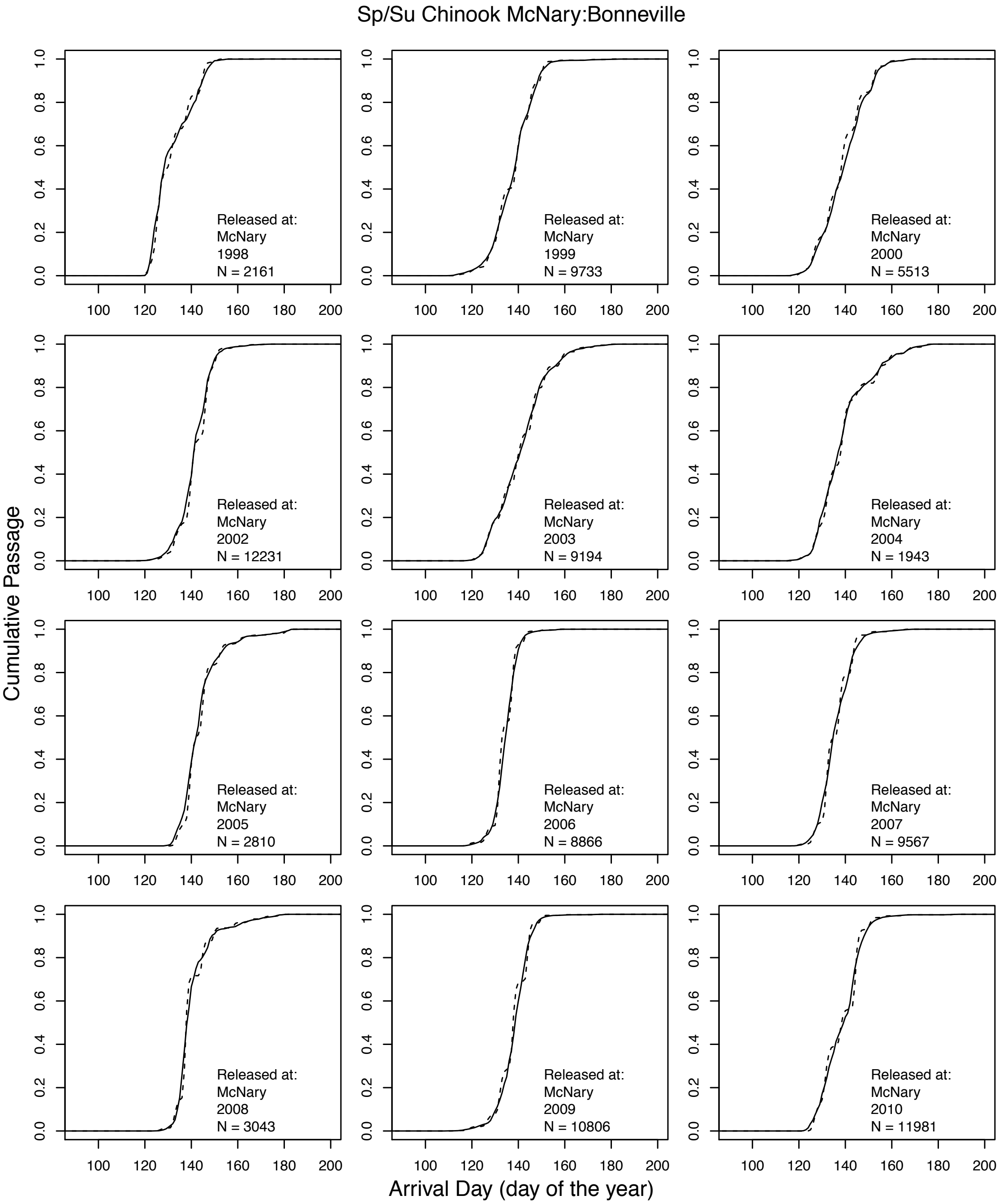

Figure A3-3 8. Predicted (dashed line) versus observed (solid line) passage distribution at Bonneville Dam for Snake River spring/summer Chinook grouped at McNary Dam. N refers to the number of observed fish.

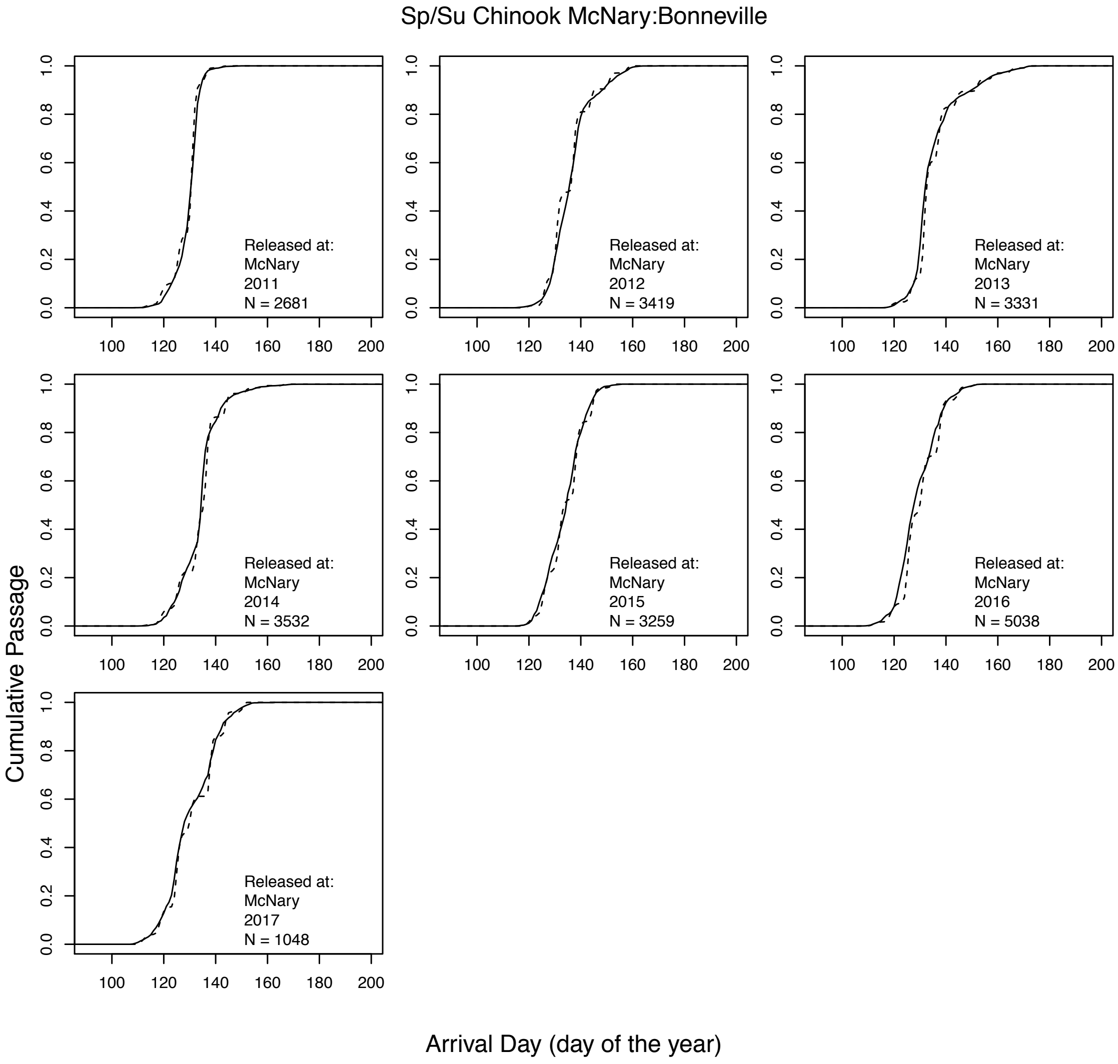

Figure A3-3 9. Predicted (dashed line) versus observed (solid line) passage distribution at Bonneville Dam for Snake River spring/summer Chinook grouped at McNary Dam. N refers to the number of observed fish.

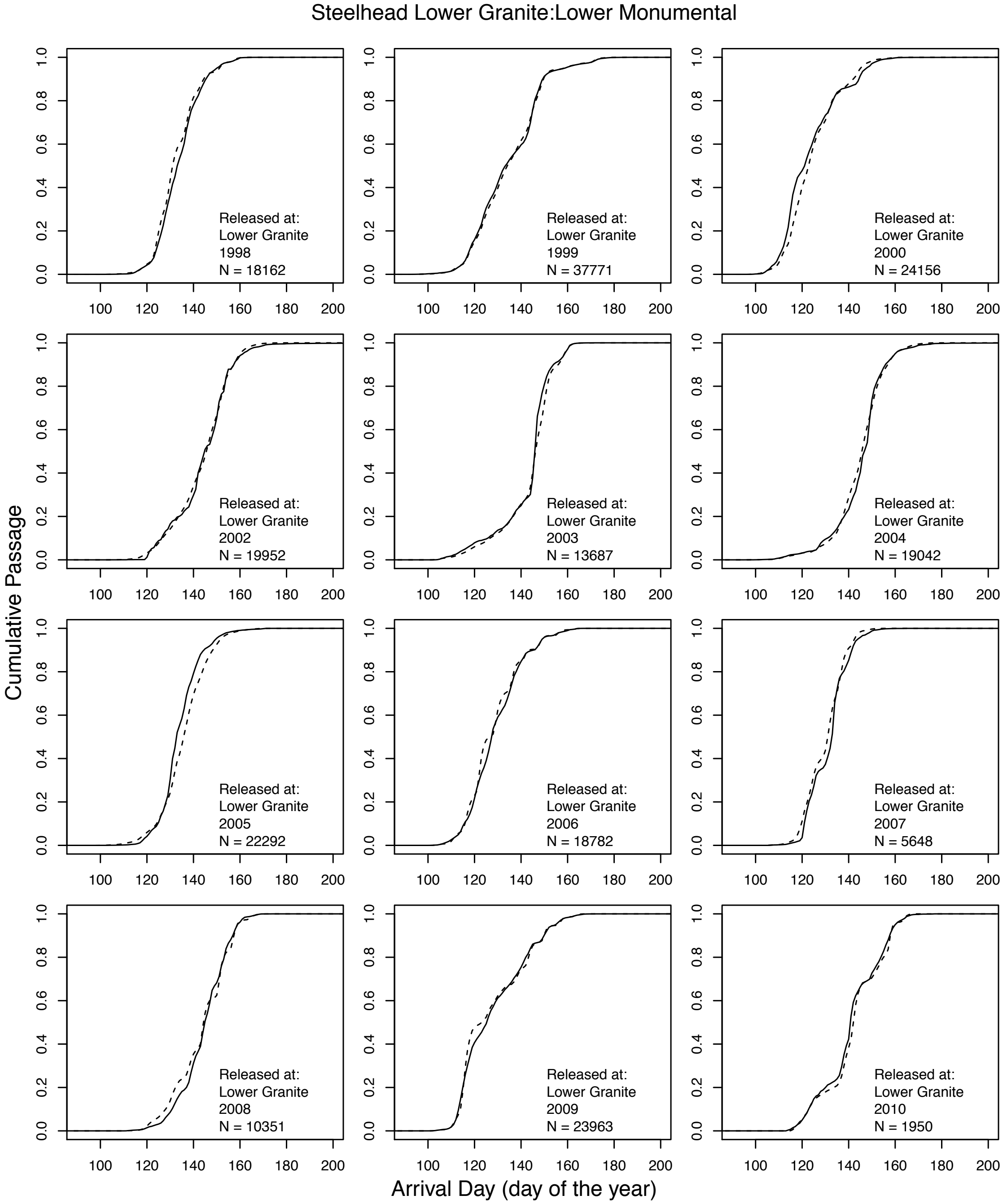

Figure A3-3 10. Predicted (dashed line) versus observed (solid line) passage distribution at Lower Monumental Dam for Snake River steelhead grouped at Lower Granite Dam. N refers to the number of observed fish.

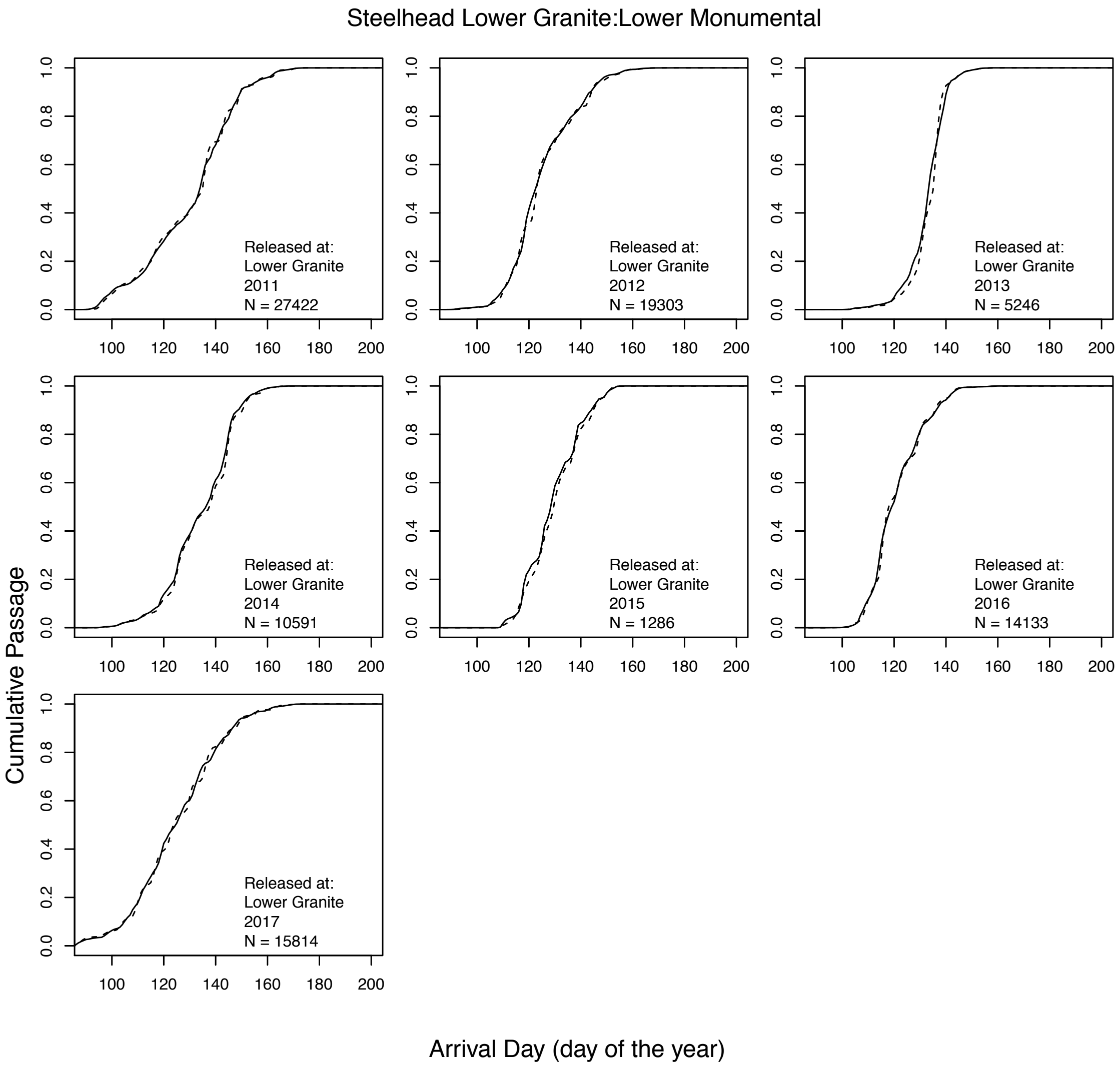

Figure A3-3 11. Predicted (dashed line) versus observed (solid line) passage distribution at Lower Monumental Dam for Snake River steelhead grouped at Lower Granite Dam. N refers to the number of observed fish.

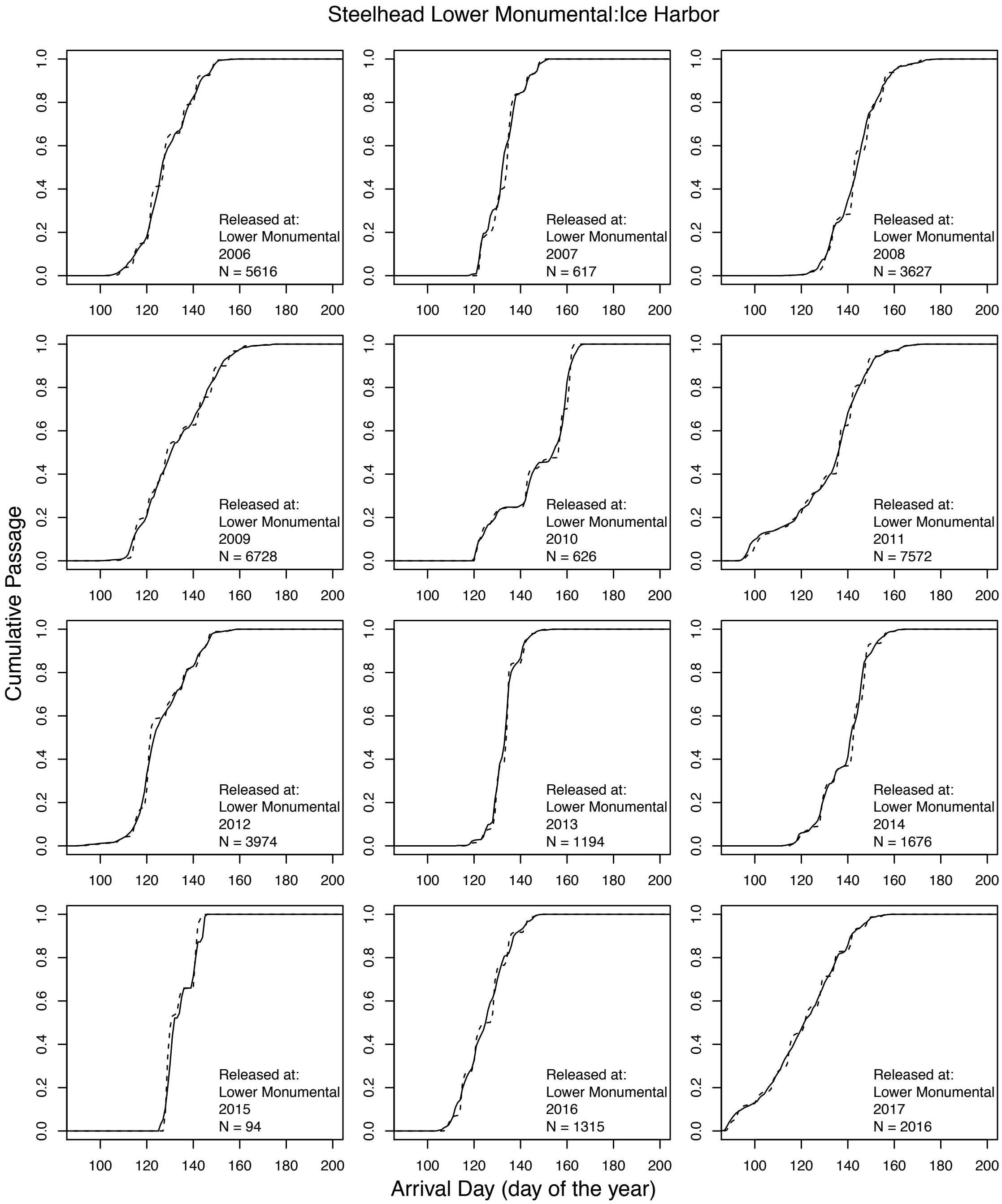

Figure A3-3 12. Predicted (dashed line) versus observed (solid line) passage distribution at Ice Harbor Dam for Snake River steelhead grouped at Lower Monumental Dam. N refers to the number of observed fish.

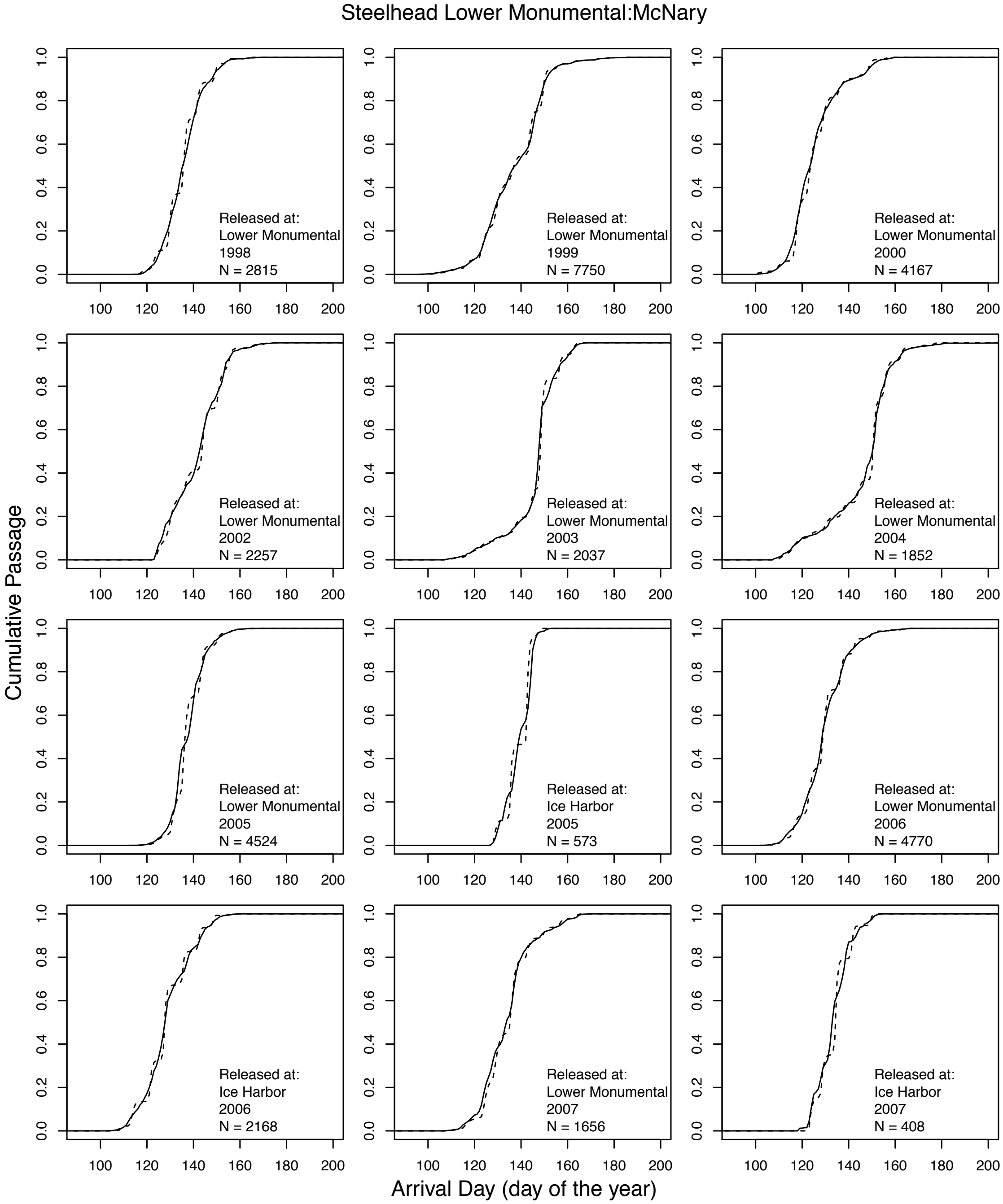

Figure A3-3 13. Predicted (dashed line) versus observed (solid line) passage distribution at McNary Dam for Snake River steelhead grouped at either Lower Monumental Dam or Ice Harbor Dam. N refers to the number of observed fish.

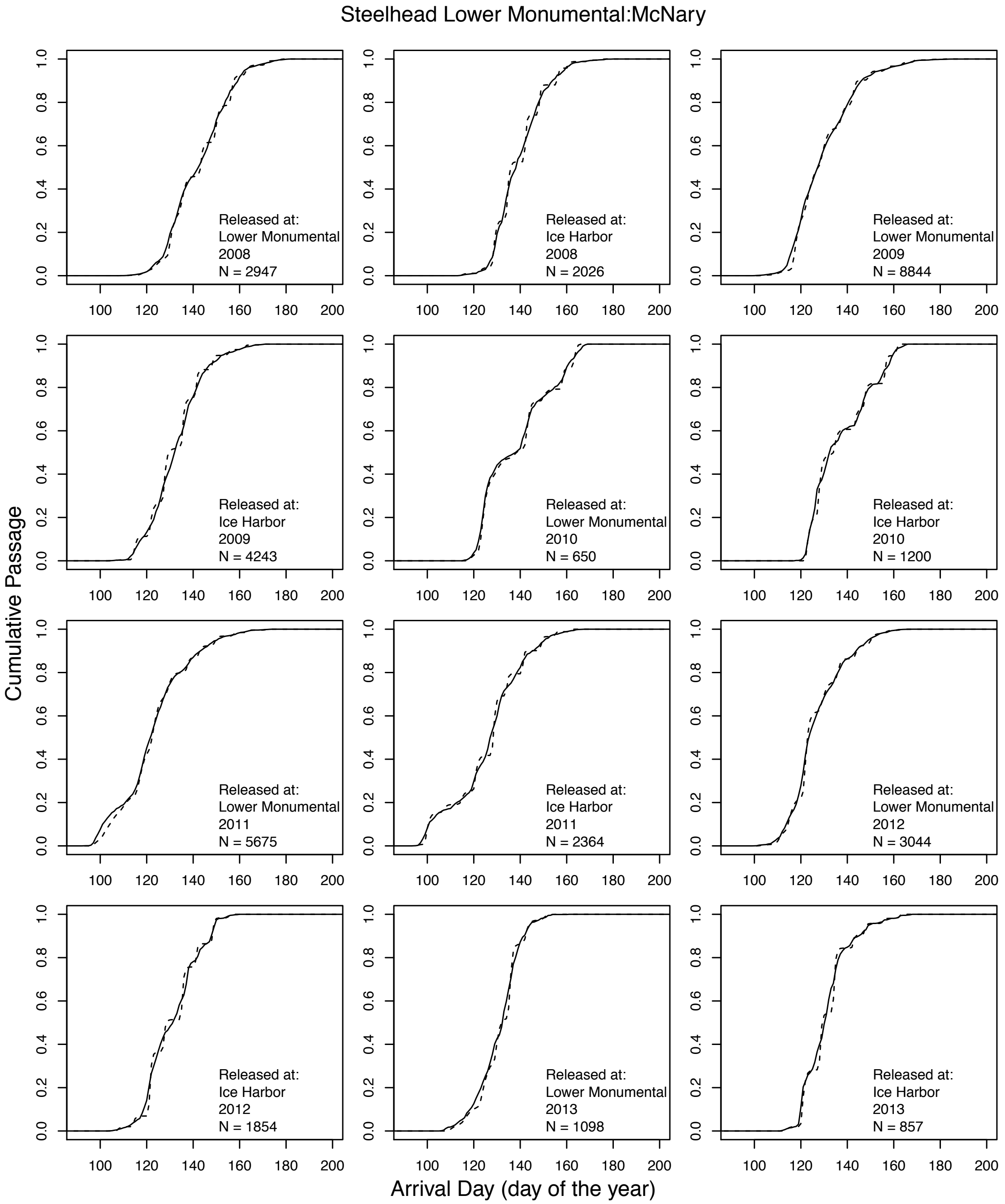

Figure A3-3 14. Predicted (dashed line) versus observed (solid line) passage distribution at McNary Dam for Snake River steelhead grouped at either Lower Monumental Dam or Ice Harbor Dam. N refers to the number of observed fish.

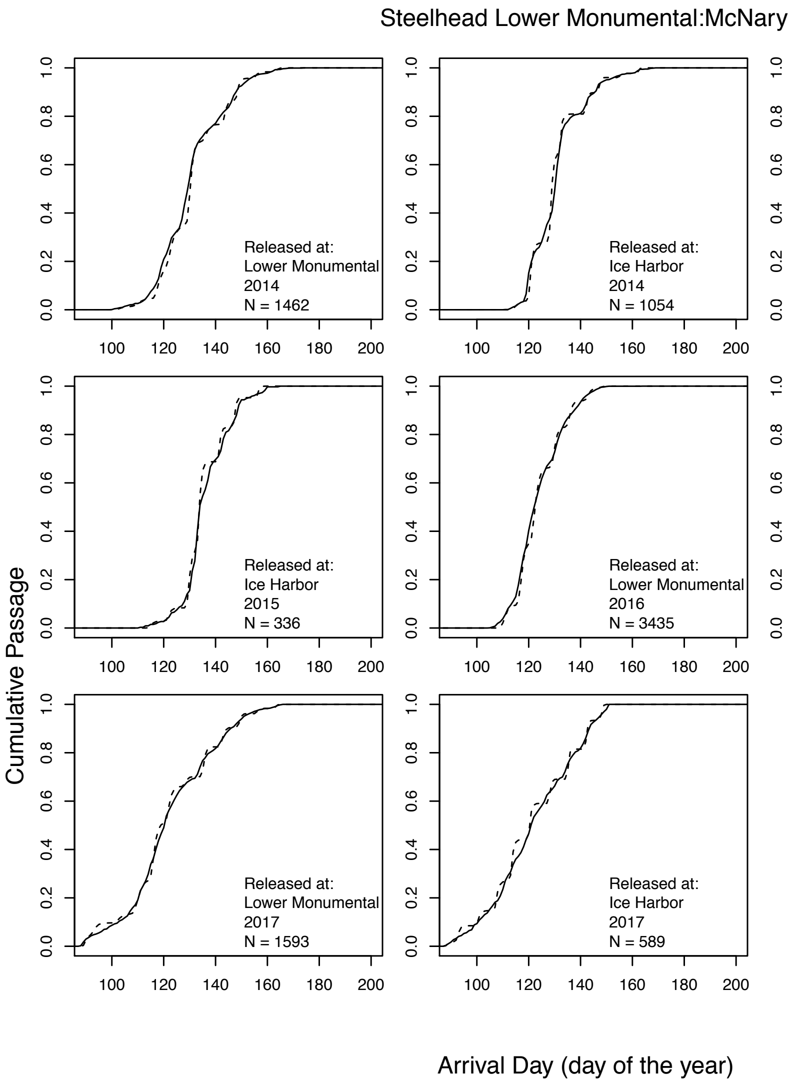

Figure A3-3 15. Predicted (dashed line) versus observed (solid line) passage distribution at McNary Dam for Snake River steelhead grouped at either Lower Monumental Dam or Ice Harbor Dam. N refers to the number of observed fish.

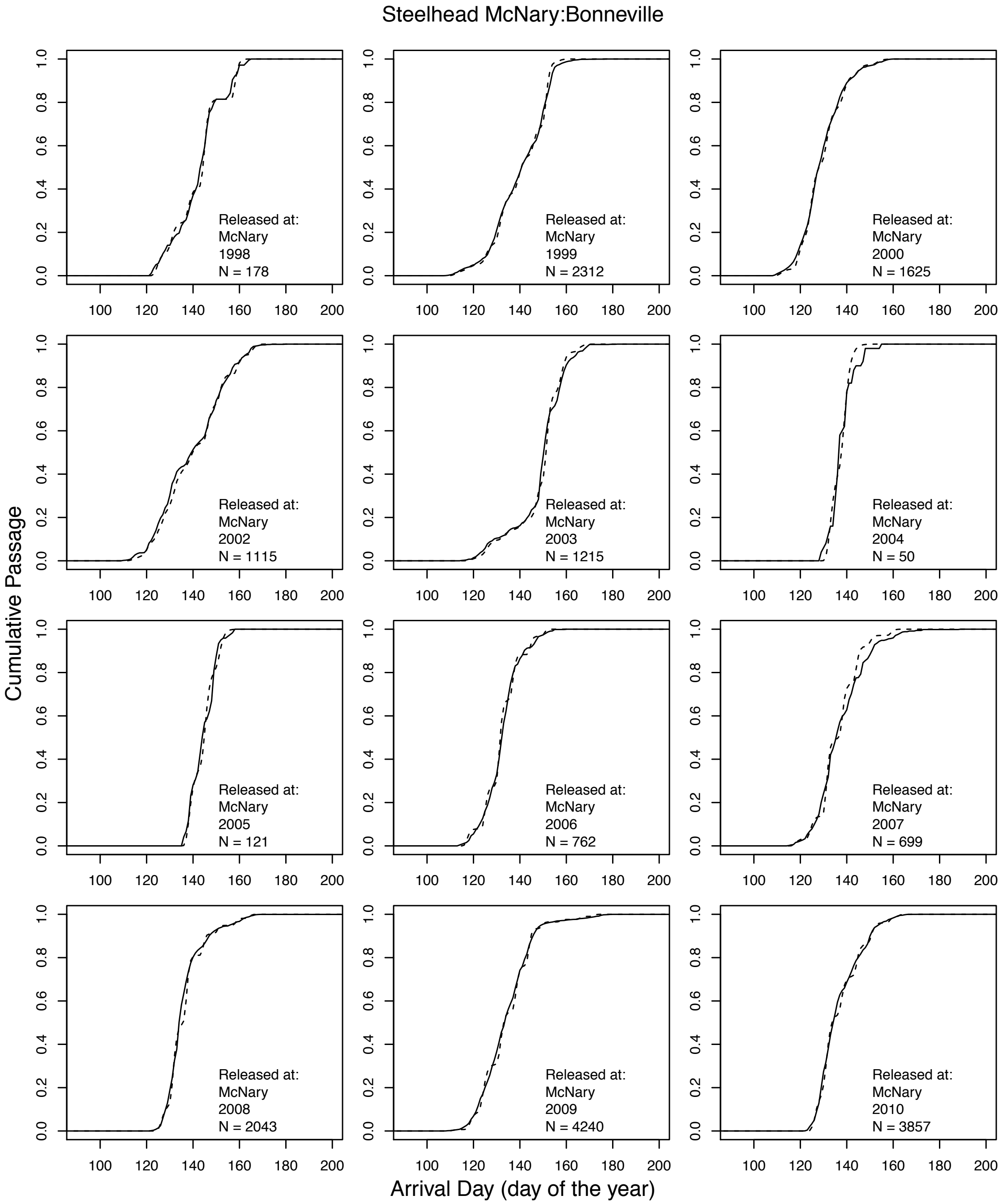

Figure A3-3 16. Predicted (dashed line) versus observed (solid line) passage distribution at Bonneville Dam for Snake River steelhead grouped at McNary Dam. N refers to the number of observed fish.

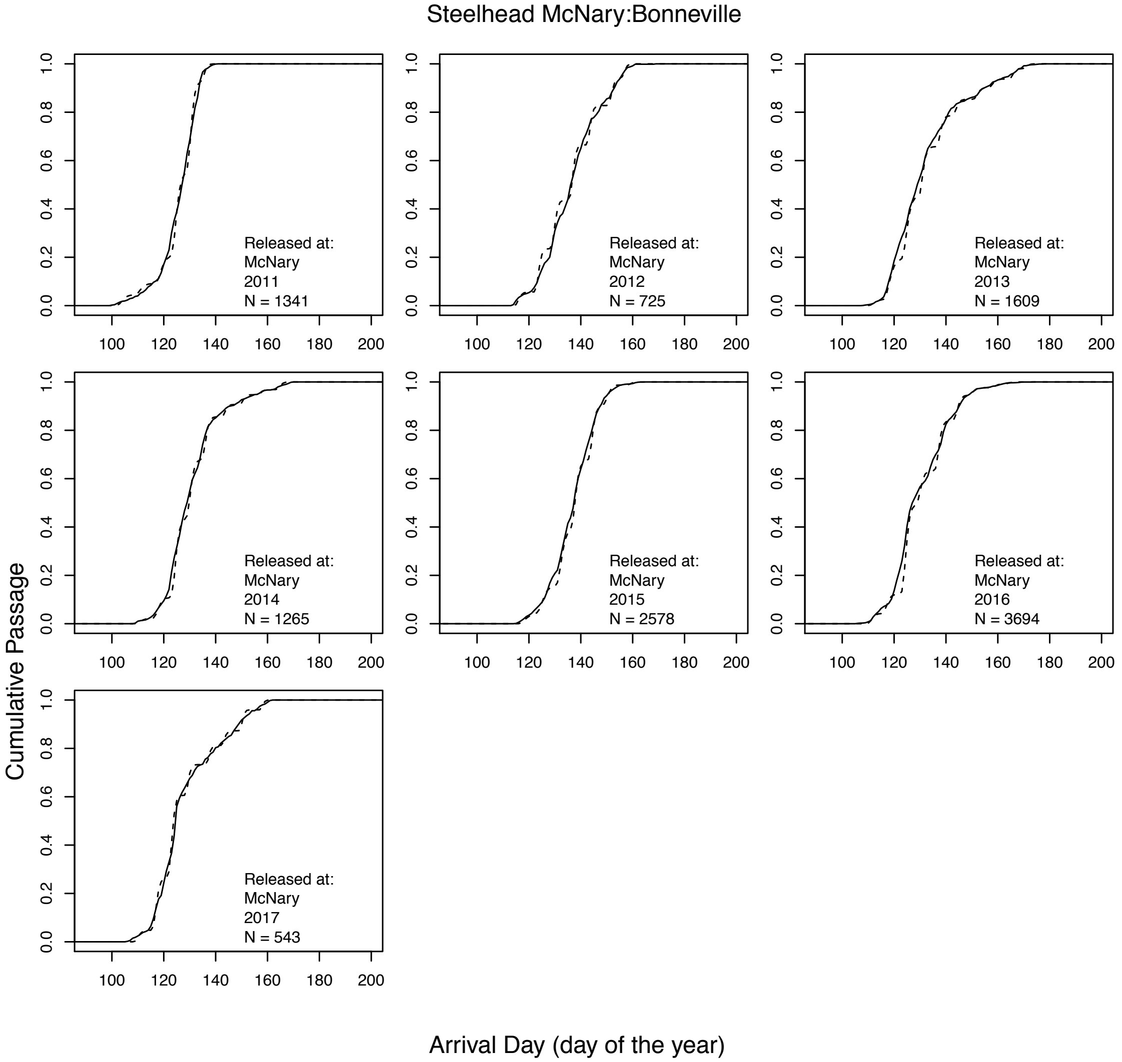

Figure A3-3 17. Predicted (dashed line) versus observed (solid line) passage distribution at Bonneville Dam for Snake River steelhead grouped at McNary Dam. N refers to the number of observed fish.

Introduction

The COMPASS model simulates passage, and survival of migrating salmonids. To accurately estimate survival related to dam passage, it is necessary to accurately estimate the proportion of fish passing through each major passage route. Whether fish pass through the spillway, turbine, juvenile bypass system or surface passage outlet can greatly influence their probability of survival. In addition, fish entering the bypass system at some dams are collected and placed into barges for transport downstream past the downstream dams, which also influences their probability of survival. Clearly, estimating the routes by which fish pass dams is integral to the estimation of survival.

This appendix addresses the modeling of passage probabilities known as spill passage efficiency (SPE) and fish guidance efficiency (FGE). SPE is the probability of passing a dam via the spillway under a given set of conditions, the main condition being proportion of water passing the spillway. FGE is the conditional probability of a fish being guided into a juvenile bypass system given it has entered the powerhouse. If SPE and FGE relationships can be estimated with some confidence, it is possible to predict the proportions of fish passing through the spillways, turbines, and juvenile bypass routes at a dam. We also address the conditional probability of passing through a removable spillway weir (RSW) given passage over a spillway. Passage through sluiceways is not addressed in the appendix.

The modeling of route-specific passage probabilities for COMPASS has evolved over the course of model development. The availability of new data and the proposal different approaches to analyzing the data allowed us to improve predictions at some sites. However, not all dams are equal in the type, quantity, or quality of data available, so uniform methods could not be applied to all dams. The end result draws upon a combination of data sets and modeling approaches to achieve the best result for each dam. The end product is best understood following a description of the data and analyses methods used along the way and a brief description of reasoning for adopting the final combination of approaches.

The first section of this appendix provides a set of tables with parameter values used in COMPASS for these models. This is followed by the methods used to fit the models to data for each different data type.

Current Models used in COMPASS

The set of models and parameters currently used in COMPASS is a combination of results from a mixture of methods. The determination of which approach is used is determined primarily by the availability of PIT tag detection or usable RT data. For Bonneville (BON) and The Dalles (TDA) we are using the FGE estimates from Table A4

4 and the original set of SPE parameters from Table A4 1. At Ice Harbor we are using the original FGE estimates from Table A4 4 and the SPE parameters from the individual RT data shown in Table A4 1. At LGR, LGS, LMN, MCN, and JDA we are using FGE and SPE models and parameter estimates from the PIT tag analyses, which are shown in Tables A4 1,3. We are using the conditional RSW passage model parameters for IHR and LGR from fits to the individual RT data shown in Table A4 2.

We used a combination of models and estimates taken directly from data for FGE. See sections on PIT and RT models for descriptions of model forms. We did not fit FGE models for Chinook salmon at Bonneville or The Dalles dam, nor for steelhead at Bonneville, The Dalles, or John Day dam. At those sites we used point estimates of FGE. The FGE estimates used were taken from a variety of studies performed at each dam over multiple years (see Table A4 4). A working group was created to review each study and compile estimates in a way that best represented the conditions and operations at each dam for chinook and steelhead between 1998 and 2017. These were the best available estimates of FGE from radio and acoustic tag studies. As one might expect, the coverage of years with available studies was not the same for each dam and species. This dictates that substitutions must be made between species when data are lacking, and that single estimates must be applied to multiple years at some dams.

Table A4 1. Spill efficiency model parameter estimates by dam and species (CH1 = Sp/Su Chinook, STHD = Steelhead). Data types are radio-telemetry (RT), pooled radio-telemetry (RT-p), and PIT tags (PIT). Also shown are the transformation method (logit or probit) used for the linear predictor and for t(% spill). The values in the columns (Intercept, t(% Spill), Flow, t(% Spill) * Flow, RSWon Intercept, and RSWon * Flow) are parameter estimates for associated model terms.

Species	Dam	Data Type	Transform	Intercept	t(% Spill)	Flow	t(% Spill) * Flow	RSWon Intercept	RSWon * Flow
CH1	BON	RT-p	Logit	0.139	1.005	0	0	0	0
	TDA	RT-p	Logit	1.046	0.992	0	0	0	0
	JDA	PIT	Probit	2.249	0.620	-0.00303	0.00429	0	0
	MCN	PIT	Probit	0.595	1.730	0	0	0	0
	IHR	RT	Probit	1.442	0.859	-0.00270	0	0.238	-0.00364
	LMN	PIT	Probit	1.738	0.455	-0.00763	0.00530	0.137	0
	LGS	PIT	Probit	1.178	0.346	-0.00340	0.00948	0	0
	LGR	PIT	Probit	0.950	0.917	-0.00038	0.00319	0.341	-0.00346
STHD	BON	RT-p	Logit	0.040	1.007	0	0	0	0
	TDA	RT-p	Logit	1.304	0.992	0	0	0	0
	JDA	PIT	Probit	2.254	0.590	-0.00506	0	0.422	0
	MCN	PIT	Probit	1.679	1.798	-0.00272	0	0.112	0
	IHR	RT	Probit	2.188	0.146	-0.01170	0.00603	-0.772	0.00721
	LMN	PIT	Probit	1.519	0.350	-0.00959	0.00753	0.506	0
	LGS	PIT	Probit	1.022	0.069	-0.00383	0.01180	0.202	0
	LGR	PIT	Probit	0.424	0.099	0.00133	0.00971	1.043	-0.00588

Table A4 2. Conditional RSW passage efficiency model parameter estimates by dam and species (CH1 = Sp/Su Chinook, STHD = Steelhead) and the transform used.

Species	Dam	Transform	Intercept	t(%RSW spill)
CH1	JDA	Logit	1.872	0.771
	MCN	Logit	1.872	0.771
	IHR	Logit	0.642	0.775
	LMN	Logit	1.879	1.623
	LGS	Logit	1.879	1.623
	LGR	Logit	1.879	1.623
STHD	IHR	Logit	2.110	0.771
	MCN	Logit	2.110	0.771
	IHR	Logit	1.231	0.771
	LMN	Logit	2.110	0.771
	LGS	Logit	2.110	0.771
	LGR	Logit	2.110	0.771

Table A4 3. Fish guidance efficiency (FGE) model parameter estimates by dam and species (CH1 = Sp/Su Chinook, STH = Steelhead) and the transform used. Estimates from data are used instead of equations for Steelhead at JDA and both species at BON PH1 and BON PH2 (see Table A4 4). There is no juvenile bypass system at The Dalles Dam.

Species	Dam	Data Type	Transform	Intercept	PH Flow	Median Day	Temperature
CH1	JDA	PIT	Probit	0.375	0	0	0
	MCN	PIT	Probit	2.680	0	0	-0.1390
	IHR	RT	Probit	1.886	0.00868	0	-0.1540
	LMN	PIT	Probit	1.183	0	0	-0.0467
	LGS	PIT	Probit	1.279	0	0	-0.0297
	LGR	PIT	Probit	1.534	0	0	-0.0571
STHD	MCN	PIT	Probit	2.781	0	0	-0.1370
	IHR	RT	Probit	2.715	0	0	-0.1060
	LMN	PIT	Probit	3.106	0	0	-0.1710
	LGS	PIT	Probit	2.546	0	0	-0.1580
	LGR	PIT	Probit	0.983	0.00783	0	0

Table A4 4. Point estimates of fish guidance efficiency (FGE) for Spring/Summer Snake River Chinook (CH1) and Snake River Steelhead (STH) by dam and year for retrospective years (1997-2017). Only included here are estimates that are directly used for historic years in COMPASS; we used estimates of FGE at other sites to fit models (presented in Table A4 3). There is no juvenile bypass system at The Dalles Dam, so no estimates of FGE are provided there. The guidance screens were not used at the Bonneville Powerhouse 1 (BON1) after 2003, so FGE there is zero during that period.

Species	**Dam**	**Years**	**FGE Estimate**
CH1	BON PH1	1998-1999	0.38[1]
		2000	0.5[2]
		2001	0.45[3]
		2002	0.5[2]
		2003	0.38[1]
		2004-2017	0
	BON PH2	1998-1999	0.44[1]
		2000	0.39[2]
		2001	0.46[3]
		2002	0.37[4]
		2003	0.505[5]
		2004	0.33[6]
		2005-2008	0.35[7]
		2009	0.33[8]
		2010	0.29[9]
		2011-2017	0.35[10]
STHD	BON PH1	1998-1999	0.41[1]
		2000	0.59[2]
		2001	0.5[3]
		2002	0.75[4]
		2003	0.41[1]
		2004-2017	0
	BON PH2	1998-1999	0.48[1]
		2000	0.55[2]
		2001	0.55[3]
		2002	0.59[4]
		2003	0.505[5]
		2004	0.4[6]
		2005-2007	0.505[5]
		2008	0.36[7]
		2009	0.34[8]
		2010	0.257[9]
		2011-2017	0.383[10]
	JDA	1998-2007	0.76
		2008-2009	0.89[11,12]
		2010	0.839[13]

Species	Dam	Years	FGE Estimate
	JDA	2011	0.892[14]
		2012-2017	0.866

1. Ferguson et al. 2005.
2. Evans et al. 2001a. Report for 2000 RT research.
3. Evans et al. 2001b. Report for 2001 RT research.
4. Evans et al. 2003. Report for 2002 RT research (season ave.).
5. Based on expert opinion.
6. Reagan et al. 2005. Report for 2004 RT research.
7. Faber et al. 2010. Report for 2008 research.
8. Faber et al. 2011. Report for 2009 research.
9. Ploskey et al. 2011. Report for 2010 research.
10. Ploskey et al. 2012. Report for 2011 research.
11. Weiland et al. 2009. Report for 2008 research.
12. Weiland et al. 2011. Report for 2009 research.
13. Weiland et al. 2013a. Report for 2010 research.
14. Weiland et al. 2013b. Report for 2011 research.

Modeling SPE with Pooled Data from Radio-Tagged Fish

For The Dalles and Bonneville Dams, SPE models were based on data points that were summaries of data from various RT studies. The data were pooled from various studies within set levels of spill. The binning of spill levels depended on the amount of data and the conditions of the studies. Simple regressions of the logit transformed proportion of fish passing on the logit of spill proportion were performed separately by species and dam as the available data permitted. Here the logit(x) = ln(x/(1-x)). This “logit-logit” model produces relationship between proportion of fish spilled and proportion of water spilled that naturally passes through (0,0) and (1,1). The parameter estimates resulting from those fits are shown in Table A4 1. The approach was used for these sites due to limited available data.

Modeling SPE and FGE with Individual Radio-Tagged Fish

We used this approach for modeling SPE and FGE at IHR and for modeling conditional RSW passage at LGR and IHR.

Methods

To develop spill passage efficiency relationships, it is first necessary to identify and acquire suitable passage data. Passage events must then be associated with dam operations data. Relationships can then be developed by fitting curves to passage and spill data. Similar techniques are applied to develop RSW passage efficiency relationships to determine what proportion of spill passage occurs through the RSW. Work to date by USGS and NOAA has been funded by the Walla Walla District of the Corps of Engineers focused on the Snake River Dams and McNary Dam. These techniques are applicable to any project where passage and operations data are available.

Passage Events

A passage event represents the passage of an individual radio-tagged fish. The species (and run), route of passage, and time of passage must be known for each event. Dam operations data must also be available for the time of passage to allow for further analysis. For spill analysis, each event is assigned a 1 if passage is through a spillway route (including RSWs), or a 0 if passage is through non-spill routes. For analysis of RSW passage as a fraction of spill passage, events that were assigned a 1 for spill passage are assigned an additional 1 if passage was through the RSW or a 0 if passage was through a normal spill bay. For FGE models, the data were subset to the set of fish passing through the powerhouse (turbine or bypass), and those passing through bypass were assigned a 1 and those through turbine a 0.

Data

Numerous radio telemetry studies have been conducted at the dams of interest. The researchers expended considerable effort to provide data in a form that was usable for developing passage events. Most data were collected in studies performed by USGS or NMFS for the Walla Walla District of the Corps of Engineers. Tables A4 5 and A4 6 show the data that were available for analysis. Note that 2002 fish passage data at Lower Granite Dam were included in the analysis despite the Behavioral Guidance Structure (BGS) operation, in an effort to increase sample size.

Table A4 5. Distribution of radio-tagged fish and spill levels at Lower Granite and Ice Harbor Dams with RSW operation and by species (CH1 = Spring chinook, STHD = Steelhead).

Species	Dam	RSW (1 on, 0 off)	Number of RT smolts	Minimum spill proportion	Mean spill proportion	Maximum spill proportion
CH1	LGR	0	470	0.158	0.524	0.859
		1	1,994	0.075	0.321	0.995
	IHR	0	4,898	0.316	0.700	0.990
		1	3,326	0.285	0.453	0.908
STH	LGR	0	381	0.102	0.554	0.794
		1	2,118	0.074	0.323	0.988
	IHR	0	1,141	0.334	0.759	0.945
		1	2,331	0.285	0.455	0.908

Table A4 6. Distribution of radio-tagged fish at Lower Granite and Ice Harbor Dams by species, year, and RSW operation.

Species	**Dam**	**RSW**	**1999**	**2002**	**2003**	**2004**	**2005**	**2006**	**Total**
CH1	LGR	Off	0	135	335	0	0	0	470
		On	0	413	582	0	379	620	1,994
	IHR	Off	697	0	892	2,315	994	0	4,898
		On	0	0	0	0	1,250	2,076	3,326
STH	LGR	Off	0	139	241	0	0	1	381
		On	0	470	404	0	458	786	2,118
	IHR	Off	0	0	0	590	551	0	1,141
		On	0	0	0	0	694	1637	2,331

Dam Operations
In most cases, dam operations data were available by passage route on a 5-minute basis. Because it is likely that operations at and prior to the passage event may influence the route of passage, several alternatives were evaluated for summarizing the operations for use in developing spill-passage relationships. Some of those alternatives for summarizing spill flow percent included:
1) Nearest 5-minute instantaneous operation
2) Average of the previous 60 minutes
3) Hourly average at the top of the hour. (e.g., 1:30 to 2:30 operations averaged for fish passing between 1:30 and 2:30)
4) Hourly average at the bottom of the hour. (e.g., 1:00 to 2:00 operations averaged for fish passing between 1:00 and 2:00)

The 5-minute operational data explained the most variation in passage route distribution in 5 of 9 comparisons (results not shown) and was selected for fitting spill passage relationships. In any case, the four measures were very highly correlated (Pearson R > 0.99), so the results are not sensitive to the spill measure employed in the analysis.

Model Estimation
Techniques developed to fit spill passage efficiency relationships to hydro acoustic data have used logit-transformed flow proportions and passage proportions. One benefit of the logit transformations is that the relationships are then fit with a simple linear regression. When back-transformed, those relationships are forced through the mandatory points of (0%,0%) and (100%,100%) (spill, passage). As a result, these relationships do not produce values of passage less than 0% or greater than 100%.

We treat individual passage events as binary variables representing passage through spill or non-spill routes, or bypass vs. turbine routes. This type of count data lends itself well to binary logistic regression (on the set of passage events for individual tagged fish) with a logit link function. When spill flow proportions are represented as logit-transformed values, this method produces curves of the same (logit-logit) described in the section on pooled RT data. This method can analyze passage events as individual data points, and did not require grouping or binning.

We fit three groups of logistic regression models: SPE, FGE, and the conditional probability of RSW passage given passage over the spillway. Let p_S, p_F, and p_R be the probabilities of passing spillway (SPE), bypass given entered powerhouse (FGE), and RSW given passed through a spillway, respectively. The fullest forms of each model for an individual fish *i* are:

SPE

$$\text{logit}\left(p_{S,i}\right) = \beta_0 + \beta_1 lg.sp_i + \beta_2 flow_i + \beta_3 lg.sp_i * flow_i + \beta_4 RSWon_i + \beta_5 RSWon_i * flow_i$$

FGE

$$\text{logit}\left(p_{F,i}\right) = \theta_0 + \theta_1 ph.flow + \theta_2 day + \theta_3 temp$$

Conditional RSW

$$\text{logit}\left(p_{R,i}\right) = \gamma_0 + \gamma_1 lg.rsw.sp$$

where the variables are:

lg.sp	logit transform of proportion of total flow that passed through spillway
flow	total flow in kcfs passing the dam
RSWon	a 0/1 indicator for whether RSW was in operation (1) or not (0)
ph.flow	flow in kcfs passing through the powerhouse
day	day of year when fish passed dam
temp	water temperature in degrees C
lg.rsw.sp	logit transform of proportion of

Note that a probit transform was used for some models that were updated at a later date. We used AIC to select the best model in each group using methods described in the following section.

Modeling FGE and SPE with Data from PIT-tagged Fish

Estimates of detection probability in a juvenile bypass system at a dam for cohorts of PIT-tagged fish using standard capture-recapture methods give direct estimates of the probability of entering the juvenile bypass system of that dam over the period of time that the cohort passed. Since detection of PIT tags is only in the bypass system, we cannot directly estimate the probability of passing through other individual passage routes. However, by assuming some general functional relationships between passage probabilities through non-bypass routes and a set of explanatory variables we can use the estimates of bypass (capture) probabilities to estimate parameters of the functional relationships and thereby indirectly estimate the passage probabilities through the other passage routes.

Model Description

The relationship between FGE, SPE, and the probability of entering the bypass can be described using basic rules of probability. The following example uses spillway, turbine, and bypass as the three possible passage routes at a dam. The route-specific probabilities of passage sum to 1.0.

$$P(Bypass) + P(Turbine) + P(Spillway) = 1.0$$

The probability of entering the powerhouse is

$$\begin{aligned} P(Powerhouse) &= P(Bypass) + P(Turbine) \\ &= 1.0 - P(Spillway) \end{aligned}$$

The conditional probability of entering the bypass given entry into the powerhouse is

$$P(Bypass \mid Powerhouse) = \frac{P(Bypass)}{P(Bypass) + P(Turbine)} = \frac{P(Bypass)}{P(Powerhouse)}$$

Using this relationship the probability of entering the bypass can be expressed as a function of FGE and SPE.

$$\begin{aligned} P(Bypass) &= P(Bypass \mid Powerhouse) P(Powerhouse) \\ &= P(Bypass \mid Powerhouse)(1 - P(Spillway)) \\ &= FGE * (1 - SPE) \end{aligned}$$

The FGE and SPE probabilities can be expressed as functions of some set of explanatory variables, which creates a modeling framework for prediction of bypass probability:

$$P(Bypass) = f(\underline{x})[1 - g(\underline{z})]$$

We assumed that SPE and FGE are both linear functions of sets of explanatory variables on the probit scale. Note that the probit is a common link function used in regression modeling of probabilities. The probit transformation is equivalent to the inverse cumulative distribution function of the standard normal distribution, so it maps the probability space to the real line. We will denote the probit function as $\Phi^{-1}(p)$ and the inverse probit as $\Phi(z)$. This is similar to the model structure used in the logistic regression modeling of SPE using the data on individual radio-tagged fish described in the previous section.

To simplify notation, we let $\mu_B = P(Bypass)$, $\mu_F = P(Bypass \mid Powerhouse)$, and $\mu_S = P(Spillway)$. Then $\mu_B = \mu_F(1 - \mu_s)$. The linear predictors on the probit scale for μ_F and μ_s are:

$$\Phi^{-1}(\mu_{F,i}) = \theta_{F,0} + \sum_{j=1}^{J} \theta_{F,j} X_{j,i}$$

$$\Phi^{-1}(\ \mu_{S,i}) = \theta_{S,0} + \sum_{k=1}^{K} \theta_{S,k} Z_{k,i}$$

Here the θ's are regression parameters and the X's and Z's are explanatory variables. Note that some variables such as indicators for dam or species could be common to both equations. Putting these functions together and back-transforming to the probability scale creates a non-linear model for predicting probability of entering the bypass system:

$$\mu_{B,i} = \Phi\left(\theta_{F,0} + \sum_{j=1}^{J} \theta_{F,j} X_{j,i}\right)\left[1 - \Phi\left(\theta_{S,0} + \sum_{k=1}^{K} \theta_{S,k} Z_{k,i}\right)\right]$$

In practice we take the logit of both sides of the equation to fit the model. The response variable is then the logit of bypass (capture) probability. The residuals on the logit scale are assumed to be distributed normal with mean zero and constant variance.

Next we develop a probability model for fitting the regression parameters to data. Let y_i be the CJS detection probability estimate for release group i and let $p_{B,i}$ be the unknown true detection probability for that group. Due to virtually 100% detection efficiency in juvenile bypass systems, this detection probability is the probability of entering the bypass system given the fish is alive at the face of the dam. We will therefore refer to this as the bypass probability. We assume the unknown bypass probability for a cohort follows a Beta distribution with mean $\mu_{B,i}$, equal to the functional form above, and precision parameter τ:

$$p_{B,i} \sim \text{Beta}(\mu_{B,i}, \tau)$$

Note that for a standard Beta(α, β) distribution we have $\alpha = \mu_B \tau$ and $\beta = (1 - \mu_B)\tau$. It follows that $\text{E}[p_{B,i}] = \mu_{B,i}$ and $\text{Var}[p_{B,i}] = \frac{\mu_{B,i}(1-\mu_{B,i})}{\tau+1}$. Further, we assume that conditional on the unknown bypass probability for a cohort, the "observed" CJS detection (bypass) probability estimates follow a Beta distribution with mean $p_{B,i}$ and variance $\sigma^2_{B,i}$:

$$y_i \mid p_{B,i} \sim \text{Beta}(p_{B,i}, \sigma^2_{B,i})$$

Here $p_{B,i}$ and $\sigma^2_{B,i}$ are the true but unknown mean and sampling variance of y_i. The true sampling variance can be written as $\sigma^2_{B,i} = \text{Var}[y_i \mid p_{B,i}] = \frac{p_{B,i}(1-p_{B,i})}{n_{eff}}$, where n_{eff} is the effective sample size and is a function of initial sample size and survival and detection probabilities at current and downstream sites. We can approximate the unknown n_{eff} using the estimated sampling variance of y_i: $\hat{n}_{eff} \approx \frac{y_i(1-y_{,i})}{\widehat{\text{Var}}[y_i \mid p_{B,i}]}$. Using the formulation of the Beta distribution above in terms of the mean and variance, it can be shown that the parameters of the distribution in standard form are: $\alpha_{y,i} = p_{B,i}\left(\frac{p_{B,i}(1-p_{B,i})}{\sigma^2_{B,i}} - 1\right)$ and $\beta_{y,i} = \alpha_{y,i}(1-p_{B,i})/p_{B,i}$. Substituting $\hat{n}_{eff}$ into the equation for $\sigma^2_{B,i}$, we get $\alpha_{y,i} = p_{B,i}(\hat{n}_{eff} - 1)$ and $\beta_{y,i} = (1-p_{B,i})(\hat{n}_{eff} - 1)$, and so $y_i \mid p_{B,i} \sim \text{Beta}(\alpha_{y,i}, \beta_{y,i})$.

The $p_{B,i}$ in these models are random effects and need to be integrated out of the complete likelihood to form a marginal likelihood. The individual marginal likelihood component for cohort *i* can be written as

$$p(y_i \mid \boldsymbol{\theta}) = \int_0^1 p(y_i \mid p_{B,i}, \boldsymbol{\theta})\, p(p_{B,i} \mid \boldsymbol{\theta})\, dp_{B,i}$$

where $\boldsymbol{\theta}$ are the other parameters in the bypass probability model, $p(y_i \mid p_{B,i}, \boldsymbol{\theta}) = \text{Beta}(p_{B,i}, \sigma^2_{B,i})$ and $p(p_{B,i} \mid \boldsymbol{\theta}) = \text{Beta}(\mu_{B,i}, \tau)$. The joint likelihood is then the product of the individual independent likelihood components. In practice we use numerical integration to solve the integrals during the maximum likelihood optimization routine used to fit model parameters.

Data

We used weekly release groups of PIT-tagged fish to get CJS estimates of detection (bypass) probabilities at a subset of dams with PIT-tag detection facilities for 1997-2017. Release groups were formed with fish detected at the next upstream dam for each dam we modeled. For example, for modeling passage at LMN we used fish detected at LGS to form release groups. This minimized the amount of spreading of the fish as they passed the dams of interest and therefore resulted in more accurate measurements of covariates. For modeling passage at LGR, we created weekly releases from the Clearwater, Grande Ronde, Imnaha, Salmon, and Snake River Traps. For passage at MCN we used releases from IHR and LMN. The release groups were split by rearing type, which resulted in separate data sets for hatchery only, wild only, and hatchery/wild combined. The analysis presented here is for hatchery/wild fish combined. We used standard Cormack-Jolly-Seber capture-recapture methods to estimate detection probabilities and associated standard errors for each release group at each dam. Table A4 7 shows number release cohorts by dam and species. Note that we did not use PIT tag data from Ice Harbor Dam or Bonneville Dam in this analysis due to data limitations and complexities introduced by sluiceway passage routes.

Table A4 7. Number of detection probability estimates (release groups) by species and dam.

River	**Dam**	**Chinook**	**Steelhead**
Snake	LGR	822	690
	LGS	272	254
	LMN	240	213
Columbia	MCN	341	328
	JDA	213	282

Daily measurements of temperature, flow, and spill for each dam were downloaded from the Columbia River DART website. We used those daily values to create weighted averages for each variable for each cohort at each dam. The weights were the daily number of detected fish for a cohort at a dam. By assuming that the daily distribution of passage for detected and non-detected fish within a cohort is the same, this approach allows estimation of the mean conditions the cohorts experienced at the time of passage.

Each species and dam were modeled separately. The explanatory variables used for the FGE component of the model for both river segments were continuous variables for mean temperature, median day of passage, and mean powerhouse flow (kcfs). Here powerhouse flow is defined as mean total flow kcfs minus mean spill kcfs. We allowed an intercept-only model for estimating a constant FGE and we also had models with FGE fixed at estimates derived from RT data for particular years (see Table A4 4).

Explanatory variables used for the SPE component for Snake River dams were an indicator for RSW on or off, mean total flow (kcfs), probit(mean spill proportion), an interaction between probit(spill) and flow, and an interaction between RSW and flow. The indicator for RSW on/off was specified at the cohort level with the restriction that RSW was coded as on if any of the detected fish in the cohort passed the dam while the RSW was on

We chose to model FGE as a function of dam, powerhouse flow, median day of passage, and temperature because they could be justified from a mechanistic standpoint. Each dam has its own unique structural and operational configuration and is expected to differ in fish guidance efficiency. Powerhouse flow provides an index of the amount of hydrologic force the fish experience when approaching the turbine intake. One might expect that swimming speed and maneuverability would be affected by powerhouse flow, and therefore the ability of fish to escape intake screens would likely be affected. Note that ideally we would use flow per turbine unit, but data on the daily per-unit flow was not available to us at the time of analysis. Water temperature could influence vertical distribution of smolts, which would affect FGE. Day of the migration season is intended to act as a surrogate measure for fish size and level of smoltification, both of which are expected to influence fish guidance. Day of season is also highly positively correlated with temperature. For this reason we decided not to allow temperature and day to be in the same models together.

We allowed total flow to be in the SPE component of the model because it seems reasonable that fish behavior while approaching a dam is likely influenced by the amount of flow. At lower flows we expect that spill, especially surface spill through RSW, may be more attractive than at higher flows. At high flows the fish are probably less likely to escape the force of flow or have time to select between powerhouse and spillway. We also included an indicator term that accounted for the experimental “bulk” spill pattern that occurred at LMN in 2007. This spill pattern was implemented through the majority of the migration season, so all cohorts at LMN in 2007 were coded with bulk spill.

Model Fitting and Selection

The response variables were the detection probabilities estimated with CJS. We used maximum likelihood to fit the models while using numerical integration to integrate over the random effects.

We used an information-theoretic approach based on Akaike’s information criterion (AIC) for model selection (e.g., Burnham and Anderson 1998). We fit all allowed combinations of models and then ranked them based on AIC score, where the lowest AIC scores correspond to the best models. We divided the set of models into those with FGE components that included median day of passage, and those that included temperature. Models that included neither of these terms were common to both sets. We assigned AIC weights based on the difference in AIC (Δ_i), from the best fitting model within each group of R models, where

$$\Delta_i = \mathrm{AIC}_i - \mathrm{AIC}_{min} \,.,$$

and the weight for the ith model is defined as

$$w_i = \frac{\exp(-\Delta_i / 2)}{\sum_{i=1}^{R} \exp(-\Delta_i / 2)} \, .$$

We then used the weights to calculate model-averaged values for the parameters within each model group, where the model average of a single parameter is the weighted average of that parameter of across all possible models in a group. When a variable did not occur in a particular model, the parameter value for that variable was set to zero to remove bias in model-averaged parameters.

Appendix Conclusions

There is a lot of quality data from a variety of sources available for estimating SPE and FGE at Snake and Columbia River dams. However, the many gaps in the data need to be filled before strong prediction models can be developed for all dams. We have used a combination of the best available data to develop our SPE and FGE models, and we have improved our predictions by incorporating the various data types and analyses methods. However, we do believe that model development is still a work in progress and will be improved as more data become available and as our methods of analyzing the data become more refined.

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This appendix contains tables of constant dam survival and passage parameters and references.

The "CC" column in each table indicates whether or not a given year represents current conditions at the dam in question. In many cases, for years in which a survival estimate was not available directly from a passage study, the data source listed for those parameters will be either "CC average" or "Pre-CC average". These indicate a weighted average of study estimates within the CC years and non-CC years respectively, where the weight for each estimate is $(1/CV)^2$.

In the case that the estimated survival from a study or a weighted average results in a value greater than one, a value of 0.999 is used in place of the estimate or average.

Unless explicitly modified by a prospective scenario, 2017 values are used for all parameters in prospective COMPASS runs.

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
1998	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.44	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no		Sluiceway/SBC_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.44	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.99	
	no		Sluiceway/SBC_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
1999	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.44	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no		Sluiceway/SBC_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.44	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.99	
	no		Sluiceway/SBC_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
2000	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.29	Evans et al. 2001a. Report for 2000 RT research.
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no		Sluiceway/SBC_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.44	Evans et al. 2001a. Report for 2000 RT research.
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.9	
	no		Sluiceway/SBC_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
2001	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.76	Evans et al. 2001b. Report for 2001 RT research.
	no		Power_Priority	2	
	no		Turbine_Survival	0.92	Best Professional Judgement, estimated improved survival due to MGR unit installation.
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement.
	no		Sluiceway/SBC_Survival	0.92	Best Professional Judgement, Assumed no better than PH1 turbine survival.
	no	*Steelhead*			

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.6	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	2	
	no		Turbine_Survival	0.92	Best Professional Judgement, estimated improved survival due to MGR unit installation.
	no		Spillway_Survival	0.98	Marmorek and Peters. 1998. Standard PATH spill survival parameter.
	no		Bypass_Survival	0.99	
	no		Sluiceway/SBC_Survival	0.92	Best Professional Judgement, Assumed no better than PH1 turbine survival.
2002	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.33	Ploskey et al. 2003. Report for 2002 HA research.
	no		Power_Priority	2	
	no		Turbine_Survival	0.92	Best Professional Judgement, estimated improved survival due to MGR unit installation.
	no		Spillway_Survival	0.977	Counihan et al. 2003. Draft report for 2002 research (this value reflects the average of 2 treatments).
	no		Bypass_Survival	0.91	Counihan et al. 2003. Draft report for 2002 research.
	no		Sluiceway/SBC_Survival	0.92	Best Professional Judgement, Assumed no better than PH1 turbine survival.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.65	Evans et al 2003
	no		Power_Priority	2	
	no		Turbine_Survival	0.92	Best Professional Judgement, estimated improved survival due to MGR unit installation.
	no		Spillway_Survival	0.977	Counihan et al. 2003. Draft report for 2002 research (this value reflects the average of 2 treatments).
	no		Bypass_Survival	0.91	
	no		Sluiceway/SBC_Survival	0.92	Best Professional Judgement, Assumed no better than PH1 turbine survival.
2003	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.6	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	2	
	no		Turbine_Survival	0.92	Best Professional Judgement, improved survival due to MGR unit installation.
	no		Spillway_Survival	0.936	Counihan et al. 2003, 2005a, 2005b. Ave of '02, '04, '05 for 75k day/TDG cap night operation.
	no		Bypass_Survival	0.91	Counihan et al. 2003. Draft report for 2002 research.
	no		Sluiceway/SBC_Survival	0.92	Best Professional Judgement, Assumed no better than PH1 turbine survival.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.6	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
	no		Power_Priority	2	
	no		Turbine_Survival	0.92	Best Professional Judgement, improved survival due to MGR unit installation.
	no		Spillway_Survival	0.936	Counihan et al. 2003, 2005a, 2005b. Ave of '02, '04, '05 for 75k day/TDG cap night operation.
	no		Bypass_Survival	0.91	
	no		Sluiceway/SBC_Survival	0.92	Best Professional Judgement, Assumed no better than PH1 turbine survival.
2004	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.53	Reagan et al. 2005. Report for 2004 RT research.
	no		Power_Priority	2	
	no		Turbine_Survival	0.996	Counihan et al. 2005a. Draft report for 2004 research.
	no		Spillway_Survival	0.91	Counihan et al. 2005a. Draft report for 2004 research.
	no		Bypass_Survival	1	Bypass route inactive
	no		Sluiceway/SBC_Survival	0.937	Counihan et al. 2005a. Draft report for 2004 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.55	Reagan et al. 2005. Report for 2004 RT research.
	no		Power_Priority	2	
	no		Turbine_Survival	0.974	Counihan et al. 2005a. Draft report for 2004 research.
	no		Spillway_Survival	0.979	Counihan et al. 2005a. Draft report for 2004 research.
	no		Bypass_Survival	1	Bypass route inactive
	no		Sluiceway/SBC_Survival	0.985	Counihan et al. 2005a. Draft report for 2004 research.
2005	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.44	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	2	
	no		Turbine_Survival	0.950	Counihan et al. 2005b. Draft 2005 research report.
	no		Spillway_Survival	0.93	Counihan et al. 2005b. Draft 2005 research report.
	no		Bypass_Survival	1	Bypass route inactive
	no		Sluiceway/SBC_Survival	0.919	Counihan et al. 2005b. Draft 2005 research report.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.44	Professional opinion of dam passage working group (better cite? See 06 spreadsheet)
	no		Power_Priority	2	
	no		Turbine_Survival	0.933	Counihan et al. 2005b. Draft 2005 research report. Based on PH1 total survival estimate.
	no		Spillway_Survival	0.955	Counihan et al. 2005b. Draft 2005 research report.
	no		Bypass_Survival	1	Bypass route inactive
	no		Sluiceway/SBC_Survival	0.933	Counihan et al. 2005b. Draft 2005 research report. Based on PH1 total survival estimate.

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
2006	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.483	Average of Evans et al 2001a, Evans et al 2001b, Evans et al 2003, and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.941	Ploskey et al 2007
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.547	Average of Evans et al 2001a, Evans et al 2003, Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2007	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.483	Average of Evans et al 2001a, Evans et al 2001b, Evans et al 2003, and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.937	Ploskey et al 2008
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.547	Average of Evans et al 2001a, Evans et al 2003, Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2008	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.483	Average of Evans et al 2001a, Evans et al 2001b, Evans et al 2003, and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.999	Ploskey et al 2009
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
	yes		Sluiceway/SBC_Proportion	0.547	Average of Evans et al 2001a, Evans et al 2003, Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.962	Ploskey et al 2009
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2009	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.483	Average of Evans et al 2001a, Evans et al 2001b, Evans et al 2003, and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.945	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.547	Average of Evans et al 2001a, Evans et al 2003, Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2010	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.3276	Ploskey et al 2011
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.987	Ploskey et al 2011
	yes		Spillway_Survival	0.935	Ploskey et al 2011
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.980	Ploskey et al 2011
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.4183	Ploskey et al 2011
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.900	Ploskey et al 2011
	yes		Spillway_Survival	0.939	Ploskey et al 2011
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.963	Ploskey et al 2011
2011	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2374	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.968	Ploskey et al 2012 and Skalski et al 2012c
	yes		Spillway_Survival	0.957	Ploskey et al 2012 and Skalski et al 2012c
	yes		Bypass_Survival	1	Bypass route inactive

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
	yes		Sluiceway/SBC_Survival	0.969	Ploskey et al 2012 and Skalski et al 2012c
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2596	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.936	Ploskey et al 2012 and Skalski et al 2012c
	yes		Spillway_Survival	0.957	Ploskey et al 2012 and Skalski et al 2012c
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	Ploskey et al 2012 and Skalski et al 2012c
2012	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2374	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.945	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2596	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2013	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2374	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.945	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2596	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2014	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2374	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.945	CC average

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2596	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2015	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2374	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.945	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2596	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2016	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2374	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average
	yes		Spillway_Survival	0.945	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2596	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average
2017	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2374	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.981	CC average

Bonneville Dam	CC	Species	Compass parameter	Value	Data Source
	yes		Spillway_Survival	0.945	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.975	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.2596	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.92	CC Average
	yes		Spillway_Survival	0.950	CC average
	yes		Bypass_Survival	1	Bypass route inactive
	yes		Sluiceway/SBC_Survival	0.954	CC Average

Bonneville Dam PH2	CC	Species	Compass parameter	Value	Data Source
1998	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no		Sluiceway/SBC_Survival	1	
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.9	2000 Biological Opinion - Biological Effects Team Judgement
	no		Sluiceway/SBC_Survival	1	
1999	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.98	Marmorek and Peters. 1998. Standard PATH bypass survival parameter. Also seems a reasonable number based on Holmberg et al. (2001) post construction evaluation in 1999.
	no		Sluiceway/SBC_Survival	1	
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	1	

Bonneville Dam PH2	CC	Species	Compass parameter	Value	Data Source
	no		Bypass_Survival	0.98	Marmorek and Peters. 1998. Standard PATH bypass survival parameter. Also seems a reasonable number based on Holmberg et al. (2001) post construction evaluation in 1999.
	no		Sluiceway/SBC_Survival	1	
2000	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.98	Marmorek and Peters. 1998. Standard PATH bypass survival parameter. Also seems a reasonable number based on Holmberg et al. (2001) post construction evaluation in 1999.
	no		Sluiceway/SBC_Survival	1	
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	1	
	no		Turbine_Survival	0.9	Marmorek and Peters.1998. Standard PATH turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.98	Marmorek and Peters. 1998. Standard PATH bypass survival parameter. Also seems a reasonable number based on Holmberg et al. (2001) post construction evaluation in 1999.
	no		Sluiceway/SBC_Survival	1	
2001	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	2	
	no		Turbine_Survival	0.929	Counihan et al. 2002. Report for 2001 research.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.962	Counihan et al. 2002. Report for 2001 research.
	no		Sluiceway/SBC_Survival	1	
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	2	
	no		Turbine_Survival	0.929	Counihan et al. 2002. Report for 2001 research.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.962	Counihan et al. 2002. Report for 2001 research.
	no		Sluiceway/SBC_Survival	1	
2002	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	2	
	no		Turbine_Survival	0.948	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.98	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Bypass survival.
	no		Sluiceway/SBC_Survival	1	
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0	

Bonneville Dam PH2	CC	Species	Compass parameter	Value	Data Source
	no		Power_Priority	2	
	no		Turbine_Survival	0.948	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.98	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Bypass survival.
	no		Sluiceway/SBC_Survival	1	
2003	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	2	
	no		Turbine_Survival	0.948	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.98	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Bypass survival.
	no		Sluiceway/SBC_Survival	1	
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0	
	no		Power_Priority	2	
	no		Turbine_Survival	0.948	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Turbine survival.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.98	Counihan et al. 2002, 2005a, 2005b. Ave of 2001,04,05 PH-2 Bypass survival.
	no		Sluiceway/SBC_Survival	1	
2004	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0.37	Reagan et al. 2005. Report for 2004 RT research.
	no		Power_Priority	2	
	no		Turbine_Survival	0.953	
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.97	Counihan et al. 2005a. Draft report for 2004 research.
	no		Sluiceway/SBC_Survival	1.016	Counihan et al. 2005a. Draft report for 2004 research.
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0.74	Reagan et al. 2005. Report for 2004 RT research.
	no		Power_Priority	2	
	no		Turbine_Survival	0.889	Counihan et al. 2005a. Draft report for 2004 research.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.951	Counihan et al. 2005a. Draft report for 2004 research.
	no		Sluiceway/SBC_Survival	1.03	Counihan et al. 2005a. Draft report for 2004 research.
2005	no				
	no	*Chinook 1*			
	no		Sluiceway/SBC_Proportion	0.29	Adams, 2005. Preliminary Data - FFDRWG Handout, Noah Adams, August 3, 2005.
	no		Power_Priority	2	
	no		Turbine_Survival	0.965	
	no		Spillway_Survival	1	
	no		Bypass_Survival	1.007	Counihan et al. 2005b. Draft 2005 research report.

Bonneville Dam PH2	CC	Species	Compass parameter	Value	Data Source
	no		Sluiceway/SBC_Survival	1.02	Counihan et al. 2005b. Draft 2005 research report.
	no	*Steelhead*			
	no		Sluiceway/SBC_Proportion	0.66	Preliminary Data - FFDRWG Handout, Noah Adams, August 3, 2005.
	no		Power_Priority	2	
	no		Turbine_Survival	0.868	Counihan et al. 2005b. Draft 2005 research report.
	no		Spillway_Survival	1	
	no		Bypass_Survival	0.956	Counihan et al. 2005b. Draft 2005 research report.
	no		Sluiceway/SBC_Survival	1.009	Counihan et al. 2005b. Draft 2005 research report.
2006	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.330	Average of Adams, August 3, 2005 and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.700	Average of Adams, August 3, 2005 and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average
2007	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.330	Average of Adams, August 3, 2005 and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.700	Average of Adams, August 3, 2005 and Reagan et al 2005
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average
2008	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.490	Faber et al 2010
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.979	Faber et al 2010
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.999	Faber et al 2010 (estimate was 1.017)

Bonneville Dam PH2	CC	Species	Compass parameter	Value	Data Source
	yes		Sluiceway/SBC_Survival	0.999	Faber et al 2010 (estimate was 1.021)
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.750	Faber et al 2010
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.982	Faber et al 2010
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.984	Faber et al 2010
	yes		Sluiceway/SBC_Survival	0.984	Faber et al 2010
2009	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.400	Faber et al 2011
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.965	Faber et al 2011
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.984	Faber et al 2011
	yes		Sluiceway/SBC_Survival	0.995	Faber et al 2011
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.590	Faber et al 2011
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.943	Faber et al 2011
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.969	Faber et al 2011
	yes		Sluiceway/SBC_Survival	0.992	Faber et al 2011
2010	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.4580	Ploskey et al 2011
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.957	Ploskey et al 2011
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.981	Ploskey et al 2011
	yes		Sluiceway/SBC_Survival	0.991	Ploskey et al 2011
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.5709	Ploskey et al 2011
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.911	Ploskey et al 2011
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.978	Ploskey et al 2011
	yes		Sluiceway/SBC_Survival	0.975	Ploskey et al 2011
2011	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.1911	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.947	Ploskey et al 2012 and Skalski et al 2012c
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.982	Ploskey et al 2012 and Skalski et al 2012c
	yes		Sluiceway/SBC_Survival	0.994	Ploskey et al 2012 and Skalski et al 2012c
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.6713	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.919	Ploskey et al 2012 and Skalski et al 2012c

Bonneville Dam PH2	CC	Species	Compass parameter	Value	Data Source
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.940	Ploskey et al 2012 and Skalski et al 2012c
	yes		Sluiceway/SBC_Survival	0.994	Ploskey et al 2012 and Skalski et al 2012c
2012	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.1911	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.6713	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average
2013	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.1911	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.6713	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average
2014	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.1911	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.6713	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average
2015	yes				
	yes	*Chinook 1*			

Bonneville Dam PH2	CC	Species	Compass parameter	Value	Data Source
	yes		Sluiceway/SBC_Proportion	0.1911	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.6713	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average
2016	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.1911	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.6713	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average
2017	yes				
	yes	*Chinook 1*			
	yes		Sluiceway/SBC_Proportion	0.1911	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.958	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.983	CC average
	yes		Sluiceway/SBC_Survival	0.992	CC average
	yes	*Steelhead*			
	yes		Sluiceway/SBC_Proportion	0.6713	Ploskey et al 2012
	yes		Power_Priority	2	
	yes		Turbine_Survival	0.928	CC average
	yes		Spillway_Survival	1	No spillway at PH2
	yes		Bypass_Survival	0.975	CC average
	yes		Sluiceway/SBC_Survival	0.977	CC average

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
1998	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004
	no		Turbine_Survival	0.84	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.928	Dawley et al. 2000a (ave. survival for coho salmon at 2 ops, 30 and 64% spill in 1998).
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.96	Dawley et al, 2000a (survival at 30% spill for coho salmon in 1998)
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.84	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.928	Dawley et al. 2000a (ave. survival for coho salmon at 2 ops, 30 and 64% spill in 1998).
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.96	Dawley et al, 2000a (survival at 30% spill for coho salmon in 1998)
1999	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.84	Counihan et al, 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.948	Dawley et al. 2000b (average survival for coho salmon at 2 ops, 30 and 64% spill in 1999)
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.96	Dawley et al, 2000a (survival at 30% spill for coho salmon in 1998)
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.84	Counihan et al, 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.948	Dawley et al. 2000b (average survival for coho salmon at 2 ops, 30 and 64% spill in 1999)
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.96	Dawley et al, 2000a (survival at 30% spill for coho salmon in 1998)
2000	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.84	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.94	Counihan et al. 2002. Data for yearling chinook.
	no		Bypass_Survival	1	

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
	no		Sluiceway/SBC_Survival	0.967	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.84	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.94	Counihan et al. 2002. Data for yearling chinook.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.967	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
2001	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.84	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.897	Dawley et al. 1998, 2000a and 2000b. Average of 1997, 1998, 1999 PIT TDA spillway survival estimates for YCH and Coho
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.993	Counihan et al. 2005c. Final report for 2001 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.84	Counihan et al. 2002, Absolon et al. 2002. Average of 2000 R/T and PIT spring migrant studies (YCH).
	no		Spillway_Survival	0.897	Dawley et al. 1998, 2000a and 2000b. Average of 1997, 1998, 1999 PIT TDA spillway survival estimates for YCH and Coho
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.993	Counihan et al. 2005c. Final report for 2001 research
2002	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.85	Counihan et al. 2006a. Report for 2002 research.
	no		Spillway_Survival	0.88	Counihan et al. 2006a. Report for 2002 research.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.91	Counihan et al. 2006a. Report for 2002 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.85	Counihan et al. 2006a. Report for 2002 research.
	no		Spillway_Survival	0.88	Counihan et al. 2006a. Report for 2002 research.

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.91	Counihan et al. 2006a. Report for 2002 research.
2003	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.83	Counihan et al. 2002 and 2006a. Average 2000, 2002 RT data for yearling chinook at 40% spill.
	no		Spillway_Survival	0.91	Counihan et al. 2002 and 2006a. Average 2000, 2002 RT data for yearling chinook at 40% spill.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.925	Counihan et al. 2002 and 2006a. Average 2000, 2002 RT data for yearling chinook at 40% spill.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.83	Counihan et al. 2002 and 2006a. Average 2000, 2002 RT data for yearling chinook at 40% spill.
	no		Spillway_Survival	0.91	Counihan et al. 2002 and 2006a. Average 2000, 2002 RT data for yearling chinook at 40% spill.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.925	Counihan et al. 2002 and 2006a. Average 2000, 2002 RT data for yearling chinook at 40% spill.
2004	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.797	Counihan et al. 2006b. Report for 2004 research.
	no		Spillway_Survival	0.909	Counihan et al. 2006b. Report for 2004 research.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.981	Counihan et al. 2006b. Report for 2004 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.797	Counihan et al. 2006b. Report for 2004 research.
	no		Spillway_Survival	0.909	Counihan et al. 2006b. Report for 2004 research.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.981	Counihan et al. 2006b. Report for 2004 research.
2005	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.838	Counihan et al. 2006c. Report of 2005 research.
	no		Spillway_Survival	0.938	Counihan et al. 2006c. Report of 2005 research.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.999	Counihan et al. 2006c. Report of 2005 research. Reported estimate was 1.006.
	no	*Steelhead*			

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.59	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.838	Counihan et al. 2006c. Report of 2005 research.
	no		Spillway_Survival	0.938	Counihan et al. 2006c. Report of 2005 research.
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.999	Counihan et al. 2006c. Report of 2005 research. Reported estimate was 1.006.
2006	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.820	Pre-CC average
	no		Spillway_Survival	0.938	Puls and Smith 2007. Average of spillbays 1-4 and 5-8.
	no		Bypass_Survival	1	No bypass at The Dalles
	no		Sluiceway/SBC_Survival	0.999	Pre-CC average is >=1 (average is 1.000)
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.590	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.836	Pre-CC average
	no		Spillway_Survival	0.918	Pre-CC average
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.996	Pre-CC average
2007	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.820	Pre-CC average
	no		Spillway_Survival	0.924	Pre-CC average
	no		Bypass_Survival	1	No bypass at The Dalles
	no		Sluiceway/SBC_Survival	0.999	Pre-CC average is >=1 (average is 1.000)
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.590	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.836	Pre-CC average
	no		Spillway_Survival	0.918	Pre-CC average
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.996	Pre-CC average
2008	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.820	Pre-CC average
	no		Spillway_Survival	0.924	Pre-CC average
	no		Bypass_Survival	1	No bypass at The Dalles
	no		Sluiceway/SBC_Survival	0.999	Pre-CC average is >=1 (average is 1.000)

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.590	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.836	Pre-CC average
	no		Spillway_Survival	0.918	Pre-CC average
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.996	Pre-CC average
2009	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.445	Average of: Nichols and Ransom 1980, Hansel et al 2000, Hansel et al 2004, Hansel et al 2005, Beeman et al 2005, Hausmann et al 2004a
	no		Turbine_Survival	0.820	Pre-CC average
	no		Spillway_Survival	0.924	Pre-CC average
	no		Bypass_Survival	1	No bypass at The Dalles
	no		Sluiceway/SBC_Survival	0.999	Pre-CC average is >=1 (average is 1.000)
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Sluiceway/SBC_Proportion	0.590	Average of: Hansel et al 2000, Hausmann et al 2004a, Beeman et al 2005
	no		Turbine_Survival	0.836	Pre-CC average
	no		Spillway_Survival	0.918	Pre-CC average
	no		Bypass_Survival	1	
	no		Sluiceway/SBC_Survival	0.996	Pre-CC average
2010	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.6231	Johnson et al 2011, Ploskey et al 2012 (data for steelhead)
	yes		Turbine_Survival	0.876	Johnson et al 2011, Ploskey et al 2012
	yes		Spillway_Survival	0.966	Johnson et al 2011, Ploskey et al 2012
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.993	Johnson et al 2011, Ploskey et al 2012
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.6231	Johnson et al 2011, Ploskey et al 2012
	yes		Turbine_Survival	0.888	Johnson et al 2011, Ploskey et al 2012
	yes		Spillway_Survival	0.958	Johnson et al 2011, Ploskey et al 2012
	yes		Bypass_Survival	1	
	yes		Sluiceway/SBC_Survival	0.944	Johnson et al 2011, Ploskey et al 2012
2011	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5058	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.930	Skalski et al 2012b, Ploskey et al 2012
	yes		Spillway_Survival	0.961	Skalski et al 2012b, Ploskey et al 2012
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.991	Skalski et al 2012b, Ploskey et al 2012
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
	yes		Sluiceway/SBC_Proportion	0.5587	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.919	Skalski et al 2012b, Ploskey et al 2012
	yes		Spillway_Survival	0.999	Skalski et al 2012b, Ploskey et al 2012 (estimate is 1.004)
	yes		Bypass_Survival	1	
	yes		Sluiceway/SBC_Survival	0.999	Skalski et al 2012b, Ploskey et al 2012 (estimate is 1.010)
2012	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5058	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.925	CC average
	yes		Spillway_Survival	0.963	CC average
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.991	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5587	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.913	CC average
	yes		Spillway_Survival	0.986	CC average
	yes		Bypass_Survival	1	
	yes		Sluiceway/SBC_Survival	0.999	CC average is >=1 (average is 1.000)
2013	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5058	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.925	CC average
	yes		Spillway_Survival	0.963	CC average
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.991	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5587	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.913	CC average
	yes		Spillway_Survival	0.986	CC average
	yes		Bypass_Survival	1	
	yes		Sluiceway/SBC_Survival	0.999	CC average is >=1 (average is 1.000)
2014	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5058	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.925	CC average
	yes		Spillway_Survival	0.963	CC average
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.991	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5587	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.913	CC average
	yes		Spillway_Survival	0.986	CC average
	yes		Bypass_Survival	1	

The Dalles Dam	CC	Species	Compass Parameter	Value	Reference
	yes		Sluiceway/SBC_Survival	0.999	CC average is >=1 (average is 1.000)
2015	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5058	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.925	CC average
	yes		Spillway_Survival	0.963	CC average
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.991	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5587	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.913	CC average
	yes		Spillway_Survival	0.986	CC average
	yes		Bypass_Survival	1	
	yes		Sluiceway/SBC_Survival	0.999	CC average is >=1 (average is 1.000)
2016	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5058	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.925	CC average
	yes		Spillway_Survival	0.963	CC average
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.991	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5587	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.913	CC average
	yes		Spillway_Survival	0.986	CC average
	yes		Bypass_Survival	1	
	yes		Sluiceway/SBC_Survival	0.999	CC average is >=1 (average is 1.000)
2017	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5058	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.925	CC average
	yes		Spillway_Survival	0.963	CC average
	yes		Bypass_Survival	1	No bypass at The Dalles
	yes		Sluiceway/SBC_Survival	0.991	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	0	
	yes		Sluiceway/SBC_Proportion	0.5587	Skalski et al 2012b, Ploskey et al 2012
	yes		Turbine_Survival	0.913	CC average
	yes		Spillway_Survival	0.986	CC average
	yes		Bypass_Survival	1	
	yes		Sluiceway/SBC_Survival	0.999	CC average is >=1 (average is 1.000)

John Day Dam	CC	Species	Compass Parameter	Value	Reference
1998	no				

John Day Dam	CC	Species	Compass Parameter	Value	Reference
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.82	Counihan et al. 2006 and 2003 (draft). Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill (78 and 82%).
	no		Spillway_Survival	0.971	Counihan et al. 2002, 2006, 2003 (draft). Ave of data for 2000, 2002, and 2003.
	no		Bypass_Survival	0.95	Counihan et al. 2006 and 2003 (draft). Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.82	Counihan et al. 2006 and 2003 (draft). Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill (78 and 82%) for chinook.
	no		Spillway_Survival	0.96	Counihan et al. 2006. Survival under 0/60 spill operation in 2002.
	no		Bypass_Survival	0.882	Counihan et al. 2006. Paired release survival under 0/60 spill operation in 2002.
1999	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.82	Counihan et al. 2006 and 2003 (draft). Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill (78 and 82%).
	no		Spillway_Survival	0.971	Counihan et al. 2002, 2006, 2003 (draft). Ave of data for 2000, 2002, and 2003.
	no		Bypass_Survival	0.95	Counihan et al. 2006 and 2003 (draft). Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.82	Counihan et al. 2006 and 2003 (draft). Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill (78 and 82%) for chinook.
	no		Spillway_Survival	0.96	Counihan et al. 2006. Survival under 0/60 spill operation in 2002.
	no		Bypass_Survival	0.882	Counihan et al. 2006. Paired release survival under 0/60 spill operation in 2002.
2000	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.805	Counihan et al. 2006. Data for 2002 research (ave of 2 operations).
	no		Spillway_Survival	0.962	Counihan et al. 2002. Data for 2000 research (ave of 2 operations).
	no		Bypass_Survival	0.951	Counihan et al. 2006. Data for 2002 research (ave of 2 operations).
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.805	Counihan et al. 2006. Data for 2002 research (ave of 2 operations) for chinook.
	no		Spillway_Survival	0.946	Counihan et al. 2002. Data for 2000 research (ave of 2 operations).
	no		Bypass_Survival	0.904	Counihan et al. 2006. Data for 2002 research (ave of 2 operations).
2001	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	

John Day Dam	CC	Species	Compass Parameter	Value	Reference
	no		Turbine_Survival	0.83	Counihan et al. 2006. Survival in 2002 at 30 day/30 night.
	no		Spillway_Survival	1	Counihan et al. 2006. Spill survival at 30/30 in 2002 (May spill 0% until end of May then ~30%).
	no		Bypass_Survival	0.932	Counihan et al. 2005. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.83	Counihan et al. 2006. Survival in 2002 at 30 day/30 night for chinook.
	no		Spillway_Survival	0.932	Counihan et al. 2006. Survival in 2002 at 30 day/30 night.
	no		Bypass_Survival	0.917	Counihan et al. 2005. Data for 2001 research.
2002	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.805	Counihan et al. 2006d. Data for 2002 (ave of 2 operations).
	no		Spillway_Survival	0.997	Counihan et al. 2006d. Data for 2002 (ave of 2 operations).
	no		Bypass_Survival	0.95	Counihan et al. 2006d. Data for 2002 (ave of 2 operations).
	no	*Steelhead*			
	no		FGE	0.76	Hansel et al. 2000 (final), Beeman et al. 2003 (Final), Beeman et al (preliminary data). USGS RT data from1999, 2000, & 2002.
	no		Turbine_Survival	0.805	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations) for chinook.
	no		Spillway_Survival	0.946	Counihan et al. 2006d. Data for 2002, ave point estimate for two operations.
	no		Bypass_Survival	0.904	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations).
2003	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.79	Counihan et al. 2003. Draft data for 2003 (average over season for 2 operations).
	no		Spillway_Survival	0.935	Counihan et al. 2003. Draft data for 2003 (average over season for 2 operations).
	no		Bypass_Survival	1.004	Counihan et al. 2003. Draft data for 2003 (average over season for 2 operations).
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.805	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations) for chinook.
	no		Spillway_Survival	0.946	Counihan et al. 2006d. Data for 2002, ave point estimate for two operations.
	no		Bypass_Survival	0.904	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations).
2004	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.82	Counihan et al. 2006d and 2003. Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.
	no		Spillway_Survival	0.964	Counihan et al. 2006d and 2003. Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.

John Day Dam	CC	Species	Compass Parameter	Value	Reference
	no		Bypass_Survival	0.95	Counihan et al. 2006d and 2003. Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.805	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations) for chinook.
	no		Spillway_Survival	0.973	Counihan et al. 2002 and 2006d. Ave of 2000 and 2002 at 0 day and 60 night spill estimates.
	no		Bypass_Survival	0.904	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations).
2005	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.82	Counihan et al. 2006d and 2003. Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.
	no		Spillway_Survival	0.964	Counihan et al. 2006d and 2003. Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.
	no		Bypass_Survival	0.95	Counihan et al. 2006d and 2003. Ave point estimates for route specific survival in 2002 and 2003 w/ 0/60 spill.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.805	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations) for chinook.
	no		Spillway_Survival	0.973	Counihan et al. 2002 and 2006d. Ave of 2000 and 2002 at 0 day and 60 night spill estimates.
	no		Bypass_Survival	0.904	Counihan et al. 2006d. Data for 2002 research (ave of 2 operations).
2006	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.838	Pre-CC average
	no		Spillway_Survival	0.957	Pre-CC average
	no		Bypass_Survival	0.978	Pre-CC average
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.781	Pre-CC average
	no		Spillway_Survival	0.953	Pre-CC average
	no		Bypass_Survival	0.975	Pre-CC average
2007	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.838	Pre-CC average
	no		Spillway_Survival	0.957	Pre-CC average
	no		Bypass_Survival	0.978	Pre-CC average
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.781	Pre-CC average
	no		Spillway_Survival	0.953	Pre-CC average
	no		Bypass_Survival	0.975	Pre-CC average
2008	no				
	no	*Chinook 1*			

John Day Dam	CC	Species	Compass Parameter	Value	Reference
	no		rsw_spill_cap	19.20	
	no		RSW_survival	0.961	Weiland et al 2009
	no		Turbine_Survival	0.855	Weiland et al 2009
	no		Spillway_Survival	0.966	Weiland et al 2009
	no		Bypass_Survival	0.976	Weiland et al 2009
	no	*Steelhead*			
	no		rsw_spill_cap	19.20	
	no		RSW_survival	0.992	Weiland et al 2009
	no		Turbine_Survival	0.749	Weiland et al 2009
	no		Spillway_Survival	0.985	Weiland et al 2009
	no		Bypass_Survival	0.999	Weiland et al 2009 (estimate was 1.002)
2009	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	19.20	
	no		RSW_survival	0.951	Weiland et al 2011
	no		Turbine_Survival	0.851	Weiland et al 2011
	no		Spillway_Survival	0.913	Weiland et al 2011
	no		Bypass_Survival	0.975	Weiland et al 2011
	no	*Steelhead*			
	no		rsw_spill_cap	19.20	
	no		RSW_survival	0.963	Weiland et al 2011
	no		Turbine_Survival	0.824	Weiland et al 2011
	no		Spillway_Survival	0.936	Weiland et al 2011
	no		Bypass_Survival	0.966	Weiland et al 2011
2010	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.952	Weiland et al 2013a. Combined estimate
	yes		Turbine_Survival	0.776	Weiland et al 2013a. Combined estimate
	yes		Spillway_Survival	0.950	Weiland et al 2013a. Combined estimate
	yes		Bypass_Survival	0.901	Weiland et al 2013a. Combined estimate
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.972	Weiland et al 2013a. Combined estimate
	yes		Turbine_Survival	0.694	Weiland et al 2013a. Combined estimate
	yes		Spillway_Survival	0.944	Weiland et al 2013a. Combined estimate
	yes		Bypass_Survival	0.943	Weiland et al 2013a. Combined estimate
2011	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.958	Weiland et al 2013b
	yes		Turbine_Survival	0.910	Weiland et al 2013b
	yes		Spillway_Survival	0.974	Weiland et al 2013b
	yes		Bypass_Survival	0.993	Weiland et al 2013b
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.989	Weiland et al 2013b
	yes		Turbine_Survival	0.797	Weiland et al 2013b
	yes		Spillway_Survival	0.990	Weiland et al 2013b
	yes		Bypass_Survival	0.999	Weiland et al 2013b (estimate was 1.003)

John Day Dam	CC	Species	Compass Parameter	Value	Reference
2012	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.949	Skalski et al 2012a, PNNL 2015
	yes		Turbine_Survival	0.871	Skalski et al 2012a, PNNL 2015
	yes		Spillway_Survival	0.984	Skalski et al 2012a, PNNL 2015
	yes		Bypass_Survival	0.994	Skalski et al 2012a, PNNL 2015
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.982	Skalski et al 2012a, PNNL 2015
	yes		Turbine_Survival	0.849	Skalski et al 2012a, PNNL 2015
	yes		Spillway_Survival	0.978	Skalski et al 2012a, PNNL 2015
	yes		Bypass_Survival	0.982	Skalski et al 2012a, PNNL 2015
2013	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.952	CC average
	yes		Turbine_Survival	0.887	CC average
	yes		Spillway_Survival	0.965	CC average
	yes		Bypass_Survival	0.990	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.979	CC average
	yes		Turbine_Survival	0.817	CC average
	yes		Spillway_Survival	0.978	CC average
	yes		Bypass_Survival	0.988	CC average
2014	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.952	CC average
	yes		Turbine_Survival	0.887	CC average
	yes		Spillway_Survival	0.965	CC average
	yes		Bypass_Survival	0.990	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.979	CC average
	yes		Turbine_Survival	0.817	CC average
	yes		Spillway_Survival	0.978	CC average
	yes		Bypass_Survival	0.988	CC average
2015	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.952	CC average
	yes		Turbine_Survival	0.887	CC average
	yes		Spillway_Survival	0.965	CC average
	yes		Bypass_Survival	0.990	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.979	CC average
	yes		Turbine_Survival	0.817	CC average

John Day Dam	CC	Species	Compass Parameter	Value	Reference
	yes		Spillway_Survival	0.978	CC average
	yes		Bypass_Survival	0.988	CC average
2016	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.952	CC average
	yes		Turbine_Survival	0.887	CC average
	yes		Spillway_Survival	0.965	CC average
	yes		Bypass_Survival	0.990	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.979	CC average
	yes		Turbine_Survival	0.817	CC average
	yes		Spillway_Survival	0.978	CC average
	yes		Bypass_Survival	0.988	CC average
2017	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.952	CC average
	yes		Turbine_Survival	0.887	CC average
	yes		Spillway_Survival	0.965	CC average
	yes		Bypass_Survival	0.990	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	19.20	
	yes		RSW_survival	0.979	CC average
	yes		Turbine_Survival	0.817	CC average
	yes		Spillway_Survival	0.978	CC average
	yes		Bypass_Survival	0.988	CC average

McNary Dam	CC	Species	Parameter	Value	Reference
1998	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.933	Perry et al. 2006b. Draft 2005 RT rept. Season 24 hr spill treatment avg.
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2005. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.886	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
1999	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	

McNary Dam	CC	Species	Parameter	Value	Reference
	no		Turbine_Survival	0.933	Perry et al. 2006b. Draft 2005 RT rept. Season 24 hr spill treatment avg.
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2005. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.886	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
2000	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.933	Perry et al. 2006b. Draft 2005 RT rept. Season 24 hr spill treatment avg.
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2005. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.886	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
2001	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.933	Perry et al. 2006b. Draft 2005 RT rept. Season 24 hr spill treatment avg.
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2005. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.886	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Spillway_Survival	0.959	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
	no		Bypass_Survival	0.898	Axel et al. 2004a, b, Perry et al. 2006a. Ave of 2002, 03, 04 RT point estimates.
2002	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.873	Absolon et al. 2003. Paired release 2002 RT study. Hose release.
	no		Spillway_Survival	0.976	Axel et al. 2004a. Results for 2002 R/T study
	no		Bypass_Survival	0.927	Axel et al. 2004a. Results for 2002 R/T study
	no	*Steelhead*			
	no		rsw_spill_cap	0	

McNary Dam	CC	Species	Parameter	Value	Reference
	no		Turbine_Survival	0.886	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Spillway_Survival	0.976	Axel et al. 2004a. Results for 2002 R/T study
	no		Bypass_Survival	0.927	Axel et al. 2004a. Results for 2002 R/T study
2003	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.933	Perry Et al. 2006b Draft 2005 RT rept. Season 24 hr spill treatment avg.
	no		Spillway_Survival	0.928	Axel et al. 2004b. Results for 2003 R/T study
	no		Bypass_Survival	0.865	Axel et al. 2004b. Results for 2003 R/T study
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.886	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Spillway_Survival	0.928	Axel et al. 2004b. Results for 2003 R/T study
	no		Bypass_Survival	0.865	Axel et al. 2004b. Results for 2003 R/T study
2004	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.872	Perry et al. 2006a. Final 2004 RT reort page xviii
	no		Spillway_Survival	0.973	Perry et al. 2005. Draft 2004 RT report.
	no		Bypass_Survival	0.902	Perry et al. 2005. Draft 2004 RT report.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.894	Perry et al. 2006a. Final 2004 RT report. Page xviii.
	no		Spillway_Survival	0.996	Perry et al. 2006a. Final 2004 RT report.
	no		Bypass_Survival	0.976	Perry et al. 2006a. Final 2004 RT report.
2005	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.933	Perry et al. 2006b Draft 2005 RT rept season 24 hour spill treatment avg.
	no		Spillway_Survival	0.972	Perry et al. 2006b. Draft 2005 RT rept Season 24 hr spill treatment avg.
	no		Bypass_Survival	0.957	Perry et al. 2006b. Draft 2005 RT rept Season 24 hr spill treatment avg.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.886	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Spillway_Survival	0.922	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
	no		Bypass_Survival	0.927	Perry et al. 2006b. Draft 2005 RT rept. 24 h spill treatment
2006	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.851	Adams and Evans 2011
	no		Spillway_Survival	0.976	Adams and Evans 2011
	no		Bypass_Survival	0.968	Adams and Evans 2011
	no	*Steelhead*			
	no		rsw_spill_cap	0	

McNary Dam	CC	Species	Parameter	Value	Reference
	no		Turbine_Survival	0.887	Adams and Evans 2011
	no		Spillway_Survival	0.986	Adams and Evans 2011
	no		Bypass_Survival	0.976	Adams and Evans 2011
2007	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	18.7	
	no		RSW_Survival	0.939	Adams and Evans 2011
	no		Turbine_Survival	0.829	Adams and Evans 2011
	no		Spillway_Survival	0.964	Adams and Evans 2011
	no		Bypass_Survival	0.923	Adams and Evans 2011
	no	*Steelhead*			
	no		rsw_spill_cap	18.7	
	no		RSW_survival	0.934	Adams and Evans 2011
	no		Turbine_Survival	0.684	Adams and Evans 2011
	no		Spillway_Survival	0.891	Adams and Evans 2011
	no		Bypass_Survival	0.859	Adams and Evans 2011
2008	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	18.7	
	no		RSW_Survival	0.959	Adams and Evans 2011
	no		Turbine_Survival	0.918	Adams and Evans 2011
	no		Spillway_Survival	0.964	Adams and Evans 2011
	no		Bypass_Survival	0.960	Adams and Evans 2011
	no	*Steelhead*			
	no		rsw_spill_cap	18.7	
	no		RSW_survival	0.999	Adams and Evans 2011 (estimate was 1.003)
	no		Turbine_Survival	0.693	Adams and Evans 2011
	no		Spillway_Survival	0.999	Adams and Evans 2011 (estimate is 1.027)
	no		Bypass_Survival	0.999	Adams and Evans 2011 (estimate is 1.034)
2009	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	18.7	
	no		RSW_Survival	0.999	Adams and Evans 2011 (estimate is 1.000)
	no		Turbine_Survival	0.905	Adams and Evans 2011
	no		Spillway_Survival	0.982	Adams and Evans 2011
	no		Bypass_Survival	0.984	Adams and Evans 2011
	no	*Steelhead*			
	no		rsw_spill_cap	18.7	
	no		RSW_survival	0.999	Adams and Evans 2011 (estimate was 1.014)
	no		Turbine_Survival	0.851	Adams and Evans 2011
	no		Spillway_Survival	0.997	Adams and Evans 2011
	no		Bypass_Survival	0.999	Adams and Evans 2011 (estimate was 1.014)
2010	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	18.7	
	no		RSW_Survival	0.951	Pre-CC average
	no		Turbine_Survival	0.886	Pre-CC average
	no		Spillway_Survival	0.972	Pre-CC average
	no		Bypass_Survival	0.956	Pre-CC average
	no	*Steelhead*			

McNary Dam	CC	Species	Parameter	Value	Reference
	no		rsw_spill_cap	18.7	
	no		RSW_survival	0.999	Pre-CC average >=1 (average is 1.003)
	no		Turbine_Survival	0.858	Pre-CC average
	no		Spillway_Survival	0.984	Pre-CC average
	no		Bypass_Survival	0.976	Pre-CC average
2011	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	18.7	
	no		RSW_Survival	0.951	Pre-CC average
	no		Turbine_Survival	0.886	Pre-CC average
	no		Spillway_Survival	0.972	Pre-CC average
	no		Bypass_Survival	0.956	Pre-CC average
	no	*Steelhead*			
	no		rsw_spill_cap	18.7	
	no		RSW_survival	0.999	Pre-CC average >=1 (average is 1.003)
	no		Turbine_Survival	0.858	Pre-CC average
	no		Spillway_Survival	0.984	Pre-CC average
	no		Bypass_Survival	0.976	Pre-CC average
2012	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_Survival	0.976	Hughes et al. 2013
	yes		Turbine_Survival	0.955	Hughes et al. 2013
	yes		Spillway_Survival	0.971	Hughes et al. 2013
	yes		Bypass_Survival	0.936	Hughes et al. 2013
	yes	*Steelhead*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_survival	0.976	Hughes et al. 2013
	yes		Turbine_Survival	0.831	Hughes et al. 2013
	yes		Spillway_Survival	0.994	Hughes et al. 2013
	yes		Bypass_Survival	0.999	Hughes et al. 2013 (estimate was 1.015)
2013	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_Survival	0.969	CC average
	yes		Turbine_Survival	0.872	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		Bypass_Survival	0.974	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_survival	0.990	CC average
	yes		Turbine_Survival	0.789	CC average
	yes		Spillway_Survival	0.981	CC average
	yes		Bypass_Survival	0.995	CC average
2014	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_Survival	0.967	Weiland et al 2015
	yes		Turbine_Survival	0.821	Weiland et al 2015
	yes		Spillway_Survival	0.972	Weiland et al 2015

McNary Dam	CC	Species	Parameter	Value	Reference
	yes		Bypass_Survival	0.988	Weiland et al 2015
	yes	*Steelhead*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_survival	0.995	Weiland et al 2015
	yes		Turbine_Survival	0.767	Weiland et al 2015
	yes		Spillway_Survival	0.975	Weiland et al 2015
	yes		Bypass_Survival	0.987	Weiland et al 2015
2015	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_Survival	0.969	CC average
	yes		Turbine_Survival	0.872	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		Bypass_Survival	0.974	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_survival	0.990	CC average
	yes		Turbine_Survival	0.789	CC average
	yes		Spillway_Survival	0.981	CC average
	yes		Bypass_Survival	0.995	CC average
2016	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_Survival	0.969	CC average
	yes		Turbine_Survival	0.872	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		Bypass_Survival	0.974	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_survival	0.990	CC average
	yes		Turbine_Survival	0.789	CC average
	yes		Spillway_Survival	0.981	CC average
	yes		Bypass_Survival	0.995	CC average
2017	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_Survival	0.969	CC average
	yes		Turbine_Survival	0.872	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		Bypass_Survival	0.974	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	18.7	
	yes		RSW_survival	0.990	CC average
	yes		Turbine_Survival	0.789	CC average
	yes		Spillway_Survival	0.981	CC average
	yes		Bypass_Survival	0.995	CC average

Ice Harbor Dam	CC	Species	Parameter	Value	Reference
1998	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.978	Eppard et al. 2002. 2000 PIT study.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.978	Eppard et al. 2002. 2000 PIT study.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
1999	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.978	Eppard et al. 2002. 2000 PIT study.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.978	Eppard et al. 2002. 2000 PIT study.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
2000	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.978	Eppard et al. 2002. 2000 PIT study.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.978	Eppard et al. 2002. 2000 PIT study.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
2001	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.893	Eppard et al. 2005a. 2002 study (PIT results, ave of day and night results).

Ice Harbor Dam	CC	Species	Parameter	Value	Reference
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.893	Eppard et al. 2005a. 2002 study (PIT results, ave of day and night results).
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
2002	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.893	Eppard et al. 2005a. 2002 study (PIT results, ave of day and night results).
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.893	Eppard et al. 2005a. 2002 study (PIT results, ave of day and night results).
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
2003	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.938	Eppard et al. 2005b, (avg. of BiOp and 50% survival estimates for RT fish in 2003)
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.938	Eppard et al. 2005b, (avg. of BiOp and 50% survival estimates for RT fish in 2003)
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
2004	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.963	Eppard et al. 2005c (avg. of bulk and flat survival estimates for RT fish in 2004)
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research.
	no	*Steelhead*			
	no		rsw_spill_cap	0	

Ice Harbor Dam	CC	Species	Parameter	Value	Reference
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag chinook)
	no		Spillway_Survival	0.977	Axel et al. 2005. 2004 RT steelhead study (95% CI from flat spill estimate since pt estimates are the same for both treatments).
	no		RSW_Survival	1	
	no		Bypass_Survival	0.996	Axel et al. 2003. Report for 2001 research. Chinook
2005	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	7.9	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag fish)
	no		Spillway_Survival	0.965	Axel G.A. et al, 2005, Letter report to COE NWW for 2005 data (avg. of spill survival estimates for both operations)
	no		RSW_Survival	0.97	Axel G.A. et al, 2005, Letter report to COE NWW for 2005 data
	no		Bypass_Survival	0.997	Axel G.A. et al, 2005, Letter report to COE NWW for 2005 data
	no	*Steelhead*			
	no		rsw_spill_cap	7.9	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	no		Spillway_Survival	0.99	Axel G.A. et al, 2005, Letter report to COE NWW for 2005 data (avg. of spill survival estimates for both operations) Steelhead
	no		RSW_Survival	0.985	Axel G.A.. et al, 2005, Letter report to COE NWW for 2005 steelhead data
	no		Bypass_Survival	1	Axel G.A.. et al, 2005, Letter report to COE NWW for 2005 steelhead data
2006	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	Axel et al 2007. Average of two operations.
	yes		RSW_Survival	0.954	Axel et al 2007. Average of two operations.
	yes		Bypass_Survival	0.978	Axel et al 2007. Average of two operations.
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	Axel et al 2007. Average of two operations. (estimate is 1.023)
	yes		RSW_Survival	0.999	Axel et al 2007. Average of two operations. (estimate is 1.002)
	yes		Bypass_Survival	0.999	Axel et al 2007. Average of two operations. (estimate is 1.005)
2007	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.992	Axel et al 2008. Average of two operations.
	yes		RSW_Survival	0.949	Axel et al 2008. Average of two operations.
	yes		Bypass_Survival	0.947	Axel et al 2008. Average of two operations.
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	

Ice Harbor Dam	CC	Species	Parameter	Value	Reference
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.966	Axel et al 2008. Average of two operations.
	yes		RSW_Survival	0.974	Axel et al 2008. Average of two operations.
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2008	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	7.9	
	no		Turbine_Survival	0.943	Axel et al 2010a
	no		Spillway_Survival	0.966	Axel et al 2010a (not included in CC average due to non-current operation)
	no		RSW_Survival	0.953	Axel et al 2010a (not included in CC average due to non-current operation)
	no		Bypass_Survival	0.977	Axel et al 2010a (not included in CC average due to non-current operation)
	no	*Steelhead*			
	no		rsw_spill_cap	7.9	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	no		Spillway_Survival	0.973	Axel et al 2010a (not included in CC average due to non-current operation)
	no		RSW_Survival	0.970	Axel et al 2010a (not included in CC average due to non-current operation)
	no		Bypass_Survival	0.971	Axel et al 2010a (not included in CC average due to non-current operation)
2009	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	7.9	
	no		Turbine_Survival	0.943	CC average
	no		Spillway_Survival	0.931	Axel et al 2010b. Average of three operations. (not included in CC average due to non-current operation)
	no		RSW_Survival	0.932	Axel et al 2010b. Average of three operations. (not included in CC average due to non-current operation)
	no		Bypass_Survival	0.904	Axel et al 2010b. Average of three operations. (not included in CC average due to non-current operation)
	no	*Steelhead*			
	no		rsw_spill_cap	7.9	
	no		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	no		Spillway_Survival	0.832	Axel et al 2010b. Average of three operations. (not included in CC average due to non-current operation)
	no		RSW_Survival	0.929	Axel et al 2010b. Average of three operations. (not included in CC average due to non-current operation)
	no		Bypass_Survival	0.932	Axel et al 2010b. Average of three operations. (not included in CC average due to non-current operation)
2010	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average

Ice Harbor Dam	CC	Species	Parameter	Value	Reference
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2011	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2012	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2013	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2014	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	

Ice Harbor Dam	CC	Species	Parameter	Value	Reference
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2015	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2016	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)
2017	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.943	CC average
	yes		Spillway_Survival	0.972	CC average
	yes		RSW_Survival	0.953	CC average
	yes		Bypass_Survival	0.968	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	7.9	
	yes		Turbine_Survival	0.871	Absolon et al. 2005. (2003 survival study direct releases PIT tag yearling chinook)
	yes		Spillway_Survival	0.999	CC average >= 1 (average is 1.022)
	yes		RSW_Survival	0.977	CC average

Ice Harbor Dam	CC	Species	Parameter	Value	Reference
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.005)

Lower Monumental Dam	CC	Species	Parameter	Value	Reference
1998	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.95	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.95	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
1999	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.958	Hockersmith et al. 2000 (report for 1999 research)
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.958	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
2000	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended

Lower Monumental Dam	CC	Species	Parameter	Value	Reference
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.958	Hockersmith et al. 2000 (report for 1999 research)
	no	Steelhead			
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.958	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
2001	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.958	Hockersmith et al. 2000 (report for 1999 research)
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.958	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
2002	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.956	Muir et al. 1995. Ave of 1994 estimates (0.927 and 0.984).
	no		Bypass_Survival	0.958	Hockersmith et al. 2000 (report for 1999 research)
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Hockersmith et al. 2000 (report for 1999 research)
	no		Spillway_Survival	0.956	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Bypass_Survival	0.958	
2003	no				

Lower Monumental Dam	CC	Species	Parameter	Value	Reference
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.9	Hockersmith et al. 2004 (report for 2003 research)
	no		Bypass_Survival	0.958	Hockersmith et al. 2000 (report for 1999 research)
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.865	Muir et al. 2001. N. Am. J. of Fish Mgmt. (PIT tagged 1993-1997 yearling chinook) Relative Survival Estimate, controls released downstream of bypass outfall, last row of table 2 & table 2-extended
	no		Spillway_Survival	0.9	Hockersmith et al. 2004 (report for 2003 research)
	no		Bypass_Survival	0.958	Hockersmith et al. 2000 (report for 1999 research)
2004	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.881	Hockersmith et al. 2005 (report for 2004 research, 2 week test)
	no		Spillway_Survival	0.961	Hockersmith et al. 2005 (report for 2004 research, 2 week test)
	no		Bypass_Survival	0.922	Hockersmith et al. 2005 (report for 2004 research, 2 week test)
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.881	Hockersmith et al. 2005 (report for 2004 research, 2 week test)
	no		Spillway_Survival	0.961	Hockersmith et al. 2005 (report for 2004 research, 2 week test)
	no		Bypass_Survival	0.922	Hockersmith et al. 2005 (report for 2004 research, 2 week test)
2005	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.881	Hockersmith et al. 2005 (report for 2004 research)
	no		Spillway_Survival	0.932	Hockersmith et al. (prelim. report for 2005 research). Average of spillbays 7 (.92) & 8 (.944).
	no		Bypass_Survival	0.922	Hockersmith et al. 2005 (report for 2004 research)
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.881	Hockersmith et al. 2005 (report for 2004 research)
	no		Spillway_Survival	0.932	Hockersmith et al. (prelim. report for 2005 research). Average of spillbays 7 (.92) & 8 (.944).
	no		Bypass_Survival	0.922	Hockersmith et al. 2005 (report for 2004 research)
2006	no				

Lower Monumental Dam	CC	Species	Parameter	Value	Reference
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.910	Hockersmith et al 2008a
	no		Spillway_Survival	0.925	Hockersmith et al 2008a
	no		Bypass_Survival	0.987	Hockersmith et al 2008a
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.838	Hockersmith et al 2008a
	no		Spillway_Survival	0.999	Hockersmith et al 2008a
	no		Bypass_Survival	0.999	Hockersmith et al 2008a (estimate is 1.010)
2007	no				
	no	Chinook 1			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.909	Hockersmith et al 2008b
	no		Spillway_Survival	0.959	Hockersmith et al 2008b
	no		Bypass_Survival	0.941	Hockersmith et al 2008b
	no	Steelhead			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	no		Spillway_Survival	0.939	Hockersmith et al 2008b
	no		Bypass_Survival	0.986	Hockersmith et al 2008b
2008	no				
	no	Chinook 1			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.999	Hockersmith et al 2010a (estimate is 1.012)
	no		Turbine_Survival	0.914	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	no		Spillway_Survival	0.976	Hockersmith et al 2010a
	no		Bypass_Survival	0.936	Hockersmith et al 2010a
	no	Steelhead			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.999	Hockersmith et al 2010a (estimate is 1.026)
	no		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	no		Spillway_Survival	0.999	Hockersmith et al 2010a (estimate is 1.014)
	no		Bypass_Survival	0.977	Hockersmith et al 2010a
2009	no				
	no	Chinook 1			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.988	Hockersmith et al 2010b. Average of two operations.
	no		Turbine_Survival	0.999	Hockersmith et al 2010b. Average of two operations. (estimate is 1.020)
	no		Spillway_Survival	0.975	Hockersmith et al 2010b. Average of two operations.
	no		Bypass_Survival	0.954	Hockersmith et al 2010b. Average of two operations.

Lower Monumental Dam	CC	Species	Parameter	Value	Reference
	no	Steelhead			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.997	Hockersmith et al 2010b. Average of two operations.
	no		Turbine_Survival	0.999	Hockersmith et al 2010b. Average of two operations. (estimate is 1.009)
	no		Spillway_Survival	0.987	Hockersmith et al 2010b. Average of two operations.
	no		Bypass_Survival	0.930	Hockersmith et al 2010b. Average of two operations.
2010	no				
	no	Chinook 1			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.988	Pre-CC average
	no		Turbine_Survival	0.914	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	no		Spillway_Survival	0.975	Pre-CC average
	no		Bypass_Survival	0.971	Pre-CC average
	no	Steelhead			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.998	Pre-CC average
	no		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	no		Spillway_Survival	0.989	Pre-CC average
	no		Bypass_Survival	0.988	Pre-CC average
2011	no				
	no	Chinook 1			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.988	Pre-CC average
	no		Turbine_Survival	0.914	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	no		Spillway_Survival	0.975	Pre-CC average
	no		Bypass_Survival	0.971	Pre-CC average
	no	Steelhead			
	no		rsw_spill_cap	8.0	
	no		RSW_survival	0.998	Pre-CC average
	no		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	no		Spillway_Survival	0.989	Pre-CC average
	no		Bypass_Survival	0.973	Pre-CC average
2012	yes				
	yes	Chinook 1			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.998	Skalski et al 2013b
	yes		Turbine_Survival	0.932	Skalski et al 2013b
	yes		Spillway_Survival	0.987	Skalski et al 2013b
	yes		Bypass_Survival	0.999	Skalski et al 2013b (estimate is 1.007)

Lower Monumental Dam	CC	Species	Parameter	Value	Reference
	yes	Steelhead			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.991	Skalski et al 2013b
	yes		Turbine_Survival	0.814	Skalski et al 2013b
	yes		Spillway_Survival	0.988	Skalski et al 2013b
	yes		Bypass_Survival	0.991	Skalski et al 2013b
2013	yes				
	yes	Chinook 1			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.998	CC average
	yes		Turbine_Survival	0.932	CC average
	yes		Spillway_Survival	0.987	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.007)
	yes	Steelhead			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.991	CC average
	yes		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	yes		Spillway_Survival	0.988	CC average
	yes		Bypass_Survival	0.991	CC average
2014	yes				
	yes	Chinook 1			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.998	CC average
	yes		Turbine_Survival	0.932	CC average
	yes		Spillway_Survival	0.987	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.007)
	yes	Steelhead			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.991	CC average
	yes		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	yes		Spillway_Survival	0.988	CC average
	yes		Bypass_Survival	0.991	CC average
2015	yes				
	yes	Chinook 1			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.998	CC average
	yes		Turbine_Survival	0.932	CC average
	yes		Spillway_Survival	0.987	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.007)
	yes	Steelhead			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.991	CC average
	yes		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013

Lower Monumental Dam	CC	Species	Parameter	Value	Reference
	yes		Spillway_Survival	0.988	CC average
	yes		Bypass_Survival	0.991	CC average
2016	yes				
	yes	Chinook 1			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.998	CC average
	yes		Turbine_Survival	0.932	CC average
	yes		Spillway_Survival	0.987	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.007)
	yes	Steelhead			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.991	CC average
	yes		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	yes		Spillway_Survival	0.988	CC average
	yes		Bypass_Survival	0.991	CC average
2017	yes				
	yes	Chinook 1			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.998	CC average
	yes		Turbine_Survival	0.932	CC average
	yes		Spillway_Survival	0.987	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.007)
	yes	Steelhead			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.991	CC average
	yes		Turbine_Survival	0.830	Recalculated mean of data from Hockersmith et al 2005, Hockersmith et al 2008a, Hockersmith et al 2008b, Hockersmith et al 2010 and Skalski et al 2013
	yes		Spillway_Survival	0.988	CC average
	yes		Bypass_Survival	0.991	CC average

Little Goose Dam	CC	Species	Parameter	Value	Reference
1998	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 2001 (PIT-tag hose release data from 1997)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research

Little Goose Dam	CC	Species	Parameter	Value	Reference
	no		Spillway_Survival	0.972	Muir et al. 1998. (PIT-tag hose release data from 1997).
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
1999	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 2001 (PIT-tag hose release data from 1997)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 1998. (PIT-tag hose release data from 1997).
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2000	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 2001 (PIT-tag hose release data from 1997)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 1998. (PIT-tag hose release data from 1997).
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2001	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 2001 (PIT-tag hose release data from 1997)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 1998. (PIT-tag hose release data from 1997).
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2002	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	

Little Goose Dam	CC	Species	Parameter	Value	Reference
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 2001 (PIT-tag hose release data from 1997)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 1998. (PIT-tag hose release data from 1997).
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2003	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 2001 (PIT-tag hose release data from 1997)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 1998. (PIT-tag hose release data from 1997).
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2004	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 2001 (PIT-tag hose release data from 1997)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	Muir et al. 1998. (PIT-tag hose release data from 1997).
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2005	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.923	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.913	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research (based on 63 RT fish)
	no		Bypass_Survival	0.964	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	

Little Goose Dam	CC	Species	Parameter	Value	Reference
	no		Turbine_Survival	0.93	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.972	
	no		Bypass_Survival	0.95	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2006	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.839	Beeman et al. 2008b, USACE 2010 and USGS 2010
	no		Spillway_Survival	0.970	Beeman et al. 2008b, USACE 2010 and USGS 2010
	no		Bypass_Survival	0.954	Beeman et al. 2008b, USACE 2010 and USGS 2010
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.918	Beeman et al. 2008b, USACE 2010 and USGS 2010
	no		Spillway_Survival	0.980	Beeman et al. 2008b, USACE 2010 and USGS 2010
	no		Bypass_Survival	0.992	Beeman et al. 2008b, USACE 2010 and USGS 2010
2007	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.886	Beeman et al. 2008c, USACE 2010 and USGS 2010
	no		Spillway_Survival	0.999	Beeman et al. 2008c, USACE 2010 and USGS 2010
	no		Bypass_Survival	0.998	Beeman et al. 2008c, USACE 2010 and USGS 2010
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.963	Beeman et al. 2008c, USACE 2010 and USGS 2010
	no		Spillway_Survival	0.982	Beeman et al. 2008c, USACE 2010 and USGS 2010
	no		Bypass_Survival	0.993	Beeman et al. 2008c, USACE 2010 and USGS 2010
2008	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.898	Pre-CC average
	no		Spillway_Survival	0.983	Pre-CC average
	no		Bypass_Survival	0.970	Pre-CC average
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.933	Pre-CC average
	no		Spillway_Survival	0.978	Pre-CC average
	no		Bypass_Survival	0.988	Pre-CC average
2009	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	Beeman et al 2010 (estimate is 1.001)
	yes		Turbine_Survival	0.928	Beeman et al 2010
	yes		Spillway_Survival	0.948	Beeman et al 2010

Little Goose Dam	CC	Species	Parameter	Value	Reference
	yes		Bypass_Survival	0.999	Beeman et al 2010 (estimate is 1.016)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.998	Beeman et al 2010
	yes		Turbine_Survival	0.999	Beeman et al 2010 (estimate is 1.005)
	yes		Spillway_Survival	0.997	Beeman et al 2010
	yes		Bypass_Survival	0.994	Beeman et al 2010
2010	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average >= 1 (average is 1.004)
	yes		Turbine_Survival	0.890	CC average
	yes		Spillway_Survival	0.948	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.000)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average
	yes		Turbine_Survival	0.853	CC average
	yes		Spillway_Survival	0.996	CC average
	yes		Bypass_Survival	0.995	CC average
2011	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average >= 1 (average is 1.004)
	yes		Turbine_Survival	0.890	CC average
	yes		Spillway_Survival	0.948	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.000)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average
	yes		Turbine_Survival	0.853	CC average
	yes		Spillway_Survival	0.996	CC average
	yes		Bypass_Survival	0.995	CC average
2012	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	Skalski et al 2013a (estimate is 1.005)
	yes		Turbine_Survival	0.870	Skalski et al 2013a
	yes		Spillway_Survival	0.949	Skalski et al 2013a
	yes		Bypass_Survival	0.988	Skalski et al 2013a
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	Skalski et al 2013a (estimate is 1.001)
	yes		Turbine_Survival	0.806	Skalski et al 2013a
	yes		Spillway_Survival	0.992	Skalski et al 2013a
	yes		Bypass_Survival	0.997	Skalski et al 2013a
2013	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average >= 1 (average is 1.004)

Little Goose Dam	CC	Species	Parameter	Value	Reference
	yes		Turbine_Survival	0.890	CC average
	yes		Spillway_Survival	0.948	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.000)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average
	yes		Turbine_Survival	0.853	CC average
	yes		Spillway_Survival	0.996	CC average
	yes		Bypass_Survival	0.995	CC average
2014	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average >= 1 (average is 1.004)
	yes		Turbine_Survival	0.890	CC average
	yes		Spillway_Survival	0.948	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.000)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average
	yes		Turbine_Survival	0.853	CC average
	yes		Spillway_Survival	0.996	CC average
	yes		Bypass_Survival	0.995	CC average
2015	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average >= 1 (average is 1.004)
	yes		Turbine_Survival	0.890	CC average
	yes		Spillway_Survival	0.948	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.000)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average
	yes		Turbine_Survival	0.853	CC average
	yes		Spillway_Survival	0.996	CC average
	yes		Bypass_Survival	0.995	CC average
2016	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average >= 1 (average is 1.004)
	yes		Turbine_Survival	0.890	CC average
	yes		Spillway_Survival	0.948	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.000)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average
	yes		Turbine_Survival	0.853	CC average
	yes		Spillway_Survival	0.996	CC average
	yes		Bypass_Survival	0.995	CC average
2017	yes				
	yes	*Chinook 1*			

Little Goose Dam	CC	Species	Parameter	Value	Reference
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average >= 1 (average is 1.004)
	yes		Turbine_Survival	0.890	CC average
	yes		Spillway_Survival	0.948	CC average
	yes		Bypass_Survival	0.999	CC average >= 1 (average is 1.000)
	yes	*Steelhead*			
	yes		rsw_spill_cap	8.0	
	yes		RSW_survival	0.999	CC average
	yes		Turbine_Survival	0.853	CC average
	yes		Spillway_Survival	0.996	CC average
	yes		Bypass_Survival	0.995	CC average

Lower Granite Dam	CC	Species	Parameter	Values	Reference
1998	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	Pre RSW, Best Professional Judgement - 2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper) Pre RSW, Best Professional Judgement.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
1999	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	Pre RSW, Best Professional Judgement - 2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper) Pre RSW, Best Professional Judgement.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research

Lower Granite Dam	CC	Species	Parameter	Values	Reference
2000	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	Pre RSW, Best Professional Judgement - 2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper) Pre RSW, Best Professional Judgement.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2001	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	Pre RSW, Best Professional Judgement - 2000 Biological Opinion (ref: 2000 NMFS Passage White Paper)
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	0	
	no		Turbine_Survival	0.945	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
	no		Spillway_Survival	0.98	2000 Biological Opinion (ref: 2000 NMFS Passage White Paper) Pre RSW, Best Professional Judgement.
	no		RSW_Survival	1	
	no		Bypass_Survival	0.97	Perry 7Oct2005 letter to Kalamasz with prelim results for 2005 research
2002	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Spillway_Survival	0.931	Plumb et al.(2004), report on 2003 season. Based on non RSW passed fish.
	no		RSW_Survival	0.98	Plumb et al.(2004), report on 2003 season
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Spillway_Survival	0.931	Plumb et al.(2004), report on 2003 season. Based on non RSW passed fish.

Lower Granite Dam	CC	Species	Parameter	Values	Reference
	no		RSW_Survival	0.98	Plumb et al.(2004), report on 2003 season
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
2003	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Spillway_Survival	0.931	Plumb et al.(2004), report on 2003 season. Based on non RSW passed fish.
	no		RSW_Survival	0.98	Plumb et al.(2004), report on 2003 season
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Spillway_Survival	0.931	Plumb et al.(2004), report on 2003 season. Based on non RSW passed fish.
	no		RSW_Survival	0.98	Plumb et al.(2004), report on 2003 season
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
2004	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Spillway_Survival	0.931	Plumb et al.(2004), report on 2003 season. Based on non RSW passed fish.
	no		RSW_Survival	0.98	Plumb et al.(2004), report on 2003 season
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Spillway_Survival	0.931	Plumb et al.(2004), report on 2003 season. Based on non RSW passed fish.
	no		RSW_Survival	0.98	Plumb et al.(2004), report on 2003 season
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
2005	no				
	no	*Chinook 1*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Spillway_Survival	0.931	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		RSW_Survival	0.979	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no	*Steelhead*			
	no		rsw_spill_cap	6.75	
	no		Turbine_Survival	0.945	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research

Lower Granite Dam	CC	Species	Parameter	Values	Reference
	no		Spillway_Survival	0.931	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		RSW_Survival	0.979	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
	no		Bypass_Survival	0.97	Perry, R., 7 Oct 2005 letter to R. Kalamasz. Prelim results for 2005 research
2006	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	Beeman et al 2008a
	yes		Spillway_Survival	0.970	Beeman et al 2008a
	yes		RSW_Survival	0.985	Beeman et al 2008a
	yes		Bypass_Survival	0.987	Beeman et al 2008a
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	Beeman et al 2008a
	yes		Spillway_Survival	0.985	Beeman et al 2008a
	yes		RSW_Survival	0.952	Beeman et al 2008a
	yes		Bypass_Survival	0.955	Beeman et al 2008a
2007	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2008	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2009	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average

Lower Granite Dam	CC	Species	Parameter	Values	Reference
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2010	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2011	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2012	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2013	yes				
	yes	*Chinook 1*			

Lower Granite Dam	CC	Species	Parameter	Values	Reference
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2014	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2015	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average
2016	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average

Lower Granite Dam	CC	Species	Parameter	Values	Reference
	yes		Bypass_Survival	0.955	CC average
2017	yes				
	yes	*Chinook 1*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.815	CC average
	yes		Spillway_Survival	0.970	CC average
	yes		RSW_Survival	0.985	CC average
	yes		Bypass_Survival	0.987	CC average
	yes	*Steelhead*			
	yes		rsw_spill_cap	6.75	
	yes		Turbine_Survival	0.879	CC average
	yes		Spillway_Survival	0.985	CC average
	yes		RSW_Survival	0.952	CC average
	yes		Bypass_Survival	0.955	CC average

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6.1 Summary

The main purpose of the hydrological processes submodel is to realistically represent the environmental conditions, particularly water flow, velocity, and temperature. The relationship of water velocity to flow is required for mechanistic fish migration modeling. In the model, these conditions vary daily and across river segments.

6.2 Methods

First, reservoir geometry is developed in order to model volumes of impounded reaches and calibrated with data from various water levels on a reach-by-reach basis. Second, water travel time data is used for calibrating the flow-velocity relationship in the impounded reservoirs. Third, a flow-velocity relationship is developed for free-flowing conditions.

Water velocity in an impounded reservoir is a function of both flow rate and reservoir volume. Volumes are computed as if the reservoir where an idealized channel with constant, symmetric slopes on the sides and a triangular profile along the thalweg. The methods are based on CRiSP (2000) and COMPASS (2008).

6.3 Pool Volume

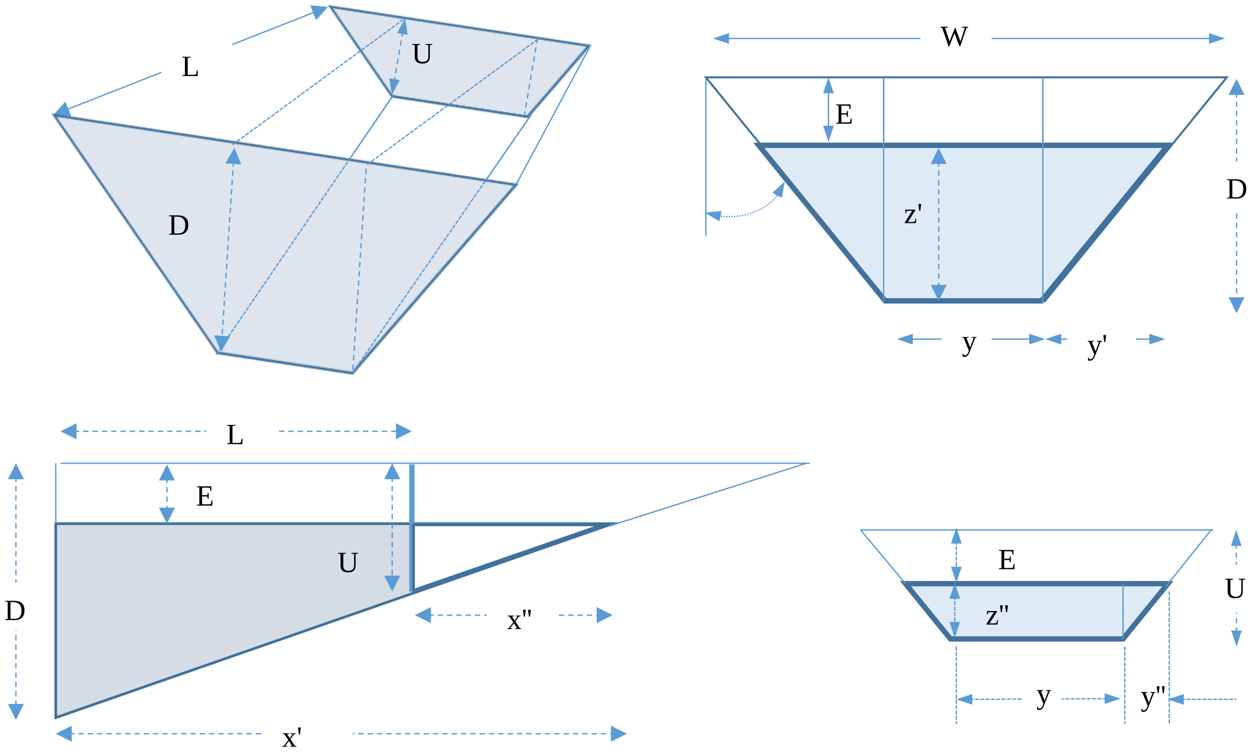

Figure 1 Reservoir volume model.

The reservoir is modeled as having a trapezoidal cross section with a sloping bottom, deeper downstream and shallower upstream. The slope is constant along the entire length. Several dimensions are specific to each reservoir (Capitals):

- L = length of the reservoir
- W = a representational width for the downstream end
- D = depth of the reservoir at downstream end at full pool
- U = depth of the reservoir at the upstream end at full pool
- E = Elevation drop below full pool, positive numbers (drawdown)
- θ = Slope of reservoir banks, equal on both sides, increasing from 0 at vertical.

These additional geometric relationships ease the computations with notation from Figure 1:

- $z' = D - E$
- $z'' = U - E$
- $y' = z' \cdot \tan\theta$
- $y'' = z'' \cdot \tan\theta$
- $y = W - 2 \cdot D \cdot \tan\theta$

- $x' = \frac{L \cdot (D - E)}{(D - U)}$
- $x'' = \frac{L(U - E)}{(D - U)}$

The total volume of the reservoir is computed in parts. First, recognize that the longitudinal profile of the volume is triangular-shaped if extended, so the total volume (V_t) is larger volume based on the downstream end (V_d) minus the smaller volume based on the upstream end (V_u). V_d and V_u each consist of a central volume (V_1, with a rectangular end), and 2 side volumes (V_2 with triangular ends).

The central volumes, based on upstream or downstream depth are wedge-shaped, thus:

$$V_{D1} = \frac{x'z'y}{2} \ , \ V_{U1} = \frac{x''z''y}{2}$$

The side volumes have a constant slope θ, and taper to a point at distance x' from the downstream end. The computation is illustrated using one side volume at the downstream location. At any position *x* along the side, the reservoir has a cross sectional area of a triangle using the local values of *z* and *y*:

$$Area_x = \frac{zy}{2} = \frac{(z)^2 \tan(\theta)}{2}$$

Since *z* changes linearly along the entire distance from 0 to x', we can write the cross sectional area in terms of x:

$$Area_x = \left(z'\left(1 - \frac{x}{x'}\right)\right)^2 \frac{\tan(\theta)}{2}$$

Now, to obtain the volume, integrate along x from 0 to x':

$$\begin{aligned} V_{D2} &= \int_0^{x'} \left(z'\left(1 - \frac{x}{x'}\right)\right)^2 \frac{\tan(\theta)}{2} dx \\ &= z'^2 \frac{\tan(\theta)}{2} \int_0^{x'} \left(1 - \frac{x}{x'}\right)^2 dx \\ &= \frac{x'z'^2 \tan(\theta)}{6} \end{aligned}$$

Calculation of V_{U2} is analogous.

The total downstream volume is computed from the above elements:

$$\begin{aligned}
V_D &= V_{D1} + 2V_{D2} \\
&= \frac{x'z'y}{2} + \frac{x'z'^2\tan(\theta)}{3} \\
&= x'z'\left(\frac{y}{2} + \frac{z'\tan(\theta)}{3}\right) \\
&= x'z'\left(\frac{W}{2} - D\tan(\theta) + \frac{(D-E)\tan(\theta)}{3}\right) \\
&= \frac{(D-E)^2}{(D-U)} L\left(\frac{W}{2} - \frac{(2D+E)\tan(\theta)}{3}\right)
\end{aligned}$$

The upstream "extra" volume is only computed in the case when E < U.

$$\begin{aligned}
V_U &= V_{U1} + 2V_{U2} \\
&= \frac{x''z''y}{2} + \frac{x''z''^2\tan(\theta)}{3} \\
&= x''z''\left(\frac{y}{2} + \frac{z''\tan(\theta)}{3}\right) \\
&= x''z''\left(\frac{W}{2} - D\tan(\theta) + \frac{(U-E)\tan(\theta)}{3}\right) \\
&= \frac{(U-E)^2}{(D-U)} L\left(\frac{W}{2} - \frac{(3D+E-U)\tan(\theta)}{3}\right)
\end{aligned}$$

$V_{total} = V_D - V_U$ if $E<U$

$V_{total} = V_D$ if $E \geq U$

Full pool volume is computed with E = 0:

$$\begin{aligned}
V_{full} &= \frac{D^2}{(D-U)} L\left(\frac{W}{2} - \frac{2D\tan(\theta)}{3}\right) - \frac{U^2}{(D-U)} L\left(\frac{W}{2} - \frac{(3D-U)\tan(\theta)}{3}\right) \\
&= \frac{L}{(D-U)}\left(\frac{D^2W}{2} - \frac{2D^3\tan(\theta)}{3} - \frac{U^2W}{2} + \frac{U^2(3D-U)\tan(\theta)}{3}\right)
\end{aligned}$$

The formula for V_{full} can be used to compute the representative slope parameter (θ). Solving for θ:

$$\theta = \arctan\left(\frac{\dfrac{V_{full}(D-U)}{L} - \dfrac{W}{2}(D^2 - U^2)}{U^2D - \dfrac{U^3}{3} - \dfrac{2}{3}D^3}\right)$$

However, it is constrained by the geometry ($y \geq 0$) and the relationship: $y = W - 2D \tan \theta$. Therefore:

$$\theta \leq \arctan\left(\frac{W}{2D}\right)$$

In practice, representative depths or widths can be altered so as to ensure that θ is valid. Also, for reservoirs with known volumes below full pool, the slope can be computed from alternative volumes.

Volume in pools where U = D are much simpler. It is conceptualized as a rectangular solid for the central volume and two simple triangular solids, each:

$$V_1 = L(D-E)y = L(D-E)(W - 2D\tan(\theta))$$

$$V_2 = \frac{L(D-E)y'}{2} = \frac{L(D-E)^2\tan(\theta)}{2}$$, then

$$V_{U=D} = L(D-E)(W-(D+E)\tan(\theta))$$

Note that these converge to rectangular solids in limits of slope and drawdown:

$V = L(D-E)W$ if slope = 0

$V \rightarrow L(D-E)y \rightarrow 0$, as $E \rightarrow D$.

Using the volume formulas, the bank slopes were computed from full pool volumes (except Bonneville Pool where a 3-foot drawdown volume was used) and the parameters used are shown in Table 1. Cross sections of the reservoirs are shown in the Appendix.

6.4 Water velocity

Water velocity is fundamentally governed by the continuity equation (Gordon et al. 1992): $Vel = \frac{Q}{A}$ where Vel = velocity in ft/sec Q = discharge in ft^3/sec and A is cross sectional area ft^2.

However, in an impounded reach compared to a free-flowing river, different processes dominate changes in A. In an impounded reach, velocity is primarily a function of the flow alone because the cross-sectional area is controlled by the elevation at the dam, so Vel ~Q. To frame this in terms of the river geometry where V= Volume and L = Length of a reservoir:

Since $A = \frac{V}{L}$, then $Vel_{imp} = \frac{QL}{V}$ or $Vel_{imp} = \alpha Q$.

In an open river, the cross sectional area of the river increases with discharge according to a power function aQ^b (Gordon 1992), so:

Since $A = aQ^b$, then $Vel_{free} = \frac{1}{a}\frac{Q}{Q^b} = \alpha Q^{\beta}$.

For a reach of river that has both an impounded and free-flowing portion, as when E > U, then the average water velocity over the entire reach is related to the total travel time (TT) across the two portions of the river:

$$Vel_{avg} = \frac{L}{TT} = \frac{L}{TT_{imp} + TT_{free}} = \frac{L}{x'/Vel_{imp} + (L-x')/Vel_{free}} = \frac{LVel_{free}Vel_{imp}}{LVel_{imp} + x'(Vel_{free} - Vel_{imp})}$$

since $x' = \frac{L \cdot (D-E)}{(D-U)}$ then $Vel_{avg} = \frac{Vel_{imp}Vel_{free}(D-U)}{Vel_{free}(D-E) + Vel_{imp}(E-U)}$ for E>U.

Using the relationship of $Vel_{imp} = \frac{QL}{V}$ the impounded water velocities in the system are estimated.

ACOE studies on the Snake River (ACOE 2001) provide simulated velocities for a free-flowing Snake River and a linearized form of Vel_{free} is fit to the data:

$$\log(Vel_{free}) = \log(\alpha) + \beta \cdot \log(Q)$$

6.5 Data

River geometry parameters are from multiple sources and summarized in Table 1. The forebay elevation is from published sources. The width, lower depth and upper depth are representative.

Flow/velocity data for impunded and unimpuounded conditions are from multiple sources. Snake River data is from ACOE (2001, Table 9-2) and uses water particle travel times between LWG and BON (McCann and Filardo 2006). A river-wide simulated velocity for the Snake River was obtained by averaging the mean velocities in each class weighted by the proportion of total river area having those velocities (Table 2). Free-flowing Columbia River reachs are calibrated with data from Davidson (1965) which includes data from 1946 – 1953 on flow and velocity at two sites on the Columbia prior to damming. The Trinidad site was located ~12 miles downstream of the Rock Island dam (built in 1933) prior to construction of Wanapum, and the Dalles site approximately half way between the current TDA and JDA dams (which did not then exist). The Hanford Reach is unique in that it is free-flowing at all times. The flow-velocity relationships here are based on specific data from Fish Passage Center (FPC 2009).

Table 1 Pool geometry parameters[1] . Units are feet unless otherwise stated. Slope (θ) is calibrated (see methods). Abbreviations with a dot and letter attached (e.g. "MCN.a") are flooded by the downstream dam and are also included when computing volume and surface area and calibrating slope which is then shared by all of the included reaches. Parentheses surround suspect measures.

Name	abbrev	Forebay	floor	Lower elev	Lower depth	Upper depth	Width	Slope (degrees)	DESC Length (Miles)	Length ACOE[2] (Miles)	DESC River Mile	Other River Mile	Full Volume (KAF)	Full Area (acres)
Bonneville.Pool	BON	76.5	-16	-16	92.5	22	5000	87.37	45.98	46.2	128.3	146.1	723	
The.Dalles.Pool	TDA	160	60	70	90	35	4624	87.06	12.2	23.9	174.2	191.5	330	
Descutes.Confluence	TDA.a			125	35	20	3624	87.06	11.4		186.4			
John.Day.Pool	JDA	268	140	160	108	20	5500	82.59	73.8	76.4	197.9	215.6	2523.9	
McNary.Pool	MCN	340	248	260	80	40	7300	87.04	32.5	(61.6)	271.7	292	1350	37000
Lower.Snake.River	MCN.a			300	40	10	2000	87.04	8.98		0	0		
Columbia.above.Snake	MCN.b			300	40	15	2000	87.04	12.99		304.2	324.2		
Priest.Rapids.Pool	PRD	488	401	401	87	30	3500	86.7	17.84		398.9	397.1	199	
Wanapum.Pool	WAN	572	456	456	116	42	3500	85.47	37.4		416.8	415.8	587	
Rock.Island.Pool	RIS	613	530	530	83	44	1500	81.35	14.6		454.1	453.4	130	
Wenatchee.Columbia	RIS.a			569	44	20	2000	81.35	5.6		468.7			
Rocky.Reach.Pool	RRH	707	599	599	108	27	1816	78.47	42		474.3	473.7	387.5	
Wells.Pool	WEL	781	670	680	101	51	3000	81.84	7.8	29.5	516.3	515.6	331.2	9740
Methow.Confluence	WEL.a			730	51	31	2500	81.84	9.9		524.1			
Okanogan.Confluence	WEL.b			750	31	21	2500	81.84	10.7		534			
Lower.Methow	WEL.c			741	50	10	300	81.84	1.53		0			
Ice.Harbor.Pool	IHR	440		330	110	18	2154	72.47	30.9	31.9	9	9.7	406.3	8375
Lower.Monumental.Pool	LMN	540		420	120	42	1938	75.61	28.6	28.7	40	41.6	377	6590
Little.Goose.Pool	LGS	638		518	120	25	2200	67.97	35.5	37.2	68.6	70.3	565.2	10025
Lower.Granite.Pool	LWG	738		598	140	25	2200	75.3	31.3	32	104.1	107.5	487.6	8900
Snake.above.Clearwater	LWG.a			713	25	10	1000	75.3	8.2		135.3	139.4		
Clearwater.River	LWG.b			713	25	10	500	75.3	4.22	4.6	0	0		

[1] Mixed sources: ACOE (2012a, 2012b), COMPASS (2008), CRiSP (2000), Google (2012), Kahler (2012), Pinney (2012), Wikipedia (2012), Benner (2012)

[2] Includes all impounded river that may span more than one COMPASS *.desc reach.

Table 2 Comparison of Simulated Velocity Distributions for the 10, 50, and 80 Percent Exceedance flows. Adapted from Table 9-2 ACOE (2001). This is used to generate the simulated velocities (bottom row): weighted averages by area.

	Flow (KCFS):	111.5	111.5	31.7	31.7	19.9	19.9
	Exceedance probability:	10%	10%	50%	50%	80%	80%
Velocity range (ft / sec)	Mean velocity (ft / sec)	Impounded area (acres)	Unimpounded area (acres)	Impounded area (acres)	Unimpounded area (acres)	Impounded area (acres)	Unimpounded area (acres)
0-0.5	0.25	9,839	176	26,210	711	31,012	1,670
0.5-1	0.75	7,936	173	4,633	1,050	1,472	1,171
1-2	1.5	8,483	463	1,656	1,625	135	2,855
2-3	2.5	3,498	942	120	2,649	0	3,608
3-4	3.5	1,681	938	0	3,424	0	2,855
4-5	4.5	829	1,496	0	2,707	0	1,607
5-6	5.5	235	2,558	0	1,632	0	835
6-7	6.5	118	3,592	0	837	0	413
7-8	7.5	0	3,497	0	405	0	171
8-9	8.5	0	2,224	0	161	0	71
9-10	9.5	0	900	0	61	0	24
10+	11	0	460	0	45	0	11
Weighted average	Velocity (ft / sec)	1.27	6.28	0.39	3.53	0.28	2.7

6.6 Water Velocity

6.6.1 Impounded reach velocity

Impounded river velocities, computed according to the continuity rule, and ACOE simulated velocities for the Snake River are shown in Table 3 and Figure 2. Volume/drawdown relationships are shown in the section:

6.8 Additional Graphics.

Velocity is integrated over multiple reaches to assess total travel time from LWG to IHR and from MCN to BON. These are compared to FPC assessments (McCann and Filardo 2006) and shown in the Table 4 and Figure 3. They are very comparable.

Table 3 Velocities (ft / sec) in each pool computed according to the continuity rule and the simulated velocities

	19.9 KCFS	31.7 KCFS	111.5 KCFS
Bonneville Pool	0.15	0.25	0.86
The.Dalles Pool	0.17	0.28	0.98
John.Day Pool	0.07	0.12	0.41
McNary Pool	0.10	0.16	0.55
Priest Rapids Pool	0.18	0.29	1.03
Wanapum Pool	0.11	0.18	0.63
Rock Island Pool	0.37	0.59	2.06
Rocky Reach Pool	0.26	0.42	1.48
Wells Pool	0.21	0.34	1.20
Ice Harbor Pool	0.19	0.30	1.06
Lower Monumental Pool	0.18	0.29	1.03
Little Goose Pool	0.16	0.25	0.89
Lower Granite Pool	0.19	0.31	1.09
Simulated velocities for the Snake River	0.28	0.39	1.27

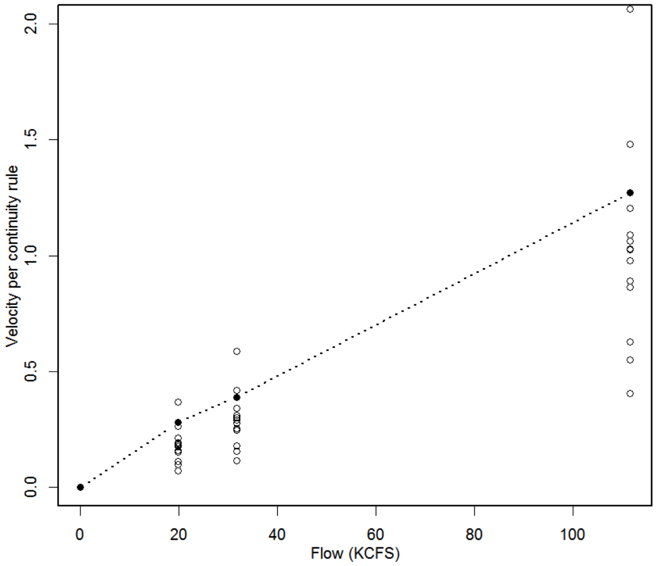

Figure 2 Velocities in each pool computed according to the continuity rule. Solid points and dashed line are ACOE computations for the Snake River's pools.

Table 4 Water particle Travel Time over Snake and Columbia River reaches.

Location	BiOP Flows (KCFS)	FPC range of water travel time (days)	COMPASS range of water travel time (days)
LWG to IHR	85-100	7.7 – 6.6	7.5 – 6.4
MCN to BON	220-260	7.6 – 6.4	8.0 – 6.6

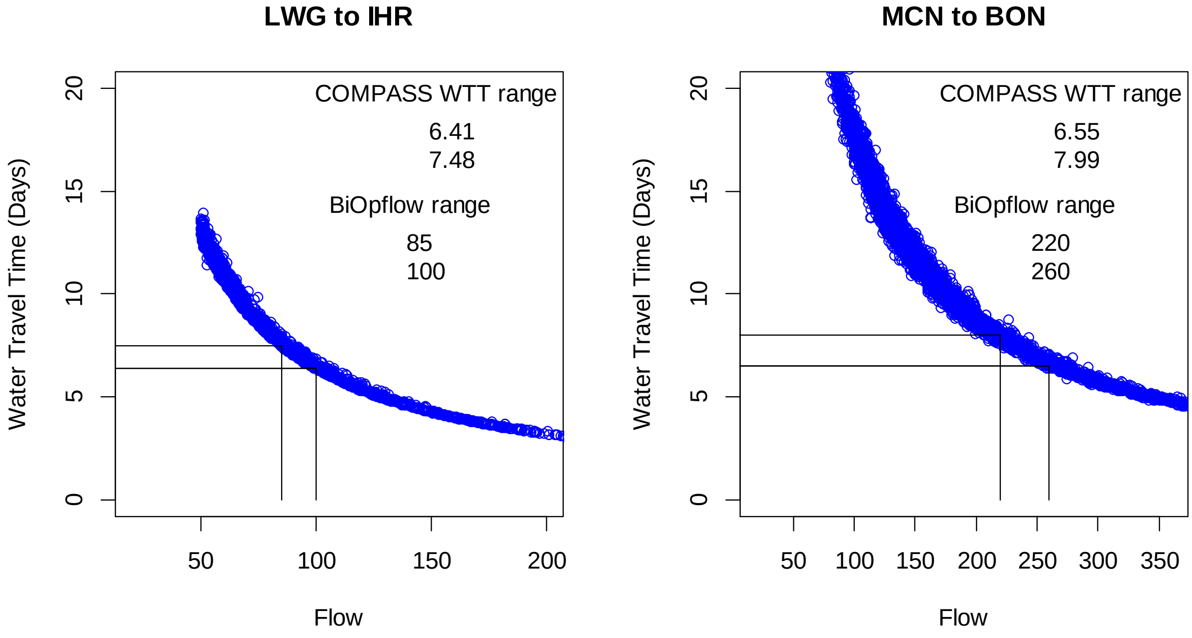

Figure 3 Computed COMPASS water particle travel time computations from velocity outputs and reach lengths.

6.6.2 Free-flowing reach velocity

The data and fitted curves for the un-impounded river velocities are shown in Figure 4 and used to calibrate the α and β parameters for Vel_{free} equation.

A power curve separately to each of the four data sets. The equations are applied to the location where the data was generated as well as adjacent reaches that are proximal to the former gage sites. The equations are below and illustrated in Figure 4.

$Vel_{free} = 0.64815 \cdot Q^{0.48318}$ on the Snake River (between Columbia and Clearwater)

$Vel_{free} = 0.3719 \cdot Q^{0.49116}$ on the Hanford Reach, Columbia River

$Vel_{free} = 0.4357 \cdot Q^{0.5222}$ at Upper Columbia River sites (based on Trinidad gage)

$Vel_{free} = 0.0926 \cdot Q^{0.70077}$ at Lower Columbia River sites (based on Dalles gage)

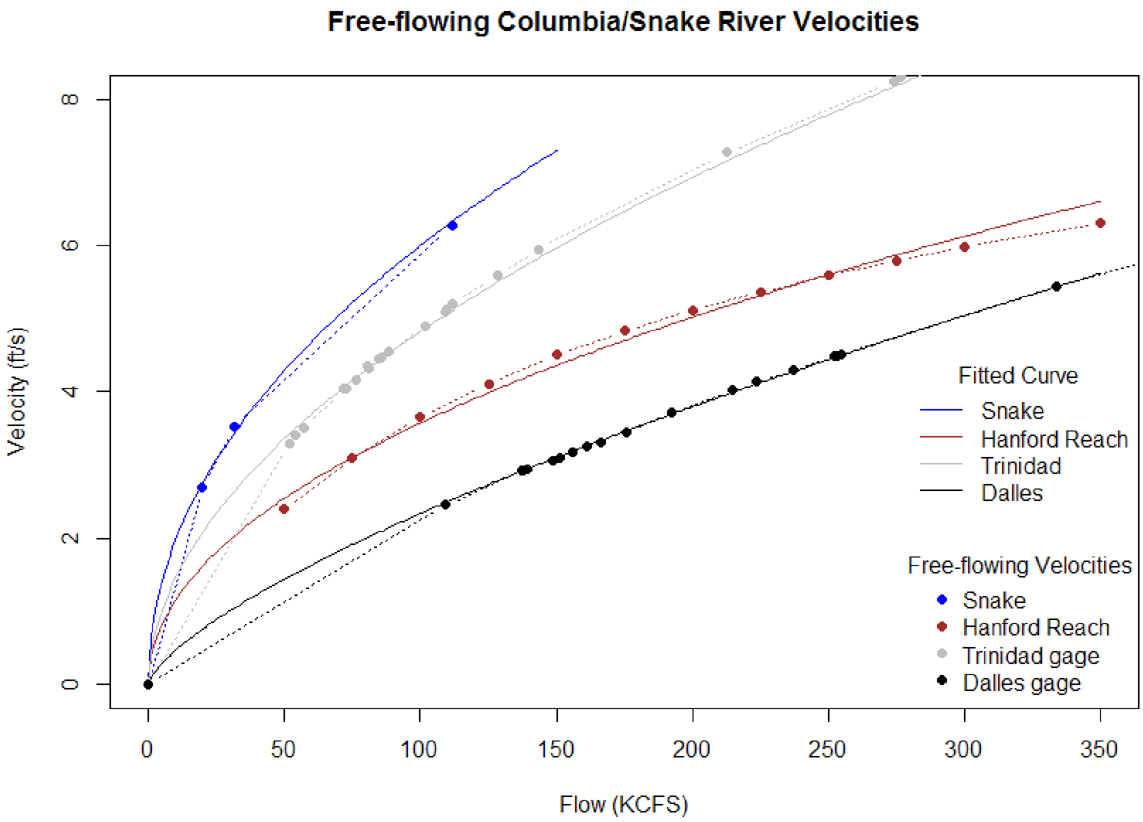

Figure 4 Velocity in free-flowing reaches of the Columbia and Snake Rivers. Simulated/Reported velocity data (points and dashed line) and the fitted curves (solid lines) following the power rule are shown.

6.7 References

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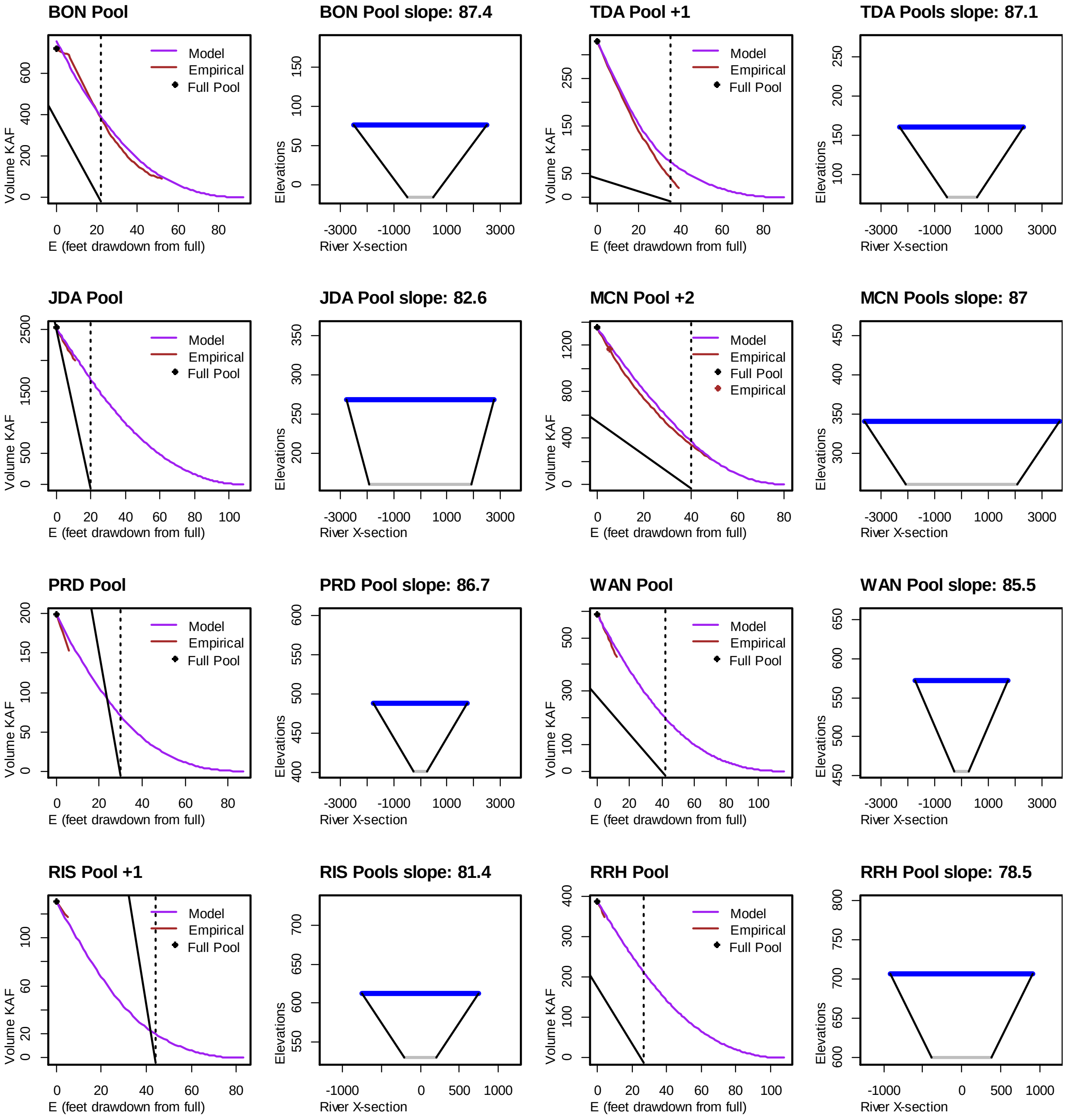
6.8 Additional Graphics

Figure 5 and Figure 6 depict volume/drawdown relationships and cross-section geometry of the pools. Vertical dashed line depicts upper depth. Scales vary between plots.

Figure 7 and Figure 8 are profiles of the Columbia and Snake Rivers reaches. Scales vary between plots.



BON Pool

BON Pool slope: 87.4

TDA Pool +1

TDA Pools slope: 87.1

JDA Pool

JDA Pool slope: 82.6

MCN Pool +2

MCN Pools slope: 87

PRD Pool

PRD Pool slope: 86.7

WAN Pool

WAN Pool slope: 85.5

RIS Pool +1

RIS Pools slope: 81.4

RRH Pool

RRH Pool slope: 78.5

Figure 5 Volume/drawdown relationships and cross-sections

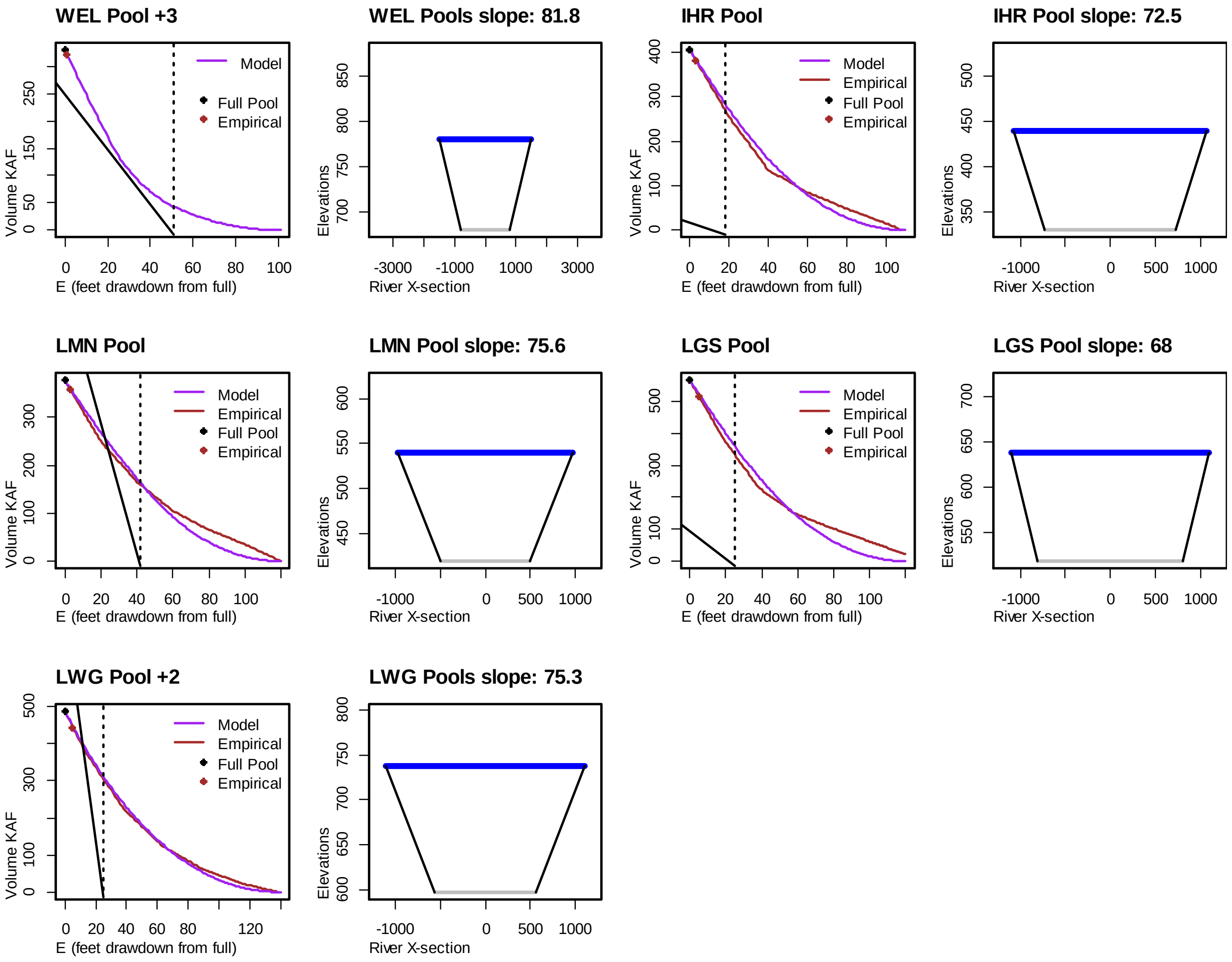
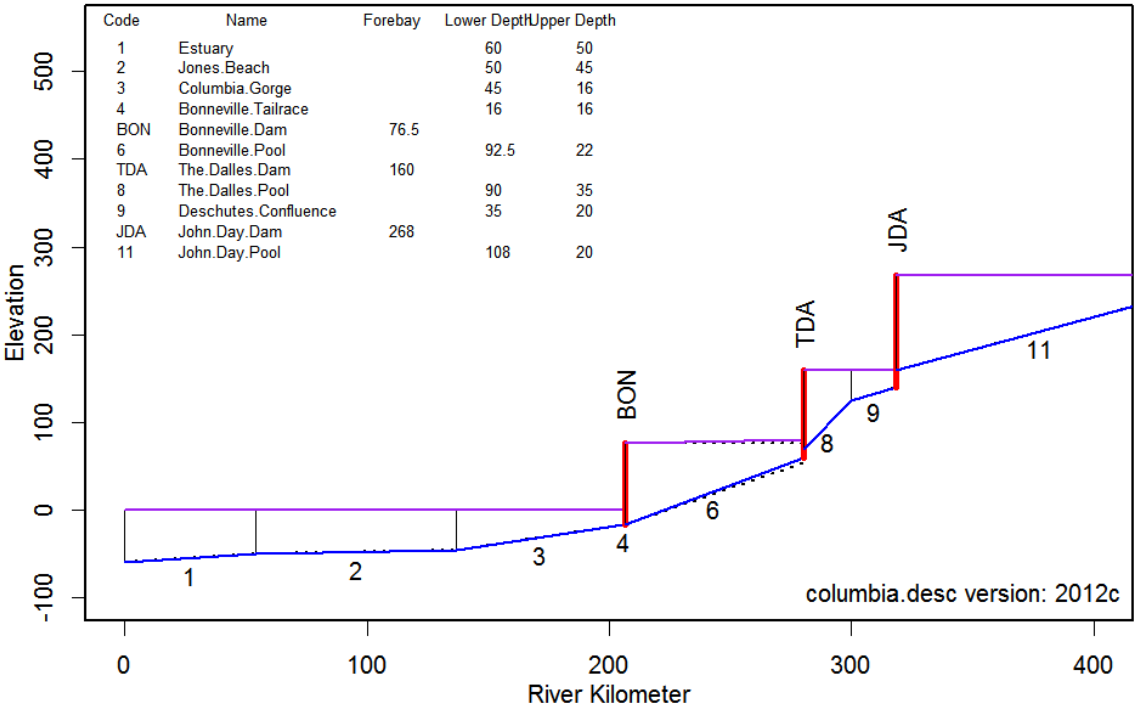
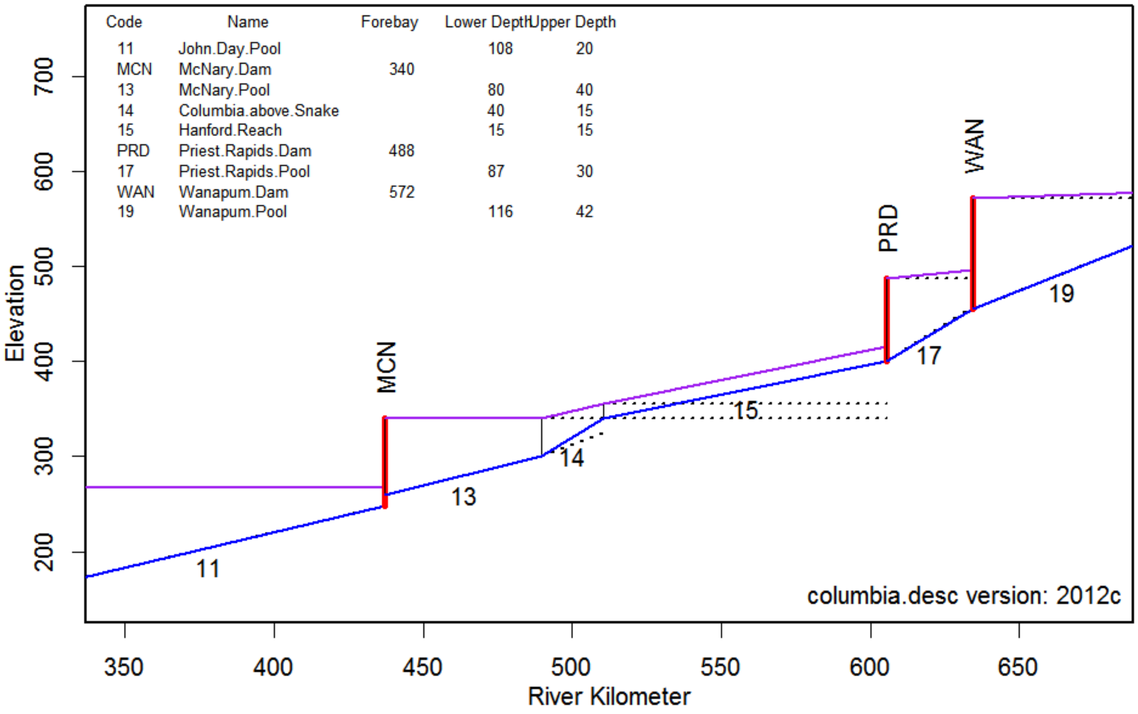


Figure 6 Volume/drawdown relationships and cross-sections

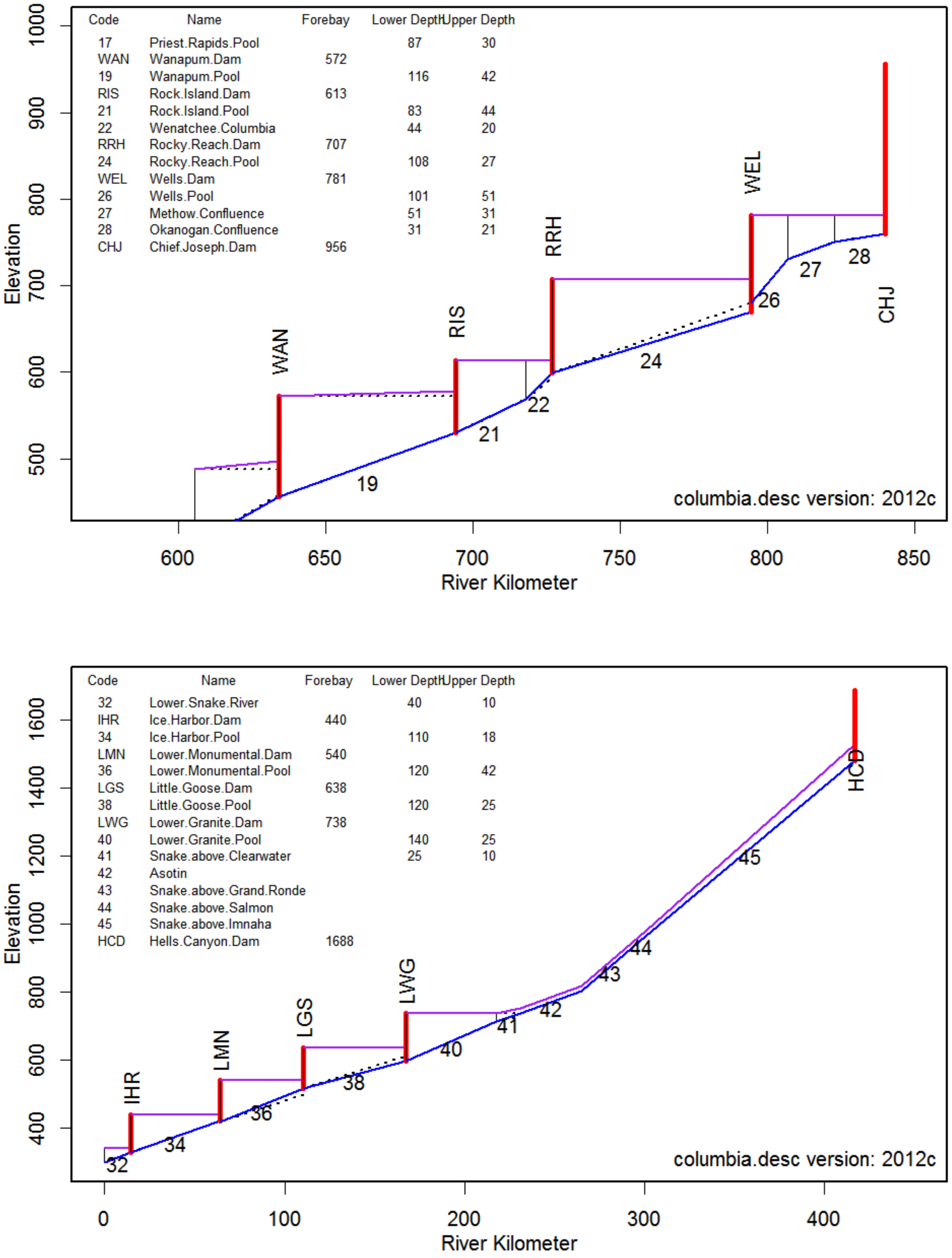


Code	Name	Forebay	Lower Depth	Upper Depth
1	Estuary		60	50
2	Jones.Beach		50	45
3	Columbia.Gorge		45	16
4	Bonneville.Tailrace		16	16
BON	Bonneville.Dam	76.5		
6	Bonneville.Pool		92.5	22
TDA	The.Dalles.Dam	160		
8	The.Dalles.Pool		90	35
9	Deschutes.Confluence		35	20
JDA	John.Day.Dam	268		
11	John.Day.Pool		108	20



Code	Name	Forebay	Lower Depth	Upper Depth
11	John.Day.Pool		108	20
MCN	McNary.Dam	340		
13	McNary.Pool		80	40
14	Columbia.above.Snake		40	15
15	Hanford.Reach		15	15
PRD	Priest.Rapids.Dam	488		
17	Priest.Rapids.Pool		87	30
WAN	Wanapum.Dam	572		
19	Wanapum.Pool		116	42

Figure 7 River profiles by reach.



Code	Name	Forebay	Lower Depth	Upper Depth
17	Priest.Rapids.Pool		87	30
WAN	Wanapum.Dam	572		
19	Wanapum.Pool		116	42
RIS	Rock.Island.Dam	613		
21	Rock.Island.Pool		83	44
22	Wenatchee.Columbia		44	20
RRH	Rocky.Reach.Dam	707		
24	Rocky.Reach.Pool		108	27
WEL	Wells.Dam	781		
26	Wells.Pool		101	51
27	Methow.Confluence		51	31
28	Okanogan.Confluence		31	21
CHJ	Chief.Joseph.Dam	956		

Code	Name	Forebay	Lower Depth	Upper Depth
32	Lower.Snake.River		40	10
IHR	Ice.Harbor.Dam	440		
34	Ice.Harbor.Pool		110	18
LMN	Lower.Monumental.Dam	540		
36	Lower.Monumental.Pool		120	42
LGS	Little.Goose.Dam	638		
38	Little.Goose.Pool		120	25
LWG	Lower.Granite.Dam	738		
40	Lower.Granite.Pool		140	25
41	Snake.above.Clearwater		25	10
42	Asotin			
43	Snake.above.Grand.Ronde			
44	Snake.above.Salmon			
45	Snake.above.Imnaha			
HCD	Hells.Canyon.Dam	1688		

Figure 8 River profiles by reach.

Modeling Arrival Distributions of Populations of Juvenile Snake River Spring-Summer Chinook and Steelhead at Lower Granite Dam and Effects of Arrival Timing on Predicted Survival and Population Experiences

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Introduction

The migration timing of juvenile salmonids determines the conditions they will experience within their migration corridor as well as conditions they will encounter when they enter the estuary and ocean. These conditions determine their probability of survival and determine the resources they will encounter in their search for continued growth. Accurate prediction of migration timing and arrival distributions of populations at key points in their migration corridor is therefore a critical component in life cycle models used for predicting population trends and assessing management scenarios.

We focus on the timing of individuals arriving at Lower Granite Dam (LGD), which is the first dam on the lower Snake River encountered by juvenile migrants. This location also acts as an entry point into the Federal Columbia River Power System (FCRPS), which is composed of a series of dams and reservoirs on the lower Snake and Columbia Rivers, is closely monitored, and benefits from a set of detailed ecological models developed to describe the process of smolt migration through the system (Zabel et al. 2008). Arrival timing at LGD is determined by both the timing of initiation of migration and the subsequent time it takes to travel to LGD.

Many biological and environmental factors can influence the initiation of migration for juvenile salmon. The main biological factor is the timing of smoltification, which coincides with the readiness to migrate. Smoltification depends on fish size, photoperiod, and temperature (Johnsson and Clarke 1988; Beckman et al. 1998; McCormick et al. 2000). Fish size is determined by growth as parr, which is dependent on temperature, photoperiod, competition, and food availability (McCormick et al. 1998). Once a fish has started smoltification and is becoming behaviorally ready to migrate, release factors that may trigger migration include photoperiod, temperature, flow, turbidity, and social cues (Bjornn 1971; Hansen and Jonsson 1985; Jonsson 1991; Sykes et al. 2009).

Migration is not always initiated from natal streams, since many individuals may begin to move downstream as parr. Shrimpton et al. (2014) found evidence for extensive downstream movements in Chinook prior to smoltification and actual migration based on stream chemistry signatures in otoliths. These pre-smolt downstream movements could be due to a variety of factors present in natal streams, including inadequate habitat for overwintering, unsuitable stream temperatures, limited food availability, and high population densities (Bjornn 1971; Cunjak 1996). Pre-smolt movements could also be involuntary and due to heavy precipitation or flow events that wash individuals downstream. The pre- and early stages of migration likely consist of a slow and iterative process of moving downstream and holding over until smoltification begins and stream conditions are right for starting migration (Steel et al. 2001).

Travel time of migrating spring-summer Chinook and steelhead has been shown to be associated with distance traveled, water velocity, temperature, degree of smoltification, and fish size (Zabel et al. 1998; Smith et al. 2002; Zabel 2002; Zabel et al. 2008). Smaller fish and those just starting smoltification will likely move slower by staying out of the main channel. Chinook tend to travel slower earlier in the migration season and then speed up as the season progresses (Zabel et al. 1998).

We currently do not have sufficient data to explicitly separate the time of initiation of migration and the travel time to LGD for individual fish. We only have data on the arrival timing of individual fish at LGD, which is a function of initiation of migration and travel time. However, the factors that determine arrival timing at LGD should be a combination of the factors that determine initiation of migration and travel time. Achord et al. (2007) analyzed arrival timing at LGD for spring-summer Chinook from the Salmon River basin and found that average temperatures in the spring and previous autumn and average streamflow in March best explained median arrival times. Higher temperatures and higher flows resulted in earlier arrival times. Autumn temperature could affect growth and pre-smolt movements downstream, and spring flow and temperatures could affect both initiation of migration and travel time.

Given the complex processes that produce arrival distributions, it is not surprising that these distributions exhibit a variety of complex characteristics, including multiple modes, sharp spikes, and long tails, and that the shape, location, and spread of these distributions can vary across populations and years. We needed a modeling method that would capture these complex distributional forms and be based on inputs that could be used in prospective modeling exercises. We developed a method based on a combination of quantile regression and nonparametric smoothing that predicts continuous probability distributions for arrival times based on a set of predictor variables. We fit the models to arrival times for populations of spring-summer Chinook and steelhead from the Snake and Salmon River basins. We then use those models to predict arrival distributions under prospective scenarios and summarize the resulting population-specific experiences in the hydropower system and subsequent adult returns.

Methods

PIT Tag Data

The observational data we used to fit our models of arrival timing were the detection times at LGD for fish implanted with passive integrated transponder (PIT) tags. For our models, we used PIT-tagged fish from Endangered Species Act (ESA) listed populations of spring Chinook salmon and steelhead trout in the Snake River basin (NMFS 2016). There are a total of 31 ESA-listed populations of spring Chinook above LGD; these populations are grouped into five different Major Population Groups (MPGs): Lower Snake, Grande Ronde/Imnaha, South Fork Salmon, Middle Fork Salmon, and Upper Salmon. Due to the small amount of data available in some of the ESA-defined MPGs, we decided to group the Lower Snake and Imnaha/Grande Ronde MPGs and the South and Middle Fork Salmon MPGs for model fitting (Table 1). Not all of the ESA-listed populations of Snake River steelhead directly correspond to those for spring Chinook, but to simplify our modeling we used the same set of population designations and groupings for steelhead.

A number of researchers and organizations have PIT tagged wild fish from these populations on a regular basis, starting from the early 1990s (e.g., Achord et al. 2007). All PIT tag mark and observation data collected within the wider Columbia River basin is stored in the PTAGIS database operated by the Pacific States Marine Fisheries Commission (PSMFC 1996-present). We queried the PTAGIS database to select all available mark and observation data of wild fish from the ESA-listed populations in the Snake River basin. Not all of the 31 ESA listed populations have had PIT tagging conducted; we were able to retrieve data from a total of 24 populations.

Table 1. A list of the ESA-listed populations above LGD for which PIT data is available, organized by the groupings we used to fit our arrival models.

ESA MPG	ESA Populations by Model Group
	Grande Ronde/Imnaha
Lower Snake	Asotin River
Grande Ronde/Imnaha	Imnaha River, Grande Ronde River, Catherine Creek, Lostine River, Minam River, Lookingglass Creek
	Lower Salmon
South Fork Salmon	East Fork South Fork Salmon, Little Salmon River, South Fork Salmon, Secesh River
Middle Fork Salmon	Bear Valley Creek, Big Creek, Camas Creek, Chamberlain Creek, Loon Creek, Marsh Creek, Sulfur Creek
	Upper Salmon
Upper Salmon	Pahsimeroi River, Lemhi River, Salmon River Above Redfish Lake, Valley Creek, Yankee Fork, East Fork Salmon River, North Fork Salmon River

For the collection of mark data, we obtained from the PTAGIS database the locations of every mark/release site in one of the Salmon, Imnaha, or Grande Ronde River hydrologic units. We then assigned every smolt trap or general riverine mark/release site in each hydrologic unit to a specific ESA-listed population, as long as the site was on the main river assigned to the population, or a tributary (Supplemental Table 1).

After assigning PTAGIS mark/release sites to each ESU population, we then queried the PTAGIS database, selecting the records of all juvenile Chinook and steelhead released at the selected mark/release sites and also detected as a juvenile at LGD. For Chinook salmon, we selected the records of fish with wild or unknown rearing types, and spring, summer, or unknown run types. For steelhead, we selected the records of fish with wild or unknown rearing types and all run types. We used the first detection time at LGD in the fish’s migration year, and ignored any later detections. The resulting data covers the years 1990-2015, with more fish tagged in later years (Table 2).

Table 2. Populations of Chinook and steelhead with numbers of fish with PIT-tag detections at LGD across all years with data. Populations are ordered by MPG. Years in which data were available varied by population, and only populations with 50 or more total detections were used in model fitting.

Population	Code	Years	Chinook	Steelhead
Asotin River	ASO	2005-2015	20	7,946
Imnaha River	IMN	1990-2015	46,842	31,870
Grande Ronde River	GRN	1993-2015	21,054	9,110
Catherine Creek	CAT	1991-2015	3,930	1,735
Lostine River	LOS	1990-2015	6,914	1,873
Minam River	MIN	1993-2015	4,837	1,415
Lookingglass Creek	LGC	1994-2015	3,076	2,312
Bear Valley Creek	BVC	1990-2015	3,065	88
Big Creek	BIG	1990-2015	7,436	1,946
Camas Creek	CAM	1993-2015	726	693
Chamberlain Creek	CHA	1992-2015	853	1,810
Loon Creek	LOO	1993-2015	1,047	67
Marsh Creek	MAR	1990-2015	12,818	801
Sulfur Creek	SUL	1990-2015	761	89
East Fork South Fork Salmon	ESF	1993-2015	14,928	3,012
Little Salmon River	LIT	1998-2014	121	1,242
South Fork Salmon	SFS	1991-2015	13,448	2,612
Secesh River	SEC	1990-2015	14,248	1,851
Pahsimeroi River	PAH	1993-2015	9,776	1,292
Lemhi River	LEM	1992-2015	12,322	2,902
Salmon River, above Redfish Lake	SAR	1990-2015	10,467	704
Valley Creek	VAL	1990-2015	1,629	25
Yankee Fork	YNK	1995-2015	721	115
East Fork Salmon River	EFS	1991-2015	2,559	69
North Fork Salmon River	NFS	1993-1995	92	0

Flow and Temperature Data

We decided to confine our predictor variable set to only those environmental covariates that would be available in a prospective modeling framework; considering this limitation, we used flow and temperature in the reservoir of Lower Granite Dam as our chief predictors of arrival timing at LGD.

We acquired raw flow data by downloading the flow records for Lower Granite Dam, 1989-2016, from the DART website (Columbia River DART 2017). For temperature data, we downloaded the 1989-2016 records of the WQM temperature reading at Lower Granite Dam, also from the DART website. For both datasets, any gaps in the time series were filled via linear interpolation; however, for the time period relevant to our analysis (January-June), gaps were infrequent and rarely longer than a few days.

We created monthly statistics for January through June from these data time series for use as our predictor variables. From the flow dataset, for each month we estimated mean flow, the Julian date of maximum flow, and the Julian date of the largest daily change in flow. This resulted in a total of 18 monthly flow predictor variables. The monthly mean flow variables were highly correlated, so we used principle components analysis (PCA; Hotelling 1933; Joliffe 2002) to find a set of linear combinations of the monthly mean flows that were uncorrelated but still captured the variation in the data. The resulting six PC’s were used as predictor variables in place of the mean flows.

We also created monthly statistics for January through June from the temperature dataset. We calculated monthly mean temperature and the range in temperature for each month, resulting in 12 monthly temperature predictors. The monthly mean temperature predictors were highly correlated, so we used PCA to calculate six PC's to be used as predictors in place of the monthly means. Monthly temperature range was not highly correlated among months so was not transformed. We also estimated the mean temperature in the previous autumn for each year by averaging October through December temperatures, for a total of 13 temperature predictors.

Prospective Environmental Data

For prospective modeling of arrival timing at LGD, we used a management scenario produced by the Bonneville Power Administration (BPA)'s HYDSIM model, referred to as the "Base" scenario. This scenario replicates current management operating rules as of 2016 and imposes them on 80 historical water years from 1929 through 2008. We used the loadings and centers generated from the PCAs of flow and temperature to produce the 18 flow and 13 temperature predictors for each year in the 80-year Base scenario.

Retrospective Modelling

We used a combination of quantile regression (Koenker and Basset, 1978; Koenker 2005; Cade and Noon, 2003) and nonparametric smoothing splines (Green and Silverman 1994; Hastie et al. 2009) to generate probability distributions for arrival times at LGD. A quantile is the value of a random variable associated with a particular value of its cumulative probability distribution. For example, in terms of arrival time distributions, the 0.05 quantile represents the time on which 5% of the population has arrived, and the 0.95 quantile represents the time when 95% has arrived. The median of a distribution is the 0.5 quantile. Quantile regression is a method used to model associations between specific quantiles and a set of predictor variables.

We used quantile regression to relate environmental factors and population indicators to arrival times. For any quantile $\tau \in (0,1)$, the quantity $\widehat{\boldsymbol{\beta}}(\tau)$ is the vector of regression parameters that solves

$$\widehat{\boldsymbol{\beta}}(\tau) = \operatorname{argmin}_{\boldsymbol{\beta} \in \mathbb{R}^p} \sum_{i=1}^{n} \rho_\tau \left(y_i - \boldsymbol{x}_i' \boldsymbol{\beta} \right)$$

where $\rho_\tau(u) = u\big(\tau - I(u < 0)\big)$ and $I(\cdot)$ denotes the indicator function. This minimization is performed with linear programming optimization methods. We used the rq function in the quantreg package in R to fit the quantile regression models. Models were fit separately for each population group, where population groups were as described previously in the Data section. Further details of the variable selection are described below.

We fit multiple quantiles simultaneously. Due to restrictions of the fitting routine, this meant that each quantile model shared the same set of predictor variables. However, the estimated parameters differed across the quantile models. This resulted in reduced flexibility in the possible sets of individual quantile models, but greatly reduced the model space we needed to explore.

The quantile regression models provided a set of predicted times of arrival corresponding to the set of quantiles specified by the models. Due to the time scale of the covariate measures (one observation per covariate per population per year), each population had a set of predicted quantiles for each year for which there were data. These quantiles provide a partial representation of the entire arrival distribution for a population in a year. For an example of a quantile regression fit to our data using a single predictor, see Figure 1.

To fill in the entire continuous set of quantiles, we fit smoothing splines to the predictions from the quantile regression models. Smoothing splines are a nonparametric regression method that fits a smooth curve to a set of data points. Smoothing splines were fit to logit-transformed cumulative probabilities corresponding to the model-predicted quantiles for each population in each year. The logit transformation constrained the predicted cumulative probabilities to the (0,1) interval. The number of *degrees of freedom* of a smoothing spline represents the effective number of parameters used to fit the smoothing spline. The maximum degrees of freedom is the number of observations in the data (assuming no replicate points). Fewer degrees of freedom results in more smoothing and the maximum degrees of freedom will result in interpolation. The number of knots for each model were equal to the number of data points. The smoothing spline fits resulted in predictive models for a continuous set of cumulative proportions. The first derivative of these models for cumulative probabilities provide an approximate probability density function for the arrival distribution of a population under a set of input conditions.

We note that smaller degrees of freedom of the smoothing splines, relative to the number of possible degrees of freedom, result in more smoothing, which means the predicted curves would lie further from the data points (model predicted cumulative probabilities) than models with higher degrees of freedom. Therefore, higher degrees of freedom are actually better for our purposes since we would like the spline predictions to be as close to the quantile model predictions as possible. We tested a range of degrees of freedom for the smoothing spline model, and decided that using a degree of freedom one less than the number of quantiles in a given model provided reliable fits while still closely capturing the shape of the quantiles.

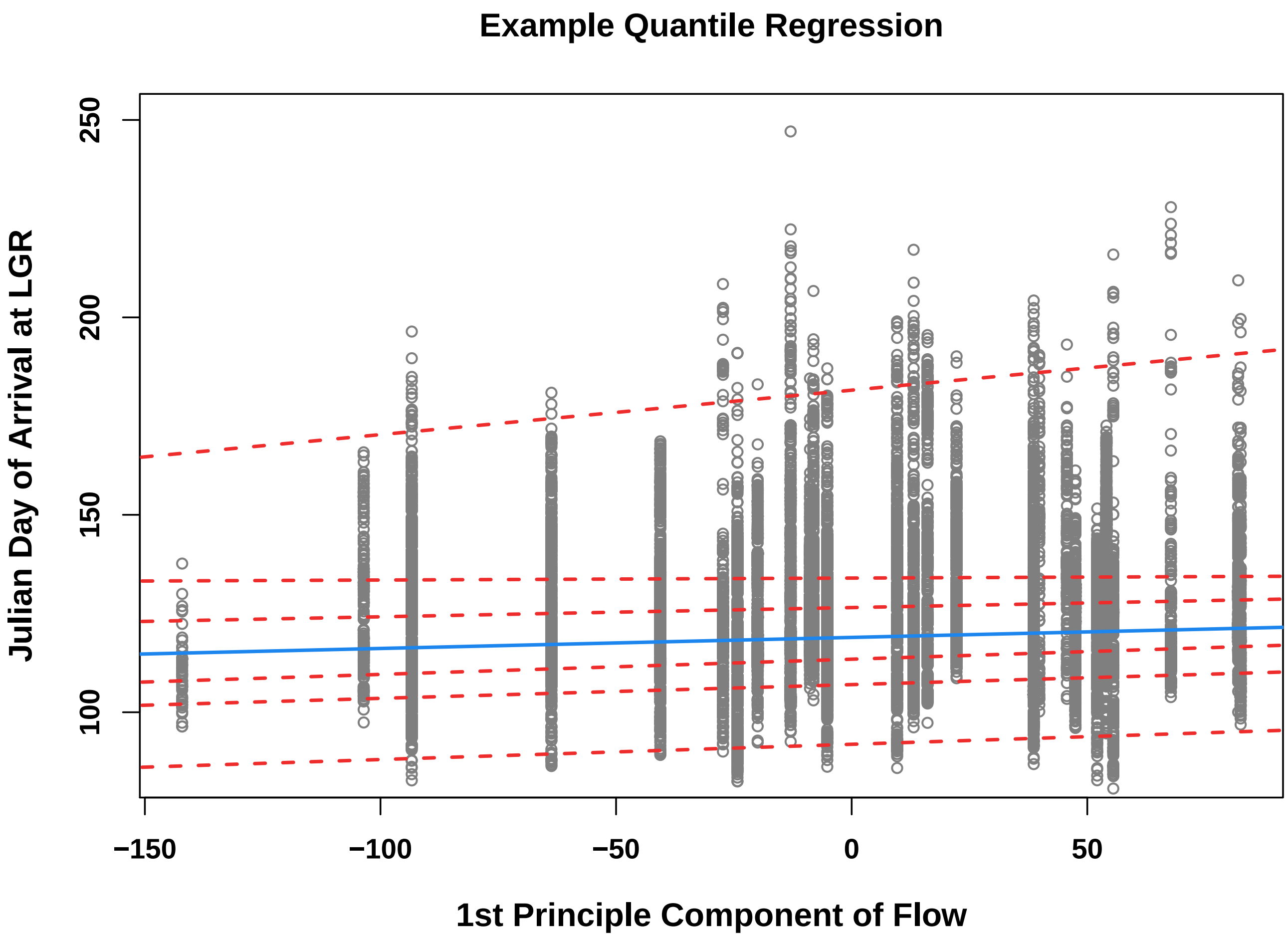


Figure 1. Example of a simple quantile regression fit to arrival time data, using only a single environmental predictor; in this case, the first principle component of monthly mean flow. Seven quantiles were fit, ranging from the 0.01 quantile to the 0.99 quantile. The median quantile is shown as a solid blue line; other quantiles are shown in red dashed lines.

The resulting predicted probability density functions could then be used to calculate the likelihood of the observed arrival times under the model and estimated parameters. The likelihoods were therefore based on the combined quantile regression and smoothing spline model predictions and used all of the individual arrival time data. The likelihood for the estimated model parameters, $\widehat{\boldsymbol{\theta}}$, given the arrival time of fish *i* in population *j* in year *k* was calculated as

$$\mathcal{L}\left(\widehat{\boldsymbol{\theta}}\middle|t_{ijk}\right) = \hat{f}_{jk}(t_{ijk}|\widehat{\boldsymbol{\theta}})$$

where $\hat{f}_{jk}(\cdot\,|\boldsymbol{\theta})$ is the estimated probability density function for the arrival times of fish in population *j* in year *k*, conditional on the estimated model parameters. The likelihood for the entire set of data given the estimated parameters was then the product of the individual likelihood components:

$$\mathcal{L}\left(\widehat{\boldsymbol{\theta}}\middle|\boldsymbol{t}\right) = \prod_{i,j,k} \hat{f}_{jk}(t_{ijk}|\widehat{\boldsymbol{\theta}})$$

We calculated likelihoods on the log scale to avoid numerical issues. We then used the resulting log-likelihood values to calculate Akaike Information Criteria (AIC) values for each model. The number of parameters in each model was equal to the number of parameters in the quantile regression model multiplied by the number of quantiles plus the number of degrees of freedom used in the smoothing spline. The appropriate number of parameters for the smoothing spline component is the number of spline degrees of freedom times the number of populations and years for each population.

We fit models for sets of 5, 7, and 9 quantiles. For each set of quantiles, the 0.01, 0.5, and 0.99 quantiles were always included, and the remaining quantiles were equally spaced between the .01 quantile and median, and 0.99 quantile and median. This arrangement was chosen to allow consistency in how the tails were modeled across quantile sets; for all models, the probability tails below 0.01 and above 0.99 were filled in with simple exponential curves fitted to match the density at 0.01 and 0.99. For each set of quantiles we used one degree of freedom less than the number of quantiles when fitting the smoothing splines.

We found best-fitting models with each set of quantiles for each combination of species and MPG. We performed a forward variable selection procedure based on the AIC values calculated from the model likelihoods described above. At each step, a single new predictor variable was selected from the set of remaining variables and added to the current best model, the quantile regression models were fit, smoothing splines were fit to the predicted cumulative probabilities for each population and year, and AIC was calculated. All of the remaining variables were tested one at a time in this manner and the new model that resulted in the largest reduction in AIC was retained as the new best model. This process was repeated until the addition of new variables no longer resulted in a reduction in AIC. The model selection process was therefore targeting the best combination of predictor variables for each set of quantiles in terms of AIC. The forward selection procedure was chosen to reduce the model space and avoid fitting all possible combinations of predictor variables.

Cumulative probability distributions are strictly non-decreasing functions. The smoothing spline fits to the cumulative probabilities predicted by the quantile regression models did not always result in strictly non-decreasing functions. When this occurred, the spline smoothing parameter was increased in increments of 0.01 until the spline function was non-decreasing.

The quantile regression models were not strictly constrained to maintain order of quantiles for all predictions. Therefore, some quantiles could be predicted close enough that their order would switch. If this occurred, we sorted the predicted quantiles to maintain the proper ordering. In most cases where a quantile crossover occurred, the predicted quantiles were close together.

We note that within-season variation in detection probabilities at LGD could affect the shape of arrival distributions, since only detected fish are included in the samples. We found that detection probabilities had more variability between years than within years, and annual variation will not adversely affect the quantile estimation. We assumed the within-season variation in detection probabilities was not large enough to affect the parameter estimation or model performance. We will investigate methods to explicitly account for detection probability in future models.

After finding the best-fit models for sets of 5, 7, and 9 quantiles via the AIC forwards selection process, we then tested each best-fit model to select a final model for use in predictive runs. We used data that was not used in the fitting process- arrival data from 2016 and 2017- as a crossvalidation dataset. We ran the models with this set of data and assessed the performance of each model, including the number of quantile crossovers and non-decreasing spline fits which required adjustment. We decided to use a consistent set of quantiles for all species and MPGs, and selected the suite of models that produced the fewest crossovers and non-decreasing splines for use in prospective modeling.

Prospective Modelling

The COMPASS model is used to assess various aspects of the passage experience of migrating juvenile salmon through the hydropower system on the Snake and Columbia Rivers under different management scenarios (Zabel et al 2008). The Bonneville Power Administration (BPA) generates hydrological data for a set of 80 water years under different scenarios using their HYDSIM hydrological model. The HYDSIM model outputs daily predictions for flow, reservoir elevation, and spill at all dams in the system for each water year; we also model water temperature for each water year. Those predictions, along with a release distribution at LGD, are input into the COMPASS model to generate predictions of passage experience and survival. Differences in the population release distributions will result in different exposures to changing river conditions, different exposures to transportation, and different timing at the estuary. Each of these components could contribute to different outcomes in COMPASS model predictions.

We used our selected best-fit models of arrival timing at LGD with the flow and temperature predictors from the 80 water years of a given HYDSIM scenario to generate unique arrival distributions for each fish population and year. Some of these predicted distributions had very early or very late tails; in these cases we truncated the predicted distributions at day 60 and day 200 and rebalanced them to sum to 1. After generating arrival distributions for each modeled population, we then combined all populations into overall arrival distributions for each species. We used census data on the average number of smolts emigrating from each population as a weight and produced the overall arrival distribution as a weighted average. For Chinook the census data used was a combination of data from Apperson et al. 2017 and Columbia River DART (2017). For steelhead the census data was based on the average number of fish PIT tagged per year that tagging occurred (PTAGIS data; PSMFC 1996-present).

We then ran COMPASS on the 80 water years using these overall arrival distributions as the release distributions at LGD. The aspects of passage experience that we summarize for a typical prospective COMPASS run are survival of fish migrating in river (not transported), proportion of fish transported, travel time from Lower Granite Dam to Bonneville Dam, and arrival distributions at Bonneville Dam for both fish that migrated in river and fish that were transported.

Results

Retrospective Modelling

Several of the populations had no or very few tagged fish, and we were unable to fit arrival models for them. These included the Asotin population of spring Chinook, and the North Fork Salmon River and Valley Creek populations of steelhead.

The Pahsimeroi River population of spring Chinook displayed a unique pattern in its arrival data, with large peaks in arrival in late June and July in many years. These peaks are much later than any other population in the dataset, and could indicate large numbers of summer Chinook in that population. Our COMPASS models of survival and migration timing are only fitted to data within the spring migration period and are thus not valid for later-migrating summer Chinook, so we decided to exclude the Pahsimeroi population of Chinook from our arrival model fitting and prospective analysis.

The Upper Salmon River MPG populations were overall lacking in data for Steelhead. We decided to combine the Upper Salmon River MPG populations with the Lower Salmon River MPG populations and fit a single joint model for the combined data.

Of the suites of quantiles tested, the 5-quantile regression models performed the best in the crossvalidation analysis. Across all MPGs of Chinook and steelhead, 5-quantile models produced a total of 84 quantile crossovers and 15 non-decreasing splines within the crossvalidation dataset. This compared favorably to the 7-quantile model suite, which produced 198 crossovers and 24 non-decreasing splines, and the 9-quantile model suite, which produced 336 crossovers and 48 non-decreasing splines. Accordingly, we selected the suite of 5-quantile models for use in prospective scenarios.

The best fitting 5-quantile models were complex, with many predictor variables selected (Tables 3a, 3b). For Chinook salmon, the Salmon River MPG models tended to select many monthly Peak Flow and Daily Change in Flow predictors; the Middle Snake MPG model selected fewer flow predictors, but all six monthly Temperature Range predictors. The best fitting models for steelhead were slightly less complex than those for Chinook. Both models for steelhead selected more principle components of monthly mean temperature than any of the Chinook models.

The best-fitting 5-quantile models are able to capture a variety of shapes in observed arrival distributions, including fairly normal distributions and distributions with long tails (Figures 2, 3). Bimodal distributions may be partially captured (Figure 3); however, multimodal observed arrival distributions tend to be smoothed over in model fits (Figure 4).

Table 3a. Predictor variables selected by the best 5-quantile models by AIC for each species and population grouping. Table 3b contains a description of the abbreviations used for predictor variables.

Species and *MPG*	**Selected Predictors**
Chinook *Imnaha/Grande Ronde*	F1, F2, F3, F4, F5, F6; PF1, PF2, PF3, PF5; DF1, DF3, DF4; T2, T4; TR1, TR2, TR3, TR4, TR5, TR6
Chinook *Lower Salmon*	F1, F2, F3, F5; PF1, PF2, PF3, PF6; DF1, DF2, DF3, DF4, DF5, DF6; T1, T2, T4; TR1, TR2, TR3, TR4
Chinook *Upper Salmon*	F1, F2; PF2, PF3, PF4, PF5, PF6; DF1, DF2, DF3, DF6; T2, T3; TR1, TR3, TR4
Steelhead *Imnaha/Grande Ronde*	F1, F4; PF1, PF3; DF3, DF4, DF5, DF6; T1, T2, T3, T4; TR2, TR5, TR6
Steelhead *Lower Salmon & Upper Salmon*	F2, F3; PF2; DF2, DF3, DF5, DF6; T1, T2, T3, T4; TR2, TR4, TR6

Table 3b. Descriptions and abbreviations used for predictor variables. LGP = Lower Granite Pool

Abbreviation	**Predictor Variable**
F1	First principle component of monthly mean LGP flow
F2	Second principle component of monthly mean LGP flow
F3	Third principle component of monthly mean LGP flow
F4	Fourth principle component of monthly mean LGP flow
F5	Fifth principle component of monthly mean LGP flow
F6	Sixth principle component of monthly mean LGP flow
PF1	Julian day of peak January LGP flow
PF2	Julian day of peak February LGP flow
PF3	Julian day of peak March LGP flow
PF4	Julian day of peak April LGP flow
PF5	Julian day of peak May LGP flow
PF6	Julian day of peak June LGP flow
DF1	Julian day of maximum daily change in LGP flow in the month of January
DF2	Julian day of maximum daily change in LGP flow in the month of February
DF3	Julian day of maximum daily change in LGP flow in the month of March
DF4	Julian day of maximum daily change in LGP flow in the month of April
DF5	Julian day of maximum daily change in LGP flow in the month of May
DF6	Julian day of maximum daily change in LGP flow in the month of June
T1	First principle component of monthly mean water temperature in LGP
T2	Second principle component of monthly mean water temperature in LGP
T3	Third principle component of monthly mean water temperature in LGP
T4	Fourth principle component of monthly mean water temperature in LGP
T5	Fifth principle component of monthly mean water temperature in LGP
T6	Sixth principle component of monthly mean water temperature in LGP
TR1	Range between min and max LGP water temperature in the month of January
TR2	Range between min and max LGP water temperature in the month of February
TR3	Range between min and max LGP water temperature in the month of March
TR4	Range between min and max LGP water temperature in the month of April
TR5	Range between min and max LGP water temperature in the month of May
TR6	Range between min and max LGP water temperature in the month of June

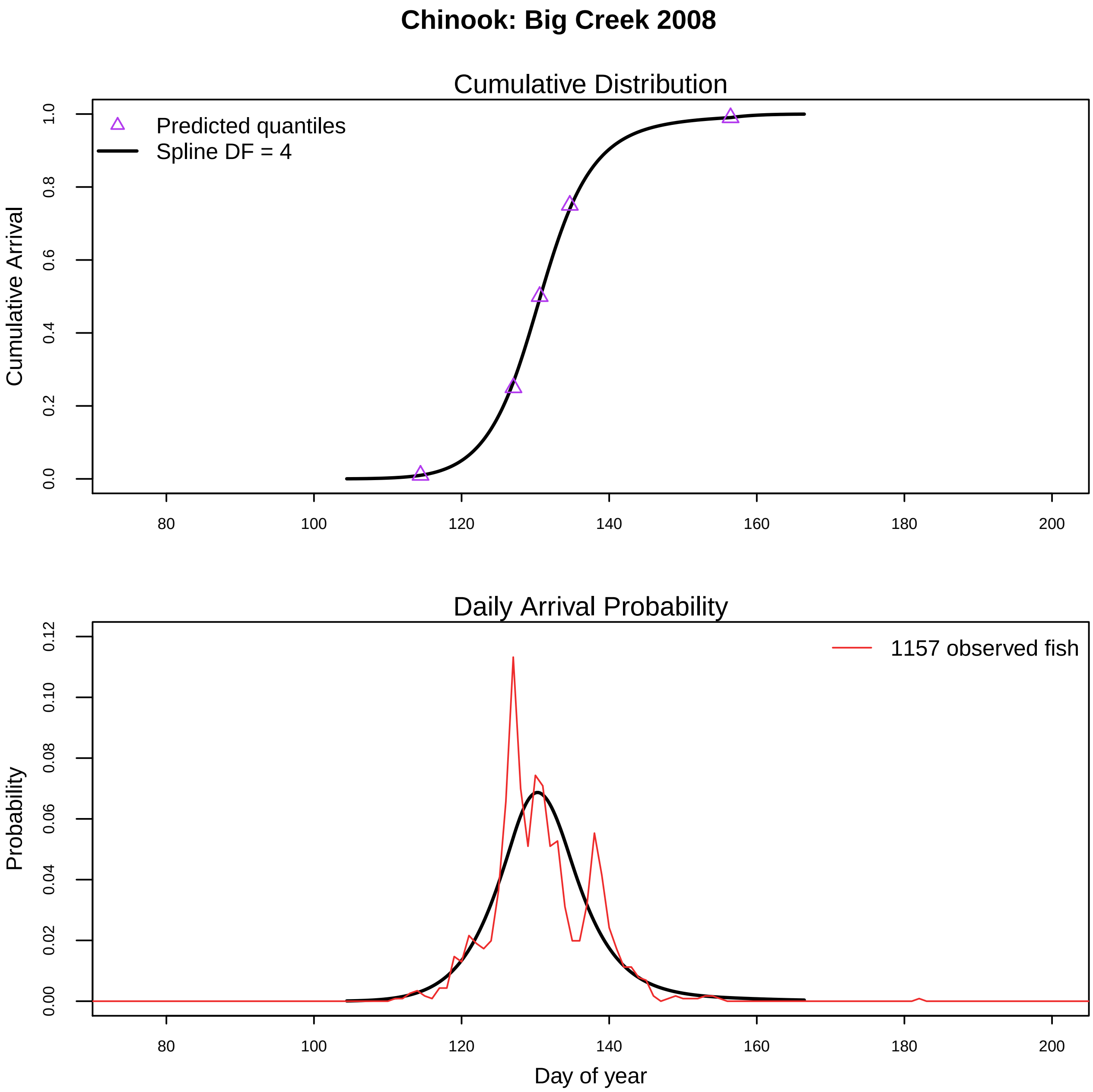
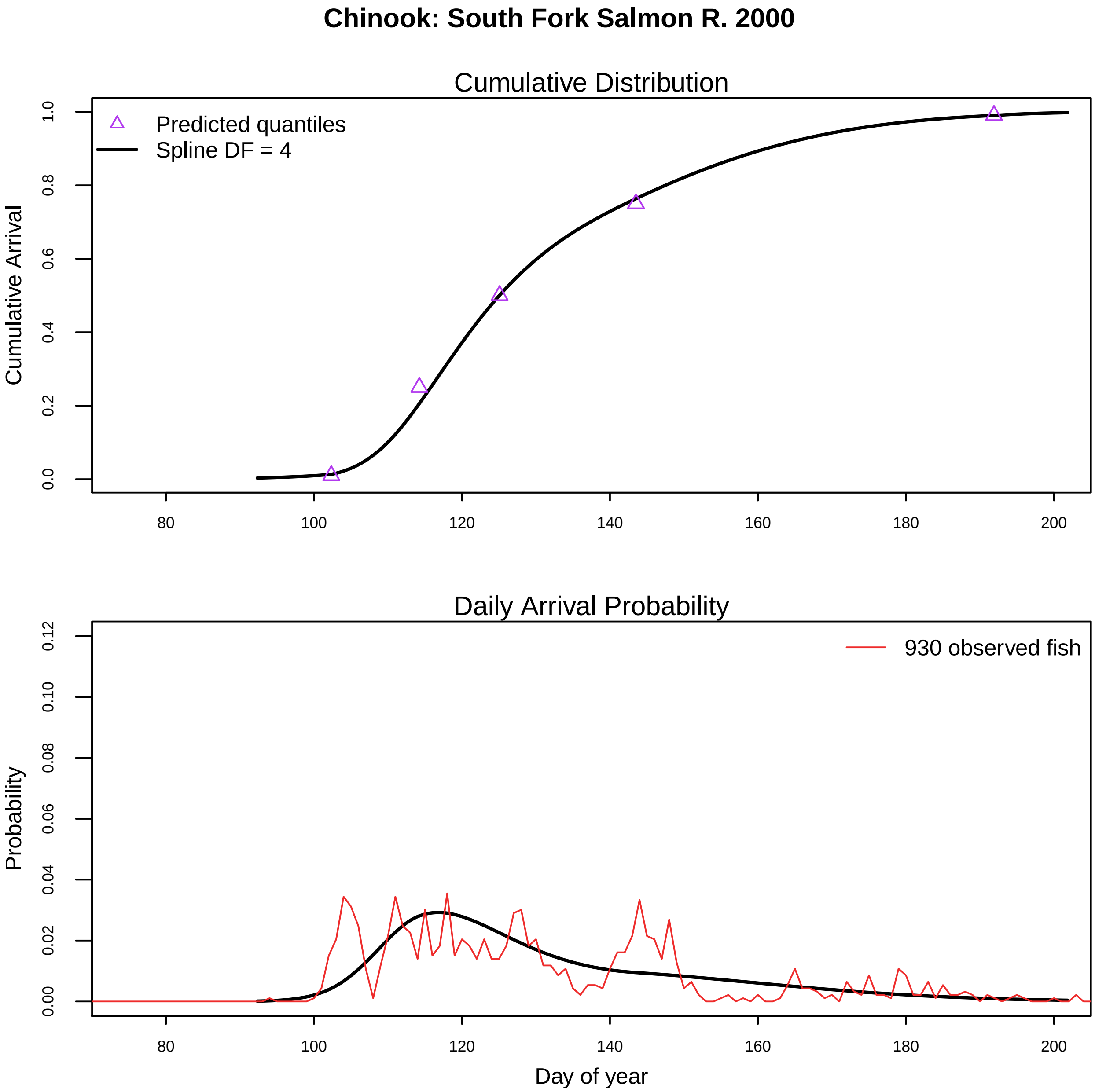


Figure 2. The top panel shows the 5 predicted quantiles and associated cumulative proportions with the fitted smoothing spline (using 4 degrees of freedom) for the Big Creek population of Chinook in 2008. The bottom panel shows the resulting probability distribution (first derivative of fitted cumulative distribution) with observed arrivals of Big Creek Chinook at Lower Granite Dam in 2008.



Chinook: South Fork Salmon R. 2000

Cumulative Distribution

Daily Arrival Probability

Figure 3. The top panel shows the 5 predicted quantiles and associated cumulative proportions with the fitted smoothing spline (using 4 degrees of freedom) for the South Fork Salmon River population of Chinook in 2000. The bottom panel shows the resulting probability distribution (first derivative of fitted cumulative distribution) with observed arrivals of South Fork Salmon River Chinook at Lower Granite Dam in 2000.

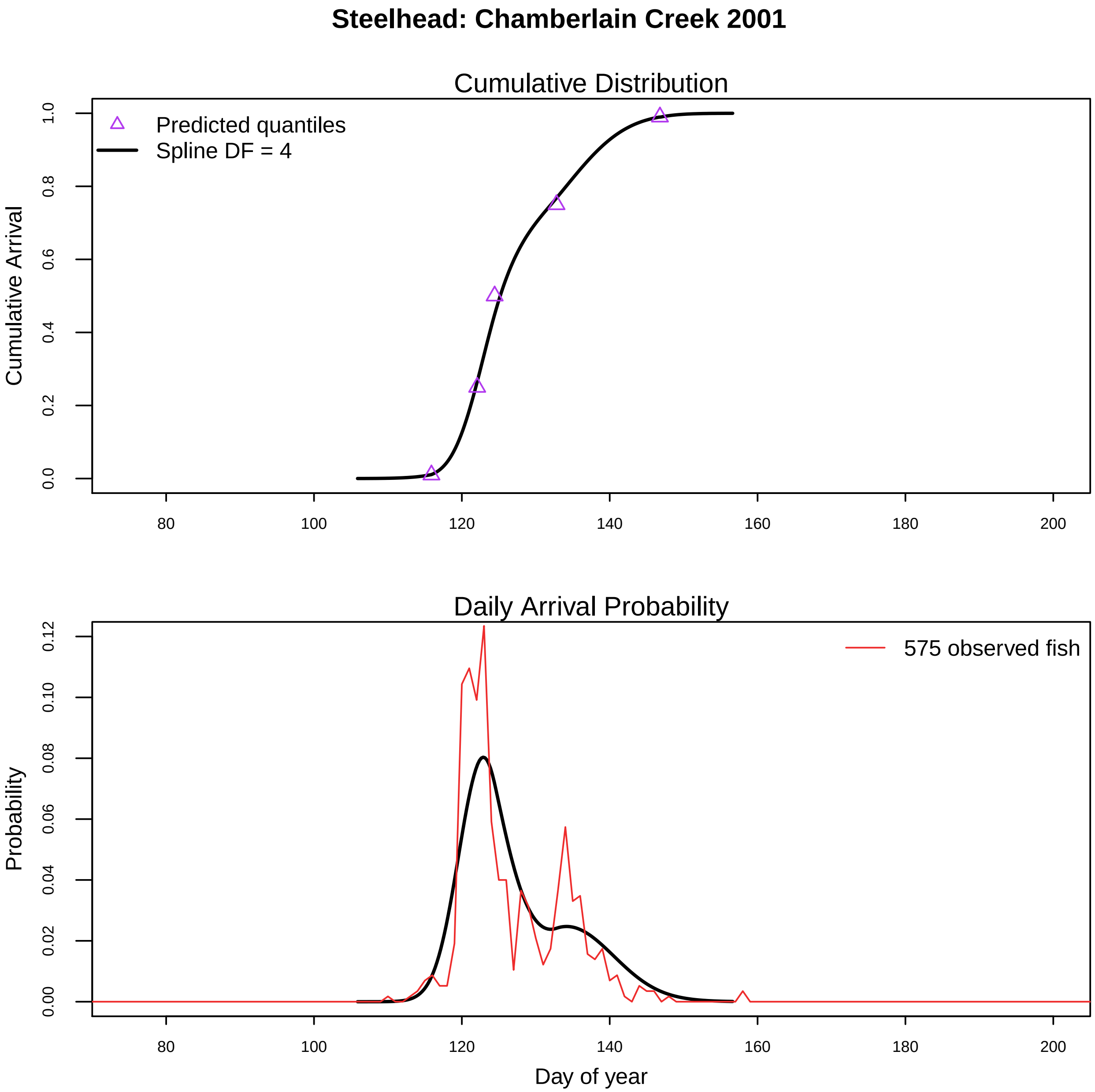


Figure 4. The top panel shows the 5 predicted quantiles and associated cumulative proportions with the fitted smoothing spline (using 4 degrees of freedom) for the Chamberlain Creek population of steelhead in 2001. The bottom panel shows the resulting probability distribution (first derivative of fitted cumulative distribution) with observed arrivals of Chamberlain Creek steelhead at Lower Granite Dam in 2001.

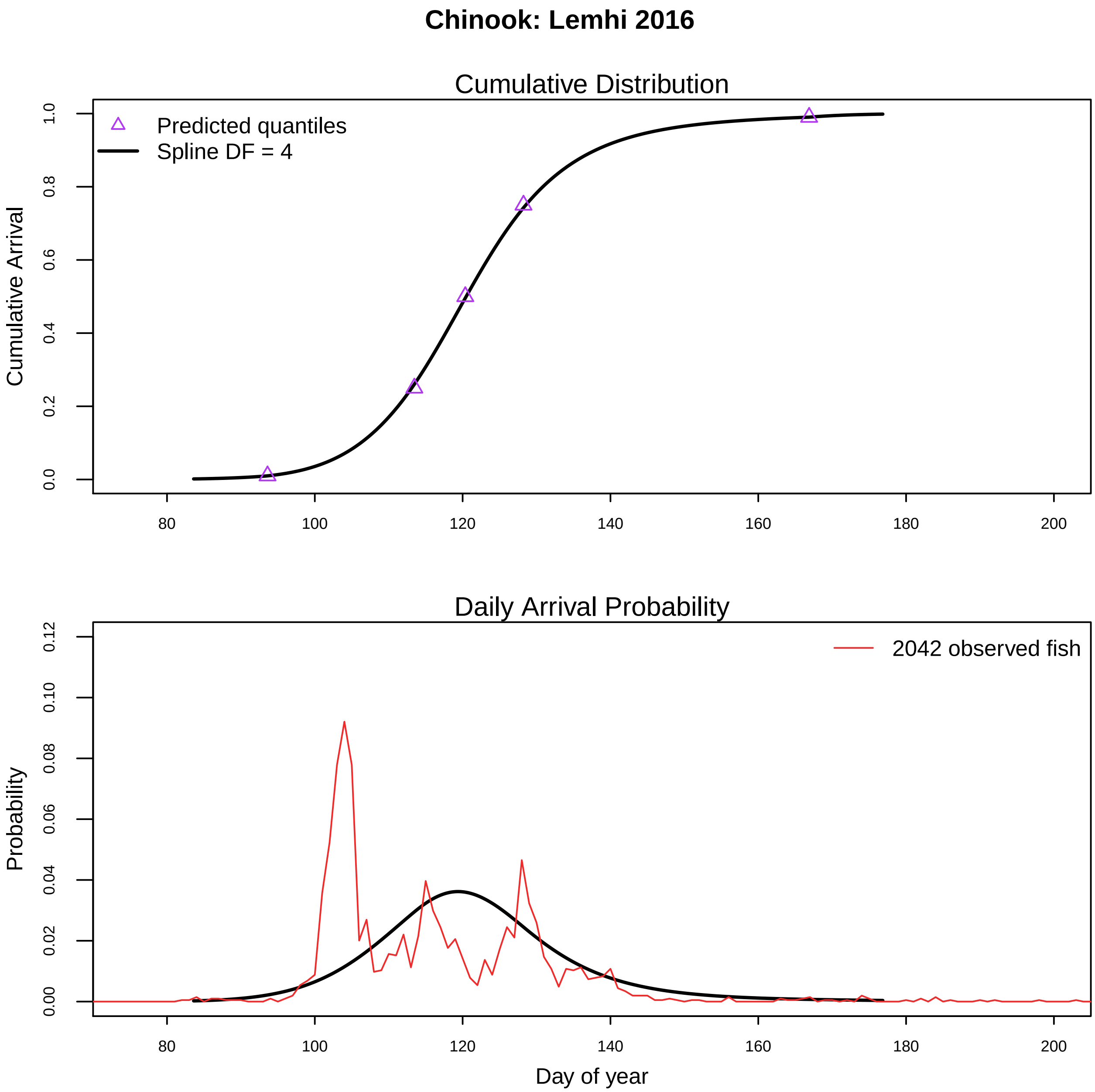


Figure 5. The top panel shows the 5 predicted quantiles and associated cumulative proportions with the fitted smoothing spline (using 4 degrees of freedom) for the Lemhi population of Chinook in 2016. The bottom panel shows the resulting probability distribution (first derivative of fitted cumulative distribution) with observed arrivals of Lemhi Chinook in 2016. This plot is an example of the model being applied predictively to the cross-validation dataset; 2016 data was not used in the fit.

Prospective Arrival Modelling

Arrival distributions predicted from the 80 water years of the “Base” HYDSIM scenario tended to show some consistent differences between population groupings, as would be expected due to the fact that different population groupings use different predictive models. However, within population groupings some populations were also significantly different from others in the same group, while other population groupings have fairly consistent predictions for all populations in the group.

For Snake River Chinook salmon (Figures 6, 7), the Lower Salmon population group had the earliest predicted arrival timings, and predicted arrival was similar for almost all populations in the group. The Upper Salmon population group tended to have slightly later predicted arrival, but populations within the group showed significant differences from each other, with the East Fork Salmon and Lemhi populations arriving no later than the Lower Salmon populations, and the Yankee Fork population arriving much later. The Imnaha/Grande Ronde population group had later predicted arrival times than the Salmon population groups, but less year-to-year variability within arrival timing. The Catherine Creek population stands out from the others, and is predicted to be the latest arriving population of spring Chinook in our dataset.

Snake River steelhead (Figures 8, 9) showed similar patterns in predicted arrival timing to Chinook salmon. The Lower Salmon population group had the earliest predicted arrival timings, and predicted arrival was very similar for all populations in the group. Both the Upper Salmon and Grande Ronde/Imnaha population groups had later predicted arrival times than the Lower Salmon Group, but unlike Chinook salmon, for steelhead the Upper Salmon population group had slightly later predicted arrival than the Grande Ronde/Imnaha population group, and populations within those groupings were similar to each other in predicted arrival timing.

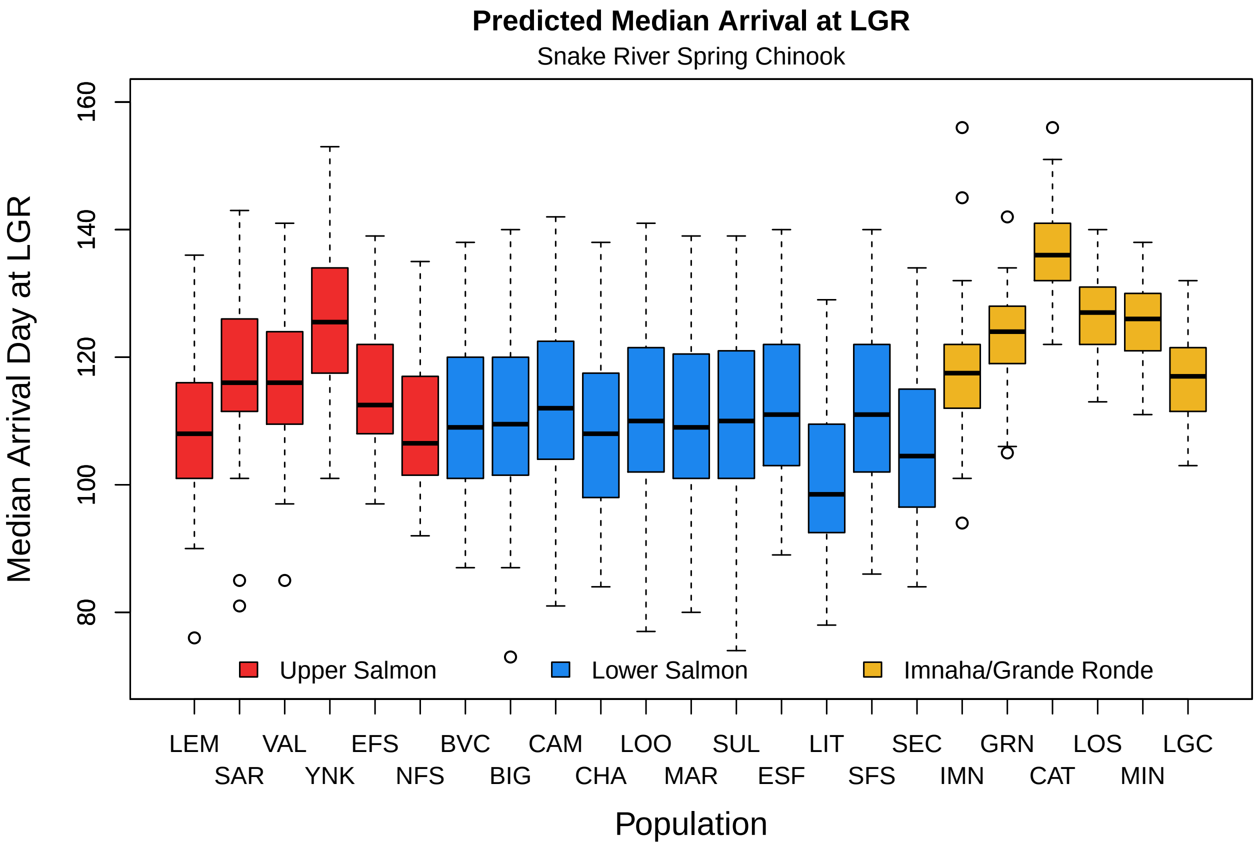


Figure 6. Boxplots of median predicted arrival timing for the 80 water years of the "Base" scenario, for all populations of spring Chinook salmon. The different population groups are broken out by color. Population abbreviation codes are in Table 2.

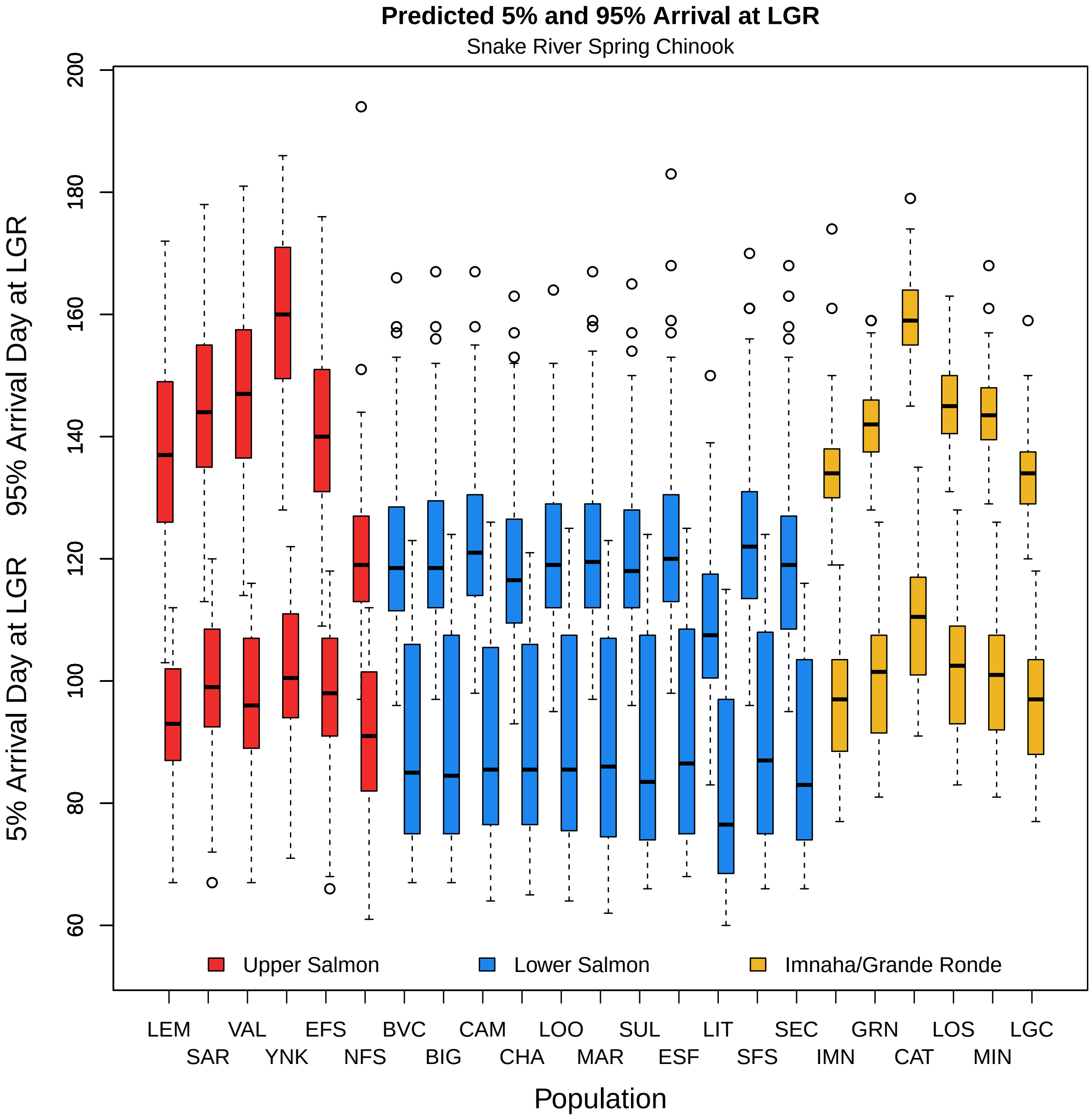


Figure 7. Boxplots of the 5% and 95% predicted arrival quantiles for the 80 water years of the “Base” scenario, for all populations of spring Chinook salmon. The different population groups are broken out by color. Population abbreviation codes are in Table 2.

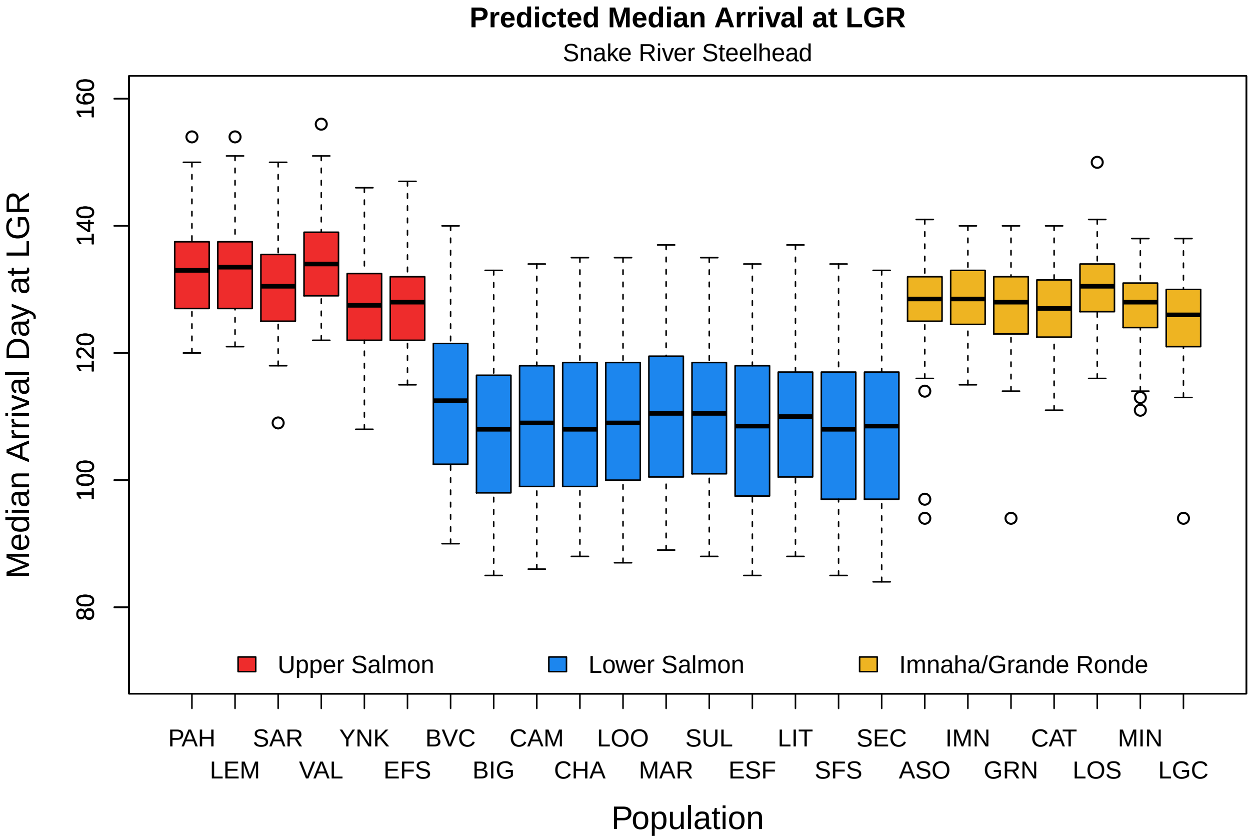


Figure 8. Boxplots of median predicted arrival for the 80 water years of the "Base" scenario for all populations of Snake River steelhead. The different population groups are broken out by color. Population abbreviation codes are in Table 2.

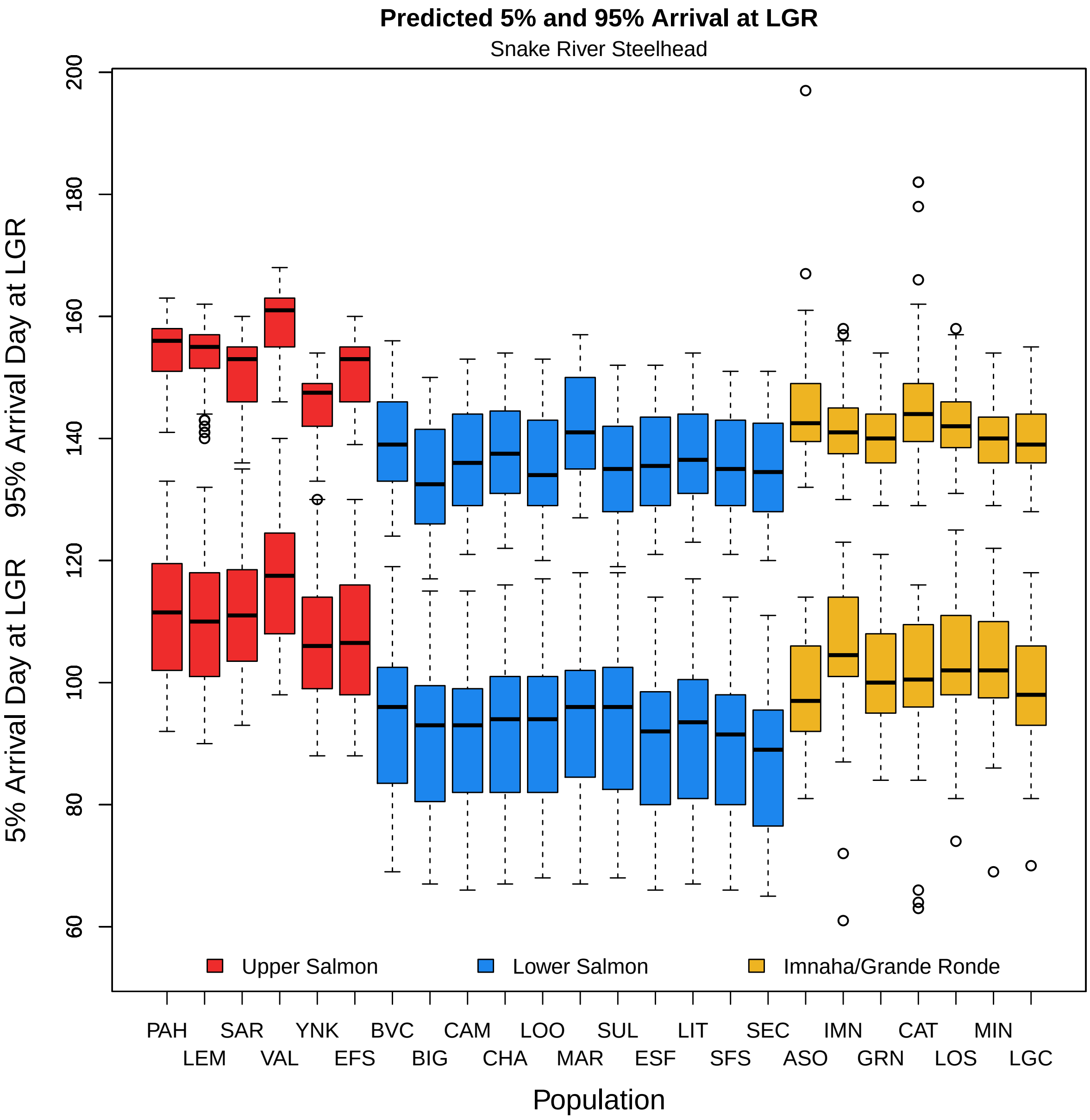


Figure 9. Boxplots of the 5% and 95% predicted arrival quantiles for the 80 water years of the "Base" scenario, for all populations of Snake River steelhead. The different population groups are broken out by color. Population abbreviation codes are in Table 2.

Prospective COMPASS Runs

The COMPASS outputs produced by running the “Base” HYDSIM scenario with the different sets of release distributions predicted by our arrival models show significant differences between populations for some statistics, but small differences for others. For Snake River spring Chinook salmon, most populations show only small differences in COMPASS predicted in-river survival (Figure 10). The only populations that significantly stand out from the others are Yankee Fork, from the Upper Salmon group, and Catherine Creek, from the Grande Ronde/Imnaha population group. These two populations had lower in-river survival than the rest. It is worth noting that these two populations are predicted to be the latest arriving at LGD.

The differences between spring Chinook populations are more noticeable in COMPASS predicted proportion destined for transport (Figure 11). Both of the later-migrating population groups (Upper Salmon and Grande Ronde/Imnaha) had significantly larger proportions destined for transport than the Lower Salmon population group, and there were large within-group differences as well. The Little Salmon River population, which had slightly earlier predicted arrival than the other Lower Salmon populations, had very low proportion destined for transport.

The Snake River steelhead populations we modeled showed only small differences in COMPASS predicted in-river survival. Those populations within the same population group were very similar to each other, but the Upper Salmon and Grande Ronde/Imnaha groups had slightly lower survival than the Lower Salmon group (Figure 12). COMPASS predicted proportion destined for transport showed similar patterns, though the magnitude of the differences was larger than for in-river survival (Figure 13).

In general, across both species and all population groups, the populations with later predicted arrival timing at LGR had lower COMPASS predicted survival and larger proportions destined for transport.

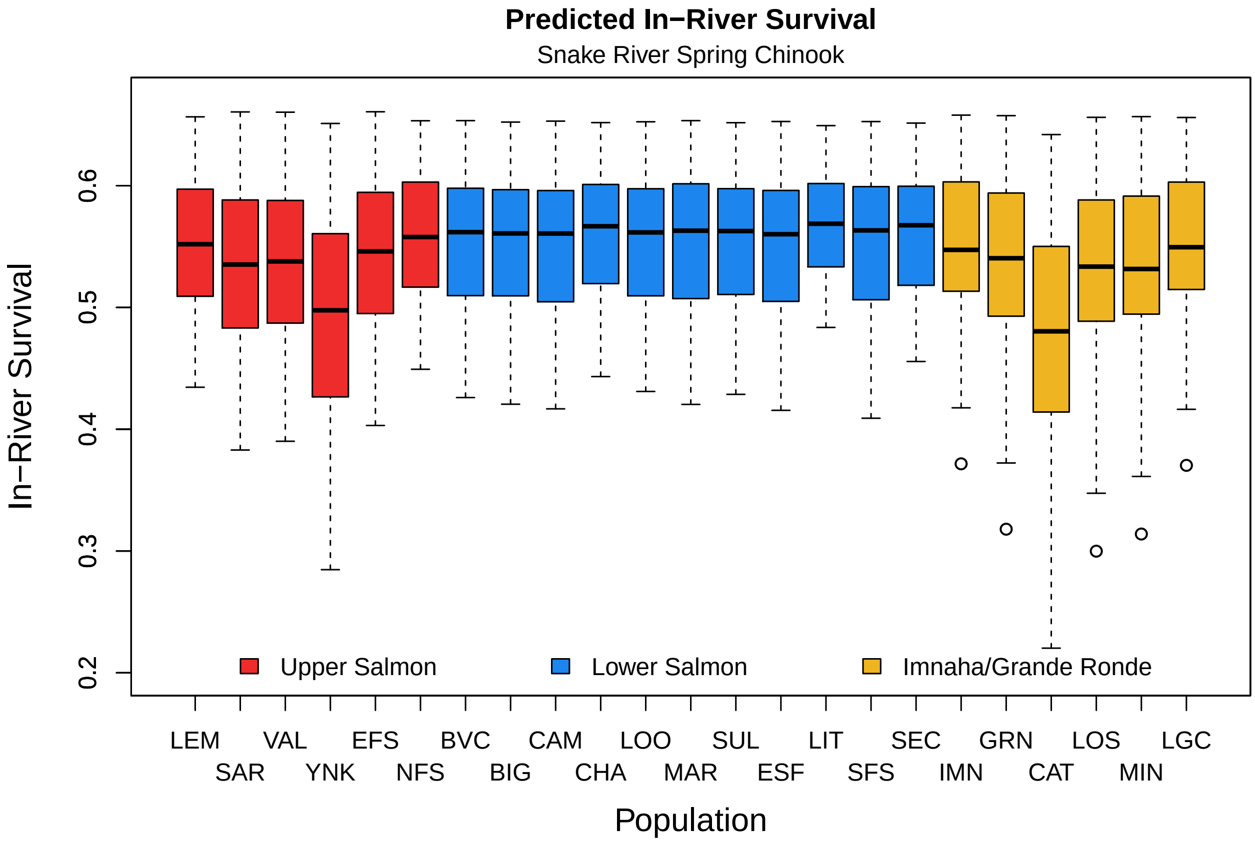


Figure 10. Boxplots of in-river survival (Lower Granite Dam to Bonneville Dam) predicted by COMPASS for the 80 water years of the “Base” scenario for all populations of Snake River spring Chinook salmon. Population groups are denoted by color; see Table 2 for population abbreviations.

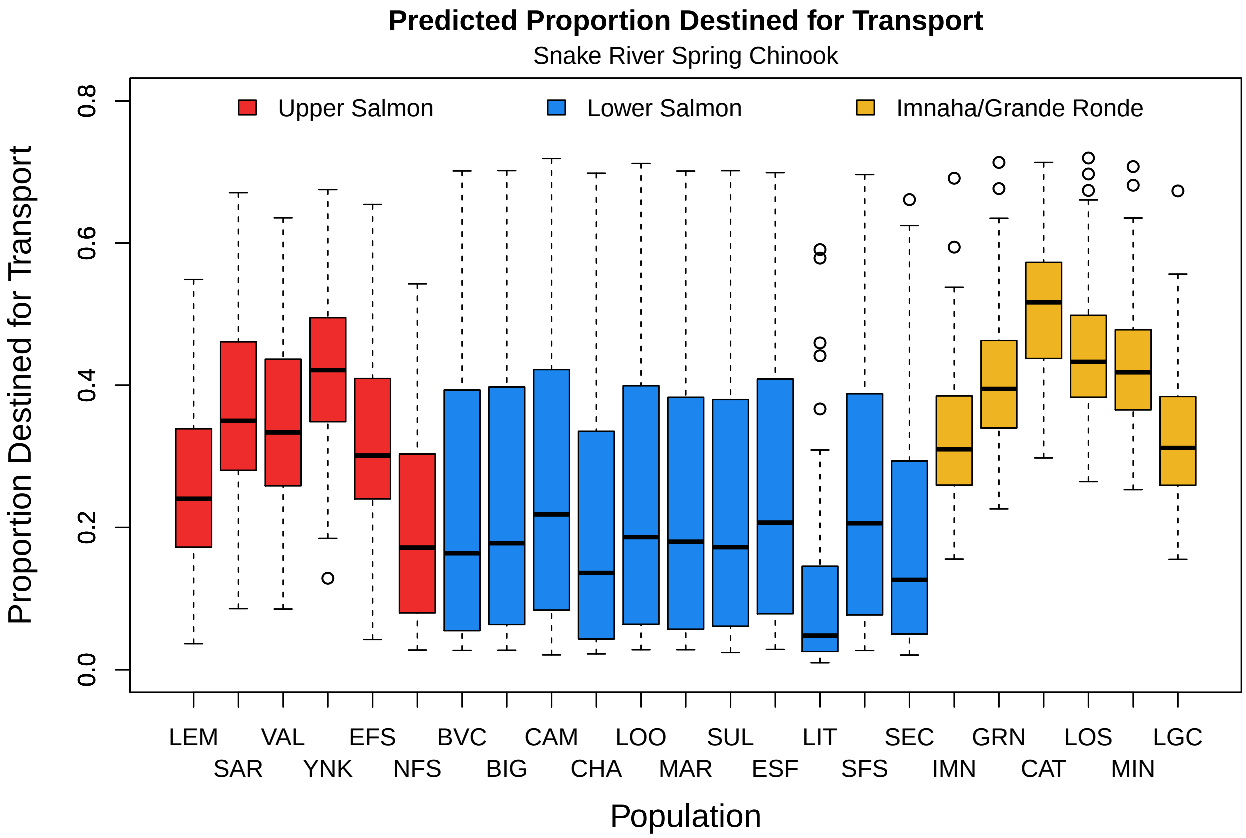


Figure 11. Boxplots of proportion destined for transport (the proportion of the population that would be transported if survival were 100%) predicted by COMPASS for the 80 water years of the "Base" scenario for all populations of Snake River spring Chinook salmon. Population groups are denoted by color; see Table 2 for population abbreviations.

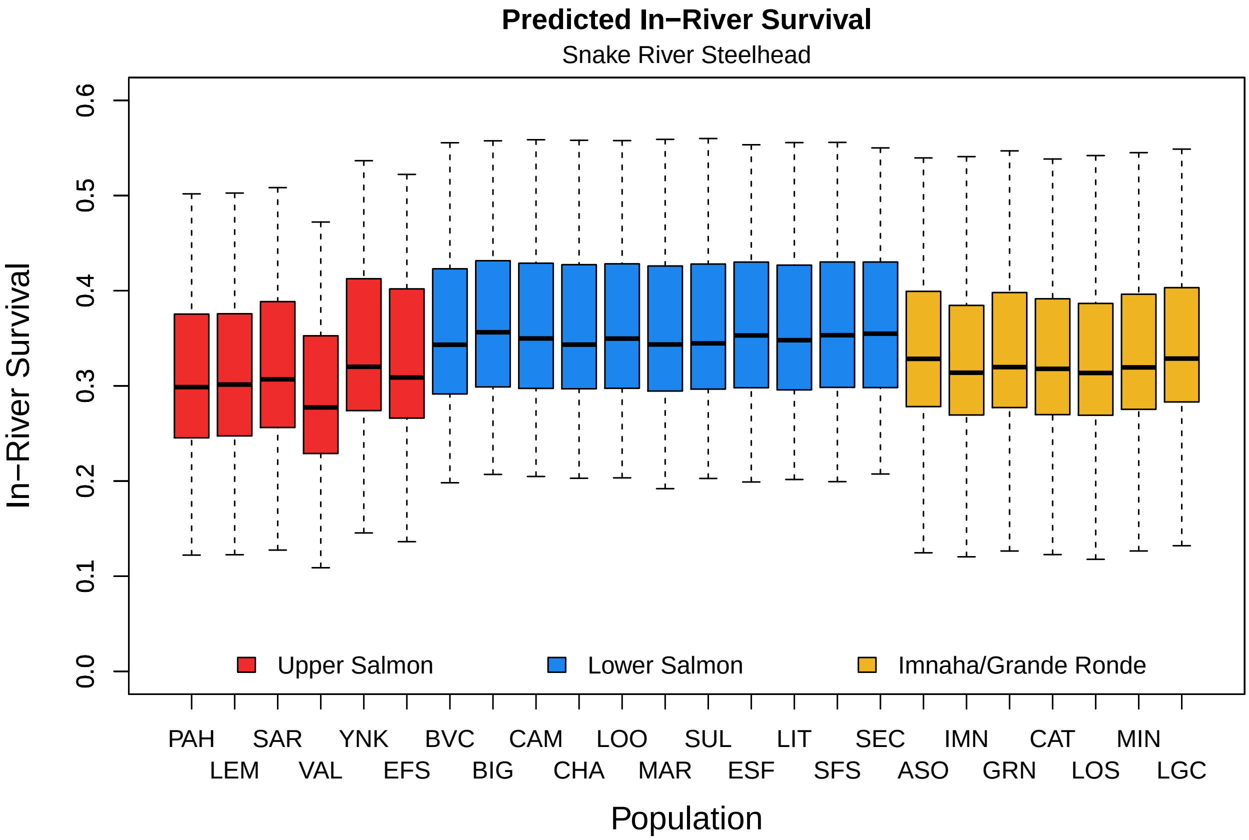


Figure 12. Boxplots of in-river survival (Lower Granite Dam to Bonneville Dam) predicted by COMPASS for the 80 water years of the “Base” scenario for all populations of Snake River steelhead. Population groups are denoted by color; see Table 2 for population abbreviations.

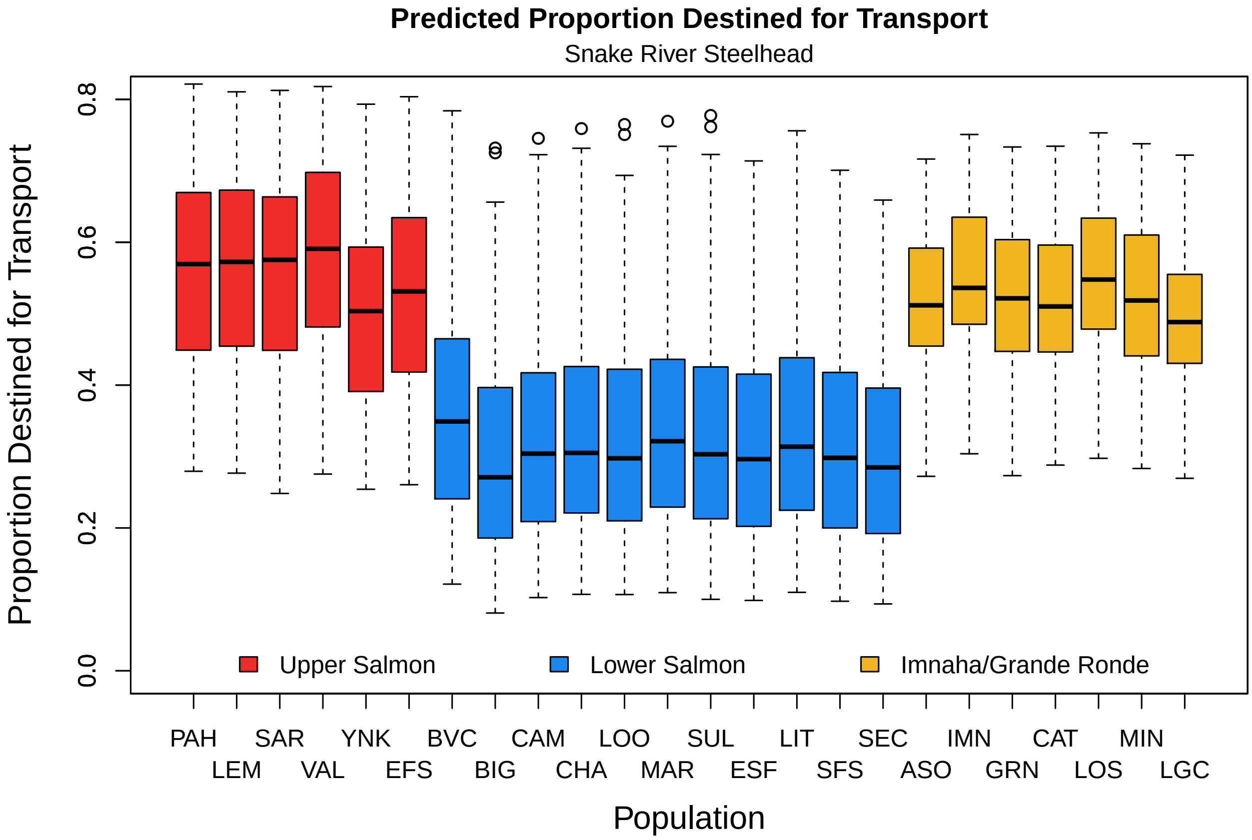


Figure 13. Boxplots of proportion destined for transport (the proportion of the population that would be transported if survival were 100%) predicted by COMPASS for the 80 water years of the "Base" scenario for all populations of Snake River steelhead. Population groups are denoted by color; see Table 2 for population abbreviations.

Discussion

We present a new method for predicting distributions of arrival times of migrating juvenile salmon at Lower Granite Dam. This method is flexible enough to capture the complex structure in arrival distributions, which can include multiple modes and long tails, yet also has the ability to produce smooth distributions with simple features and single modes. The models are built on a set of predictor variables that can be used in prospective models used to assess the subsequent survival and passage experience of migrating smolts below Lower Granite Dam. Accurate predictions of arrival distributions will allow for more accurate predictions produced by the subsequent predictive models that use arrival distributions as inputs.

The results from the prospective modelling exercises show that variation in arrival timing can result in different experiences of populations both in the hydropower system and after exiting the hydropower system. Later arriving populations tended to have lower SARs and higher proportions transported. In-river survival was less affected by arrival timing, but later arriving populations tended to have lower survival. We do not have sufficient PIT tag data to fit separate travel time or in-river survival models for the different population groups. However, it is clear that we can capture some of the variation in conditions experienced by these populations with our models of arrival timing.

The models we selected in the retrospective modeling process were deliberately chosen to maximize robustness. The crossvalidation analysis showed that larger numbers of quantiles may become prone to overfitting or spurious predictions. Despite limiting the number of quantiles in the models to five, the resulting best-fit models still produced some quantile crossovers and non-decreasing smoothing splines. In future refinements of these arrival timing models we intend to investigate various ways to improve robustness, such as limiting the predictors that can enter the model or linking the slope coefficients among quantiles.

The models described here perform well but could be improved upon to allow a more mechanistic representation of the processes driving arrival timing. Our models are based on environmental variables summarized at a monthly level. The model predictions could likely be improved if daily measurements of environmental variables could be included in the models. Our current methods do not easily allow for such daily data. Our methods also require a two-step model fitting process that involves many model components. This makes the resulting models cumbersome and could possibly lead to overfitting if care is not taken in the model selection process. The two-step method also does not adequately account for uncertainty in the joint model predictions. A different modeling approach based on methods developed for time-to-event data or counting processes may allow a simpler model representation that better captures the underlying processes involved and associated prediction uncertainty while also allowing predictor variables measured on a finer time scale. We intend to develop such models in the future as well as develop models that more explicitly account for the migration process from rearing sites to Lower Granite Dam.

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Supplemental

Supplemental Table 1. A complete list of all ESA-listed populations within the Snake River basin, separated into major population group, and the PTAGIS mark/release sites we assigned to each population. Insufficient PIT tag data was found for several populations and they were not included in the rest of the analysis (Big Sheep Creek, Wenha, Middle Fork Salmon both above and below Indian Creek, Salmon River below Redfish Lake, and Panther Creek).

Population	PTAGIS Mark/Release Sites
	Lower Snake
Asotin River	ASOTIC, ASOTNF, ASOTSF, GEORGC, CHARLC
	Grande Ronde/Imnaha
Big Sheep Creek	BSHEEC, LSHEEC, LICK2C, SALTC, CANALC, REDMOC, MCCULC
Imnaha River	IMNAHW, IMNTRP, IMNAHR, GUMBTC, HORS3C, MAHOGC
Grande Ronde River	GRNTRP, GRANDR, GRAND1, GRAND2, GRANDW, GRANDP, JOSEPC
Wenha River	WENR, WENRNF, WENRSF
Catherine Creek	CATHEC, CATHEP, CATHEW, CATCMF, CATCNF, CATCSF, LCATHC
Lostine River	LOSTIR, LOSTIW, BCANF, WALLOR
Minam River	MINAMR
Lookingglass Creek	LOOKGC
	Middle Fork Salmon
Bear Valley Creek	BEARVC, ELKC, CAPEHC
Big Creek	BIG2C, CROO2C, BRAMYC, BEAV4C, SMITHC, LOGANC, CAVEC, CABINC, BUCK2C, RUSHC, RUSHWF, MONUMC, SNOSLC, MONCWF
Camas Creek	CAMASC, YELLJC
Chamberlain Creek	CHAMBC, CHAMWF, FLOSSC, MOOSEC, SALR2
Loon Creek	LOONC
Marsh Creek	MARSHC, MARTRP, MARTR2, KNAPPC
Sulfur Creek	SULFUC, BOUNDC, DAGGEC
Middle Fork Salmon, Below Indian Creek	SALMF1, WILSOC, SHEPC
Middle Fork Salmon, Above Indian Creek	SALMF2, INDIAC, PISTOC, RAPR, FALLC

Supplemental Table 1. Continued.

Population	PTAGIS Mark/Release Sites
	South Fork Salmon
East Fork South Fork Salmon	SAEFSF, JOHTRP, SUGARC, JOHNSC, BURNLC
Little Salmon River	LSALR, BOUL2C, HARDC, HAZARC, RAPIDR, RAPIWF, RPDTRP
South Fork Salmon	SALRSF, LSFTRP, SFSRKT, ELK2C, GOATC, BEAR4C, SFSTRP, KNOXB, SALSFW, RICEC, FITSUC
Secesh River	SECESR, SECTRP, ALEXC, FLATC, GROUSC, LICKC, LAKEC, PHOEBC, PIAHC, RUBYC, SUMITC, ZENAC, ZENAWF
	Upper Salmon
Pahsimeroi River	PAHTRP, PAHSIW, PAHSIR
Lemhi River	LEMHIW, LEMHIR, 18MILC, AGNCYC, BASINC, BASN2C, BIG8MC, BIGB2C, BIGSPC, BOHANC, BOHEFC, BTIMBC, BUCK4C, CANY2C, CRUIKS, DEERC, FLUMEC, HAWLYC, HAYDEF, HAYDNC, HAYNSC, KENYC, LEEC, LIT8MC, LLSPRC, LTIMBC, MCDEVC, MILL5C, PATTEC, PRATTC, QKASPC, RESVRC, TEXASC, TRAILC, WILDCC, WIMPYC, WITHGC, WRIGTC, YRIANC
Salmon River, Below Redfish Lake	RLCTRP, REDFLC, SALR3, SALR4, SLAT2C, SQAW2C, CHALLC, CROOC, BASN3C, IRONC, SQUAWP
Salmon River, Above Redfish Lake	SAWTRP, GOLDC, WILLIC, FISHEC, CHAMPC, 4JULYC, POLEC, FRENCC, SMILEC, BEAVEC, ALTULC, YELLLC, VATC, PETTLC, HELLRC, HUCKLC, DECKEC
Valley Creek	VALEYC, STANLC, ELK3C
Yankee Fork	YANKFK, YANKWF
East Fork Salmon River	SALEFT, SALEFW, HERDC, SALREF
North Fork Salmon River	SALRNF, CARMEC, TOWERC, 4JUL2C
Panther Creek	PANTHC, MUSCRC, MOYERC

Introduction

We assessed the sensitivity of COMPASS passage model outputs to input levels of river environment and river operation variables. The sensitivity analysis focused on the effects of varying levels of flow, temperature, and spill on dam survival, inriver survival, and travel time between Lower Granite Dam and Bonneville Dam. We used a transportation start date of May 1st and 2017 parameters at all dams for this analysis. The scenario was run for both yearling Chinook and steelhead.

Methods

The sensitivity analysis focused on the response of inriver survival, dam survival, and travel time to varying inputs of flow, temperature, and spill proportion. Inriver survival included both dam and reservoir survival and was defined as the cumulative survival from the forebay of Lower Granite Dam (LGR) to the confluence of the Snake and Columbia rivers and from the confluence to the tailrace of Bonneville Dam (BON), or the overall reach from LGR to BON. Dam survival included the survival at individual dams, and the cumulative dam survival for LGR through BON. Travel time was the median time of passage between LGR and the confluence and between the confluence and BON. Flow, temperature, and spill proportion were the input variables used because these are the three input variables for the migration rate and reservoir survival models that can be directly manipulated as daily inputs. Spill proportion also affects dam survival, since it influences the predicted spill efficiency and fish guidance efficiency.

Daily river environment data collected at Lower Granite Dam (LGR) and McNary Dam (MCN) from 1995-2017 were used as a guide for setting input levels of flow, temperature, and spill proportion. Daily river environment data were taken from the Columbia River DART website (http://www.cbr.washington.edu/dart/dart.html).

The Scenarios were constructed using continuous and categorical levels of input variables. Each level of a continuous variable was assessed at each combination of the categorical levels for the remaining two variables. Table A9 1 shows continuous and categorical levels of inputs used to construct the scenarios.

Table A9 1. Input levels for sensitivity scenarios in Set 1.

	Continuous Levels Range (step)	Categorical Levels
Flow (kcfs)		
Snake	20 - 200 (20)	50, 100, 150
Columbia	118 - 462 (38)	175, 270, 365
Temperature (°C)	4 - 24 (1)	6, 12, 18
Spill proportion	0.00 - 0.80 (0.10)	0.00, 0.25, 0.50, 0.75

Not all combinations of input levels were observed in the historic data. We wanted to keep the model inputs within the experience of the observed data to which the model was calibrated. Therefore, if a combination was outside the bounds of the observed data, that scenario was dropped from the sensitivity analysis. For example, temperatures of 18° C or greater were not observed when flow exceeded 160 kcfs at LGR (385 kcfs at MCN). Another example is spill percentages of 30% or less were not observed at MCN when flow was 340 kcfs or greater. This resulted in a total of 311 scenarios run.

For each scenario in the sensitivity analysis, input data values for sensitivity variables were set constant across every day in the year. All river segments had the same temperature value and every dam had the same spill proportion. All Snake River segments had the same constant Snake River flow level and all Columbia River segments had the same constant Columbia River flow level.

The parameter values used the reservoir survival equations and the migration rate equations were those specified in Tables A2.2-1 and A2.2-2, respectively, in Appendix 2 of the COMPASS Manual. The parameter values used for dam passage (route-specific passage and survival probabilities, spill efficiencies, etc.) were those specified for 2017 in Appendices 4 and 5. We used a transportation start date of May 1st at Lower Granite Dam, Little Goose Dam, and Lower Monumental Dam for all scenarios.

For all scenarios, fish were released into the forebay of LGR using the same release profile. The release profiles for Chinook and steelhead were based on average smolt passage distributions at LGR for wild fish. The first day of release for both chinook and steelhead was March 24th.

Results

The inriver survival of both Snake River spring/summer Chinook and steelhead was sensitive to varying levels of flow, water temperature, and proportion river spilled (Figures A8 1-6). The survival of both Chinook and steelhead was strongly sensitive to water temperature, with both species exhibiting a nonlinear response. Chinook inriver survival was moderately sensitive to flow in the Snake River, but insensitive to flow in the Columbia River. Steelhead inriver survival was moderately sensitive to flow in both the Snake and Columbia Rivers. For both species, spill only had a noticeable impact on inriver survival at the lowest levels of spill.

Dam survival was only somewhat responsive to proportion spill (Figure A8 7), although the response varied across dams. For most Snake River dams, survival at zero spill was markedly lower than the other levels of spill. Most dams showed only small changes in survival between spill proportions of ten to eighty percent. Across all 8 dams, overall dam survival increased by approximately 5 percent as spill proportion increased from zero to eighty percent. Also, dam survival of steelhead was approximately 5 percent higher than that of Chinook.

The travel time of both Chinook and steelhead was strongly sensitive to river flow in the Snake River but only moderately sensitive to river flow in the Columbia River (Figure A8 8). Chinook were more sensitive than Steelhead to proportion spill, with total travel time for Chinook varying by several days across levels of spill. Both Chinook and steelhead were very sensitive to water temperature in the Snake River, but only slightly sensitive to water temperature in the Columbia River (Figure A8 9).

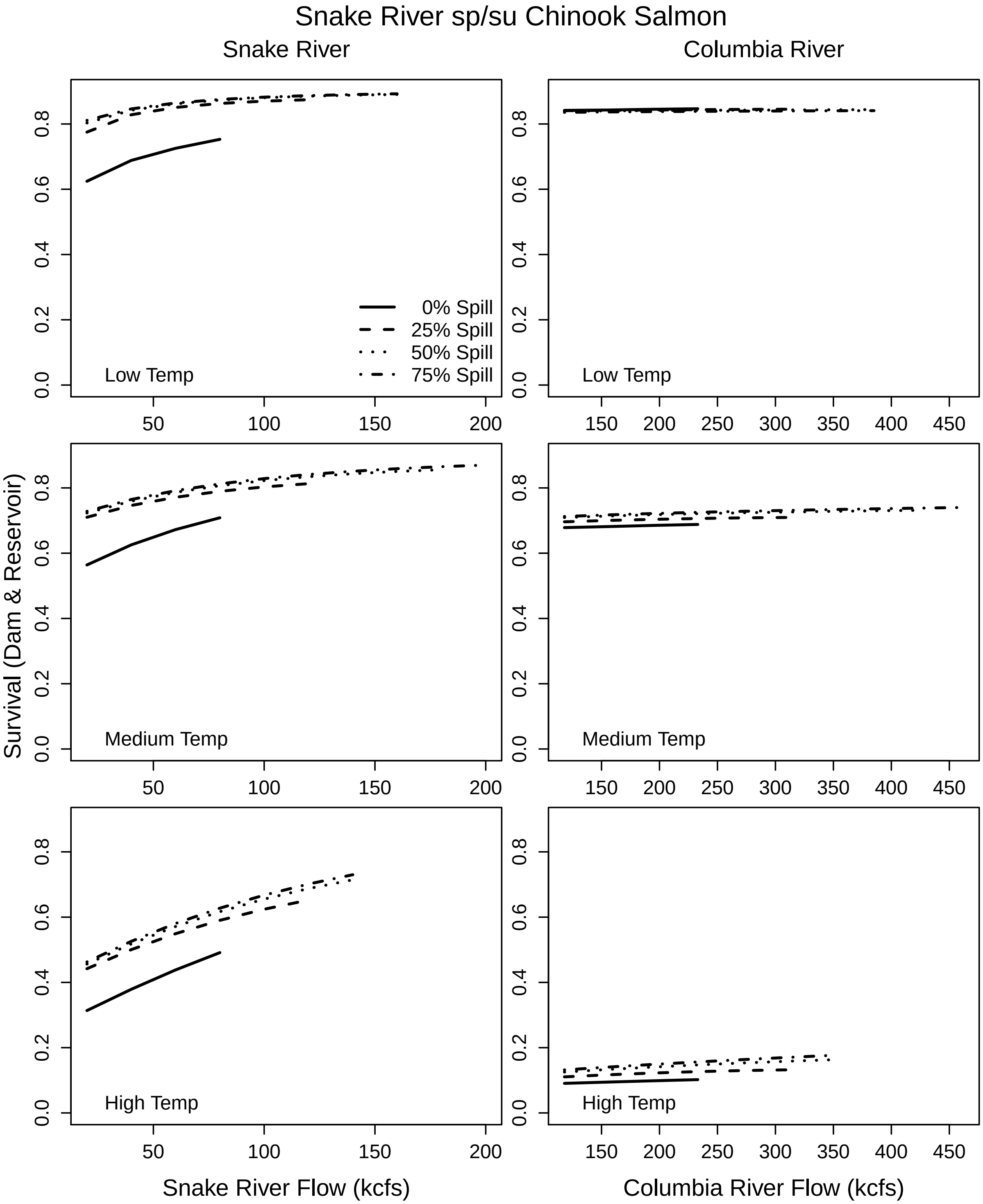

Figure A8 1. Sensitivity of overall survival (dam and reservoir) through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of river flow for Snake River spring/summer Chinook. Sensitivities were performed for three levels of temperature and four levels of spill.

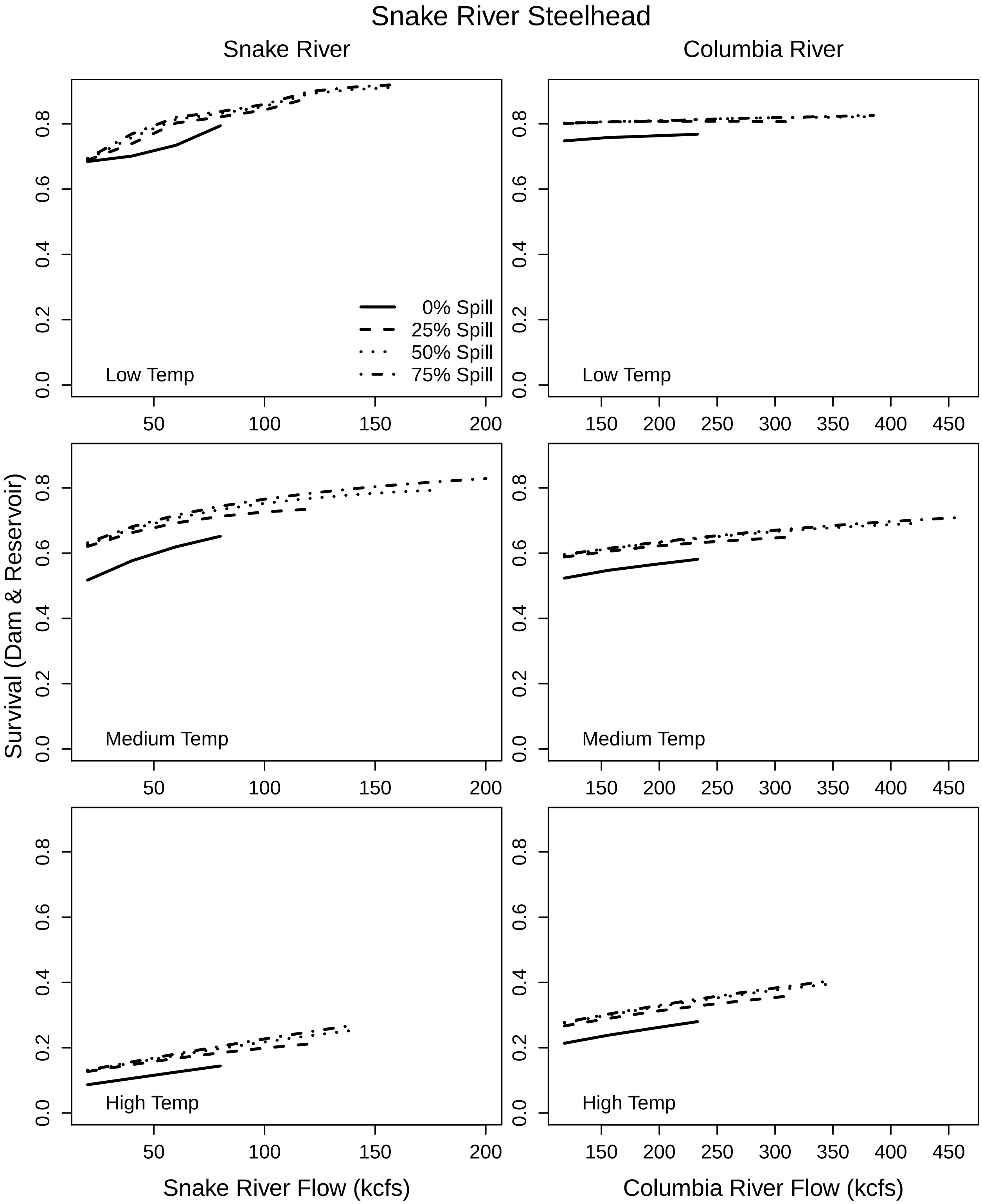

Figure A8 2. Sensitivity of overall survival (dam and reservoir) through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of river flow for Snake River steelhead. Sensitivities were performed for three levels of temperature and four levels of spill.

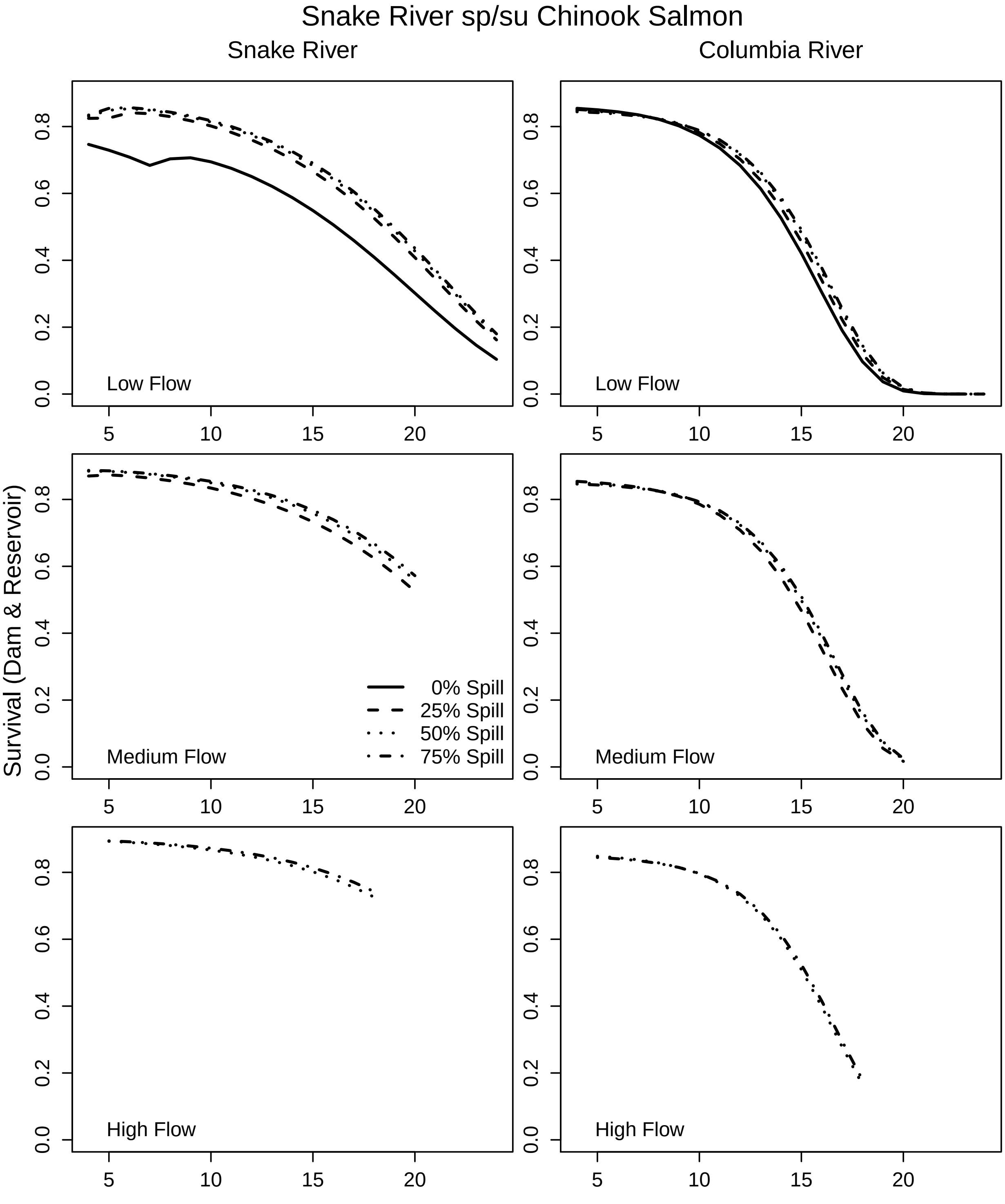

Figure A8 3. Sensitivity of overall survival (dam and reservoir) through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of water temperature for Snake River spring/summer Chinook. Sensitivities were performed for three levels of flow and four levels of spill.

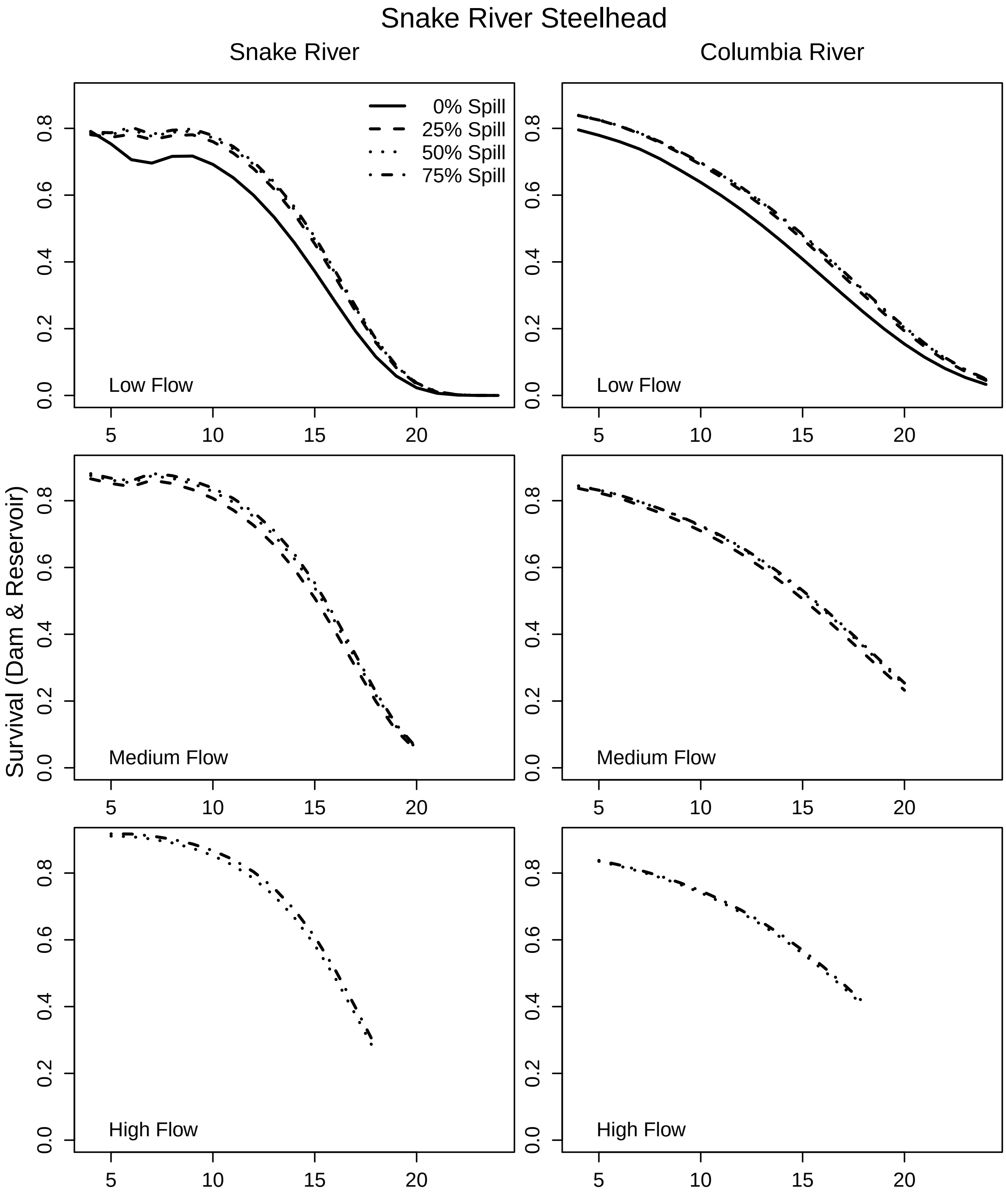

Figure A8 4. Sensitivity of overall survival (dam and reservoir) through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of water temperature for Snake River steelhead. Sensitivities were performed for three levels of flow and four levels of spill.

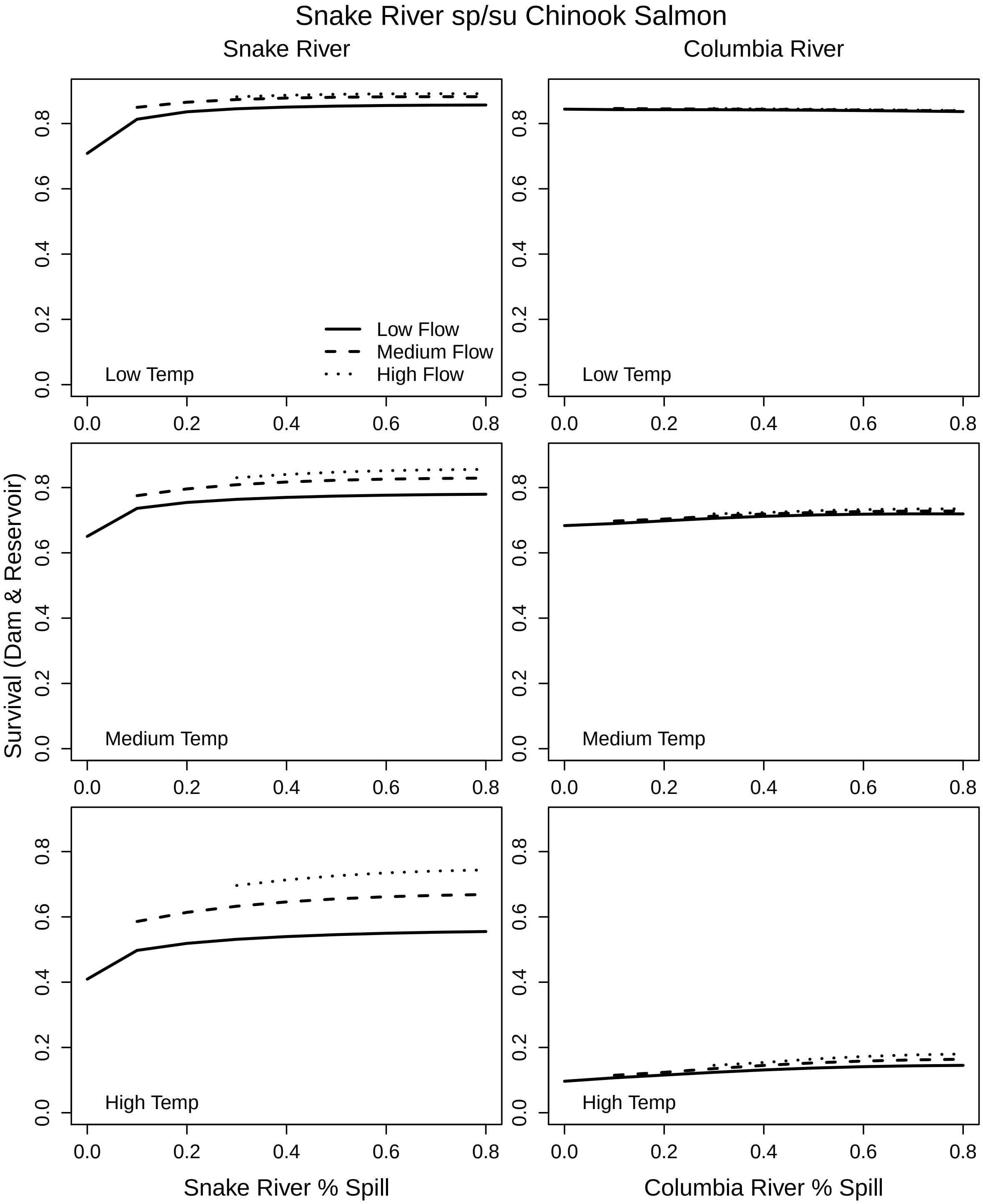

Figure A8 5. Sensitivity of overall survival (dam and reservoir) through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of proportion spill for Snake River spring/summer Chinook. Sensitivities were performed for three levels of flow and three levels of temperature.

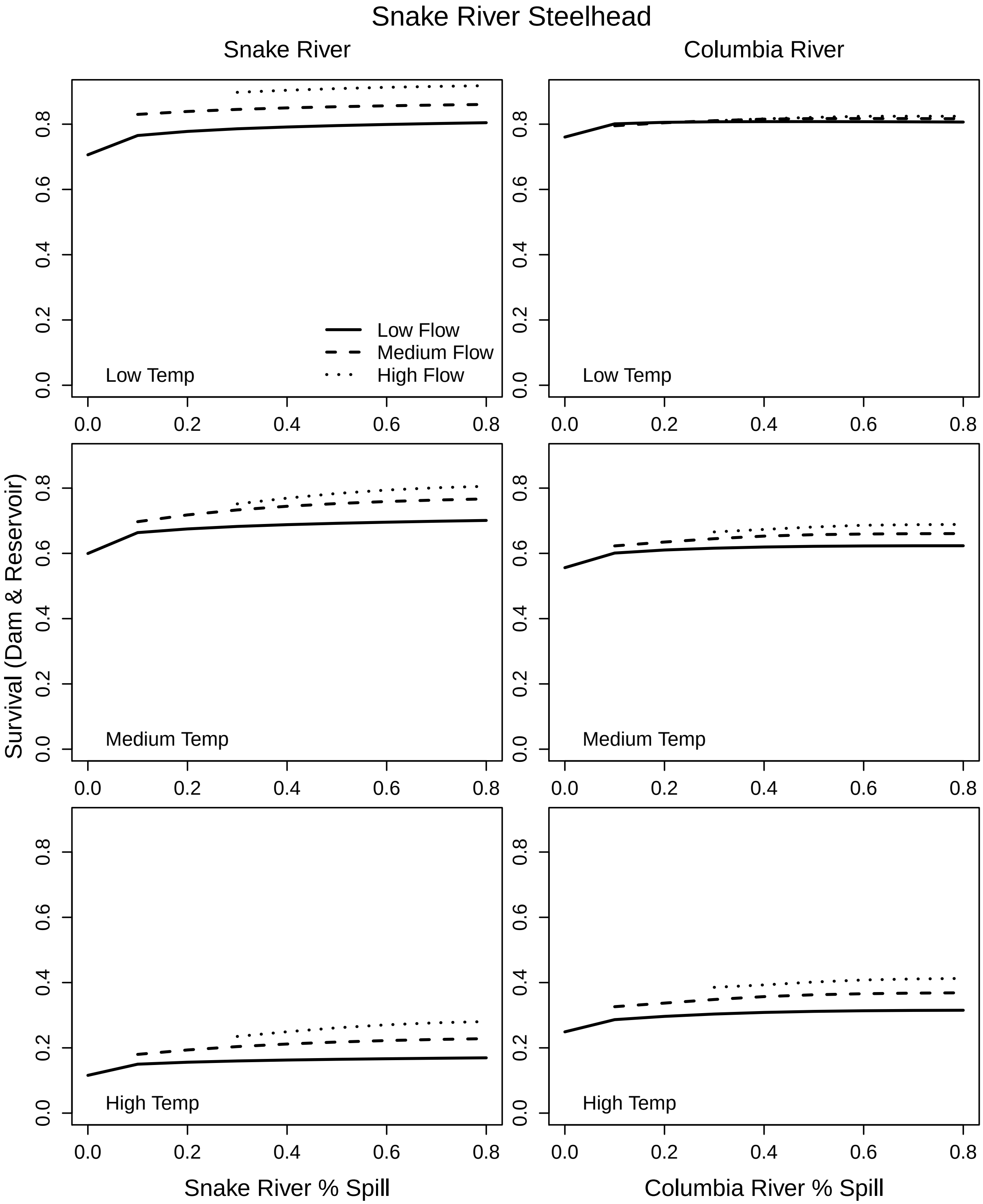

Figure A8 6. Sensitivity of overall survival (dam and reservoir) through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of proportion spill for Snake River steelhead. Sensitivities were performed for three levels of flow and three levels of temperature.

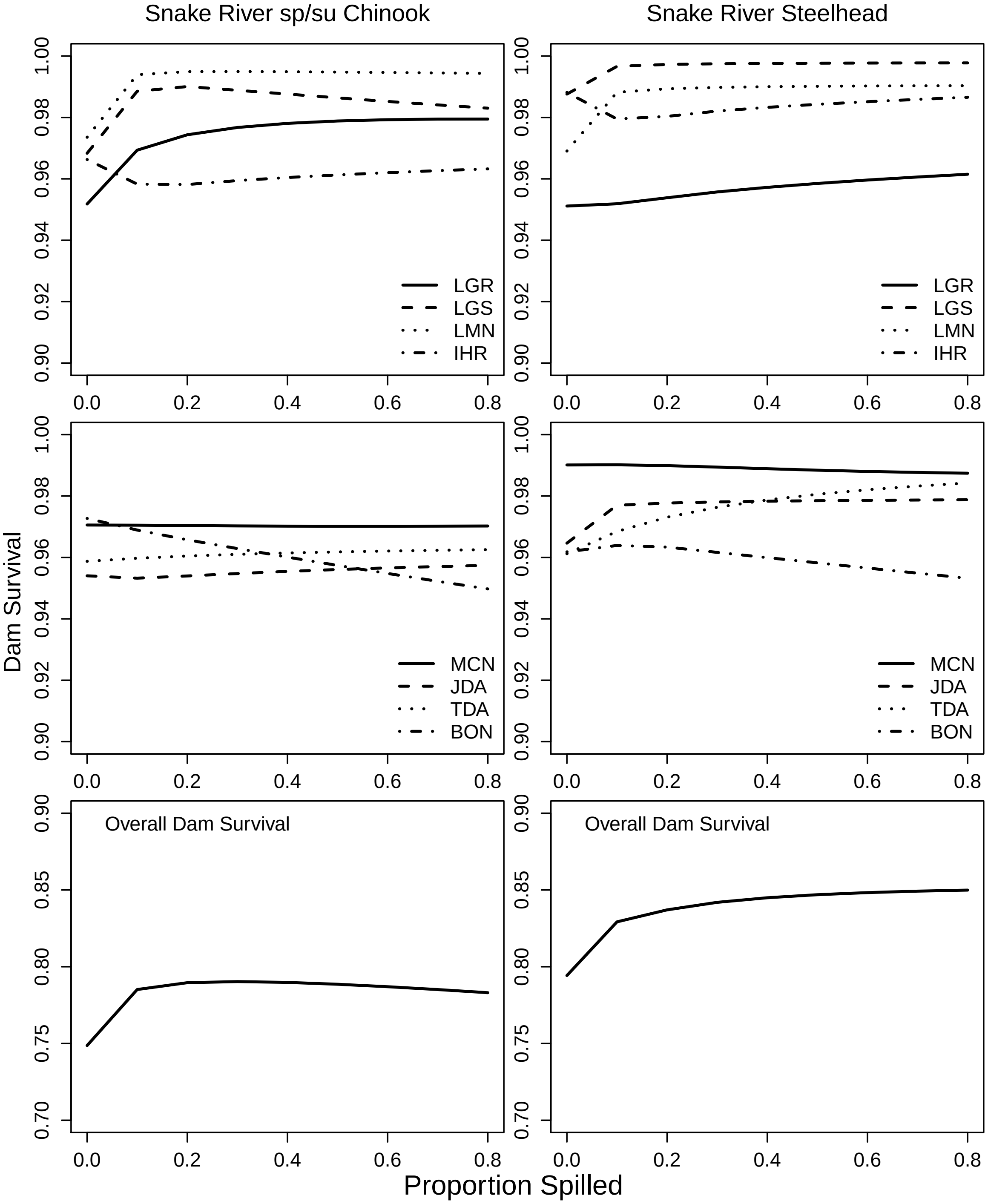

Figure A8 7. Sensitivity of dam survival through the Snake River dams (LGR=Lower Granite Dam, LGS=Little Goose Dam, LMN=Lower Monumental Dam, IHR=Ice Harbor Dam) and Columbia River dams (MCN=McNary Dam, JDA=John Day Dam, TDA=The Dalles Dam, BON=Bonneville Dam) as a function of proportion flow spilled for Snake River spring/summer Chinook and steelhead. These runs were conducted using the medium level for both flow and temperature.

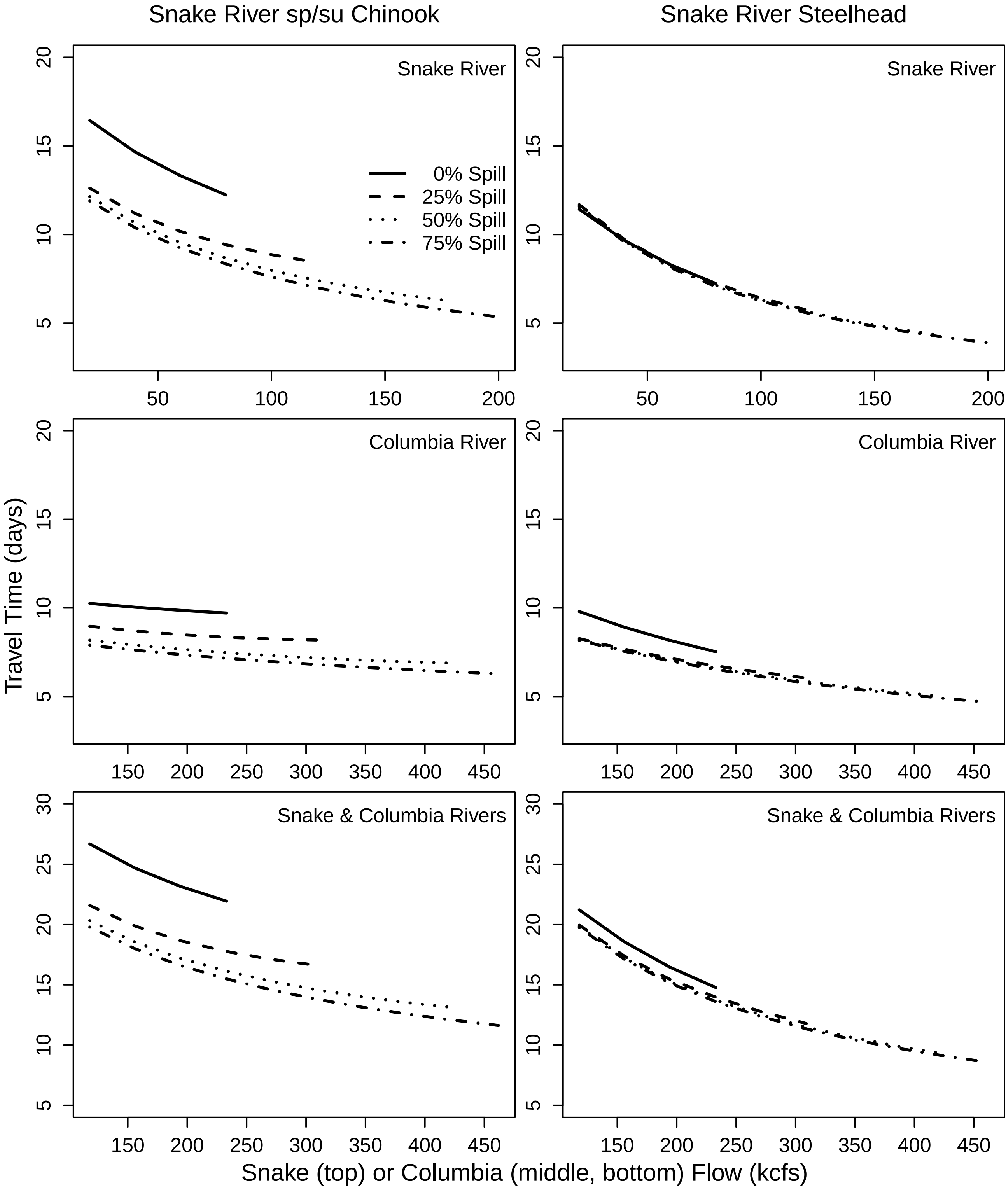

Figure A8 8. Sensitivity of travel time through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of river flow for Snake River spring/summer Chinook and steelhead. These runs were conducted using the medium level of temperature and four levels of spill.

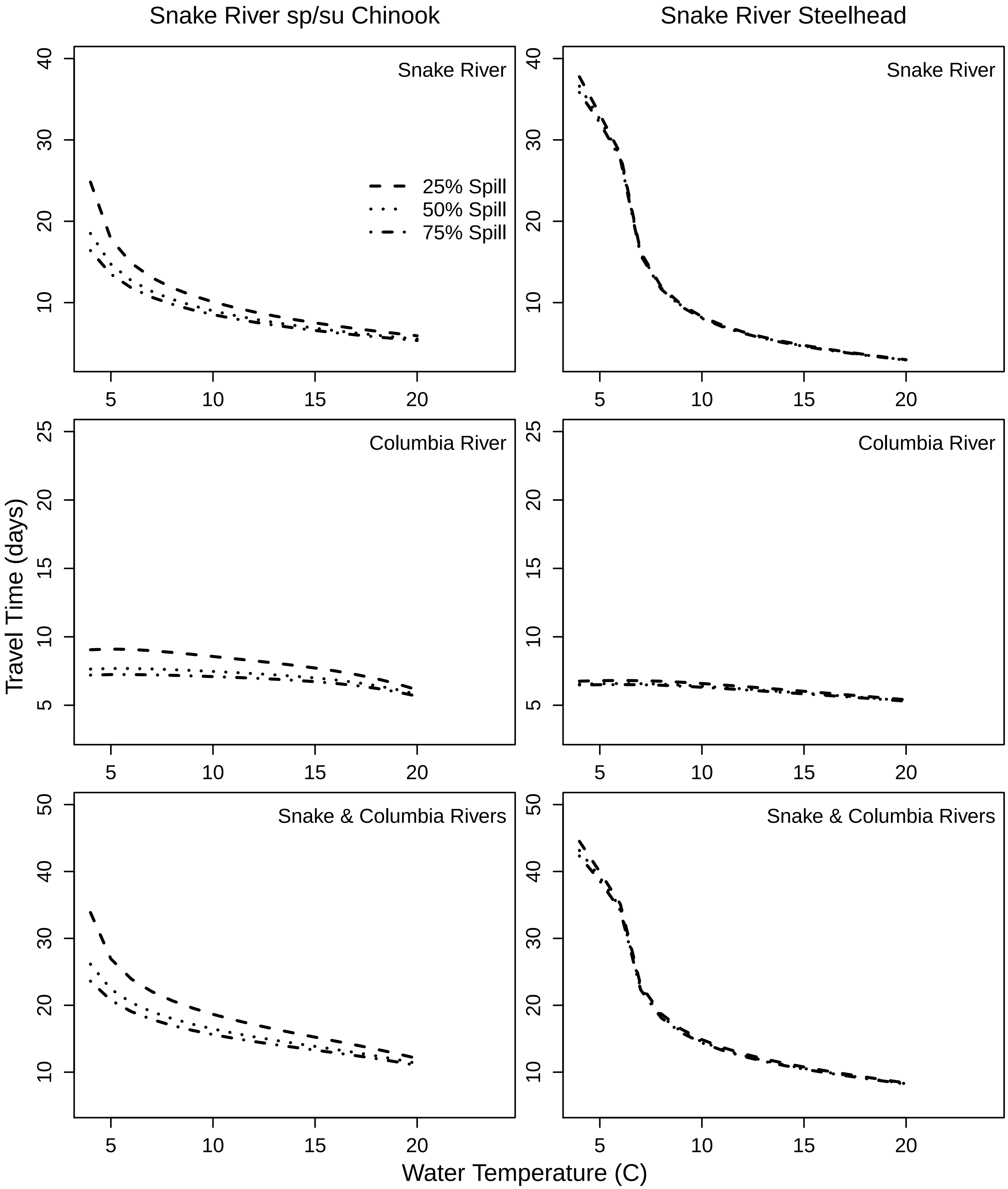

Figure A8 9. Sensitivity of travel time through the Snake (Lower Granite forebay to the mouth) and Columbia (mouth of the Snake River to Bonneville tailrace) as a function of water temperature for Snake River spring/summer Chinook and steelhead. These runs were conducted using the medium level of flow and three levels of spill.