PACIFIC SALMON FOUNDATION

RELEASE STRATEGY EFFECTS ON SURVIVAL AND RETURN AGES FOR BRITISH COLUMBIA CHINOOK AND COHO HATCHERY RELEASES, 1972-2017

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Strategy | Assessment | Training

Background

This paper presents a statistical modelling approach to evaluating Fisheries and Oceans Canada (DFO) Salmon Enhancement Program (SEP) release strategies on survival rates and return ages of Chinook and Coho salmon in B.C. Between 1972 and 2017, SEP used a range of experimental release strategies comprising one or more of weight-at-release, day-at-release, life stage at-release, number of releases, stock, and release site. The specific choices behind release strategies differ widely by hatchery, geographical area, and species. Of these release strategies, only weight and day of release effects on Coho survival in Southern B.C. have been examined with studies showing mixed results (Bilton et al. 1982, Labelle et al. 1997, Irvine et al. 2013, Brouwer et al. 2014). For instance, Bilton et al. (1982) and Labelle et al. (1997) found that release timing has a larger effect on survival than release size, while Irvine et al. (2013) found that ocean entry year and mean release weight are the key variables for predicting Coho survival. Furthermore, the survival response and statistical significance of the estimated effect sizes appear to vary by year, stock, and environmental conditions (Labelle et al. 1997; Irvine et al. 2013).

In this paper, we evaluate weight-at-release, day-at-release, stock, and site-of-release effects on Chinook and Coho survival for a larger dataset of B.C. hatcheries (22 hatcheries for Chinook and 16 for Coho), with more stocks (55 Chinook stocks/hybrids, 20 Coho stocks), release sites (81 sites for Chinook, 52 sites for Coho), and years (1972-2017 ocean entry years). We also evaluate whether release strategies such as weight-at-release, stock, and release site affect the ages of returning spawners for Coho and Chinook for a smaller subset of data with sex composition information (4 hatcheries for Chinook, 7 hatcheries for Coho). We first investigate hatchery- and life-stage specific models, which then inform subsequent multi-hatchery hierarchical models for Chinook and Coho that share release effect information among regions, including Strait of Georgia, West Coast Vancouver Island, Northeast Vancouver Island, Central Coast, and North Coast. These hierarchical models accommodate the range of data quality and quantity arising from the broad range of hatcheries within B.C.

Methods

Hatchery release and return data

British Columbia Chinook and Coho release and recovery information for brood years 1970-2018 were extracted from SEP's Enhancement Planning and Assessment Database (EPAD) in December 2019 (data provided by Cheryl Lynch, SEP). The EPAD includes information from hatcheries on each release event, such as number of release events (we refer to these as "releases" for the remainder of this report), numbers released, average size-at-release, average weight-at-release, and day of release. In addition, the database includes CWT-based estimates of catch-at-age and escapement-at-age for each release event. Biological sampling for sex composition of escapement is available for approximately 30% and 47% of Chinook and Coho CWT release events, respectively. There is no biological sampling for sex composition of catch and so the return age data only reflects escapement.

Note that we identify tables and figures using prefixes CH for Chinook and CO for Coho for easier referencing. All CH tables and figures are presented first in the Tables and Figures sections followed by those for CO.

Hatchery and CWT data filtering

The raw CWT datasets were filtered to remove release events lacking average weights-at-release, or usable estimates of exploitation rates (indicated in EPAD by usability flags). It was determined that multiple release codes may not always represent unique release events and instead may consist of releases from the same rearing containers with multiple tags (Pers. Comm., Cheryl Lynch, SEP). We aggregated return data that had the same average length at-release, weight-at-release, dates of release, stock, release site, and hatchery.

Over all hatcheries, about 75 % of releases take place over a period of 7 days or less with about 50% of total releases occurring during a short 1- or 2-day period. Occasional releases take place over several weeks, which makes it difficult to reliably determine a day-of-release effect on smolt-to-adult survival; therefore, we removed releases with a period greater than 15 days. The midpoint day of the release period was then used for releases that occurred over multiple days – this includes the few cases (1 Chinook and 6 Coho release events) in which only the release month and year were given (i.e., we used the 15th day of the month). For Chinook datasets, more than 99% of weights-at-release are less than 20 g and we removed 10 release events with weights of 26-99 g so that these outliers would not lead to overfitting models. For Coho datasets, more than 99% of weights-at-release are less than 40 g and we removed 1 Quinsam River release event of 54 g so that this outlier would not lead to overfitting.

The range of return ages vary by hatchery with minimum ages ranging from 2-3 years for Chinook and 2 years for Coho, while maximum ages range from 5-7 years for Chinook and 4-6 years for Coho. The EPAD does not include zero entries for returns of each age class (ages 2-7), so we assume returns for missing age classes in a particular year are actually zero (Pers. Comm., Cheryl Lynch, SEP). The majority of returns are 2-3 years old for Coho (99.6% of data) and 2-5 years old for Chinook (99.5% of data). The age-6 Coho returns occurred for two brood years (1978, 1981) at Capilano and should be noted as a possible error, as we are unaware of other records for Coho older than 5 years. These age-6 return ages were not included in the return age models since they have no sex composition information that is needed for return age modelling. Finally, brood years after 2013 were excluded for Chinook because adult return estimates are not yet available for age-5 fish. Brood years after 2015 were excluded for Coho because adult return estimates are not yet available for age-3 fish. For return age modelling we excluded release events that did not sample at least 10 fish or 40% of annual escapement for sex composition, as simulations indicated they would not provide accurate estimates of the sex composition (See Appendix Figure A.1).

Interviews were conducted with hatchery management staff to verify data and identify any unusual events (e.g., disease outbreaks, high mortality events, predation mitigation, operational or environmental changes) for release groups in specific brood years that should be flagged for the analysis (unpublished data, Samantha James, PSF). These interviews identified that all Coho and Chinook broodstock from Puntledge River Hatchery have been transferred and reared at Rosewall Creek facility since 2011 due to high river temperatures at Puntledge. The Puntledge release events from 2011 onwards were therefore not included in the datasets used to fit Puntledge hatchery models. A summary of the flagged release groups that were excluded from model fitting is provided in the appendix Table A.1.

Graphical summaries of release events by area, hatchery, stock, life-stage, and year for the final filtered data used for survival and return age model fitting are provided in Figures CH.1-CH.2 and Figures CO.1-CO.2. The final filtered CWT dataset includes release and returns of Chinook and Coho salmon from BC hatcheries for 1971-2013 (1972-2015 ocean entry years) and 1971-2015 brood years (1973-2017 ocean entry years), respectively. Data inputs for survival and return age models are shown in figures CH.3-CH.14 for Chinook and figures CO.3-CO.14 for Coho.

After the initial data filtering, we identified 16 hatcheries for Chinook and 12 hatcheries for Coho that had at least 16 CWT release events and return data to allow fitting hatchery and life-stage specific survival models (Fig CH.1, CO.1). The hierarchical structure of the multi-hatchery models allows for data pooling and information sharing across all hatcheries, which allowed us to include hatcheries with smaller sample sizes that were excluded from the single-hatchery models. For the multi-hatchery models, we included 22 hatcheries for Chinook and 16 hatcheries for Coho, each of which had at least 5 CWT release events. Many of the hatchery returns included in the analysis include PSC stocks for Chinook (e.g., Atnarko, Big Qualicum, Chilliwack, Cowichan, Harrison, Kitsumkalum, Shuswap, Nicola, Puntledge, Quinsam, Robertson) and Coho (Big Qualicum, Coldwater River, Eagle River, Inch Creek, Puntledge, Quinsam, Robertson Creek, Toboggan Creek) that have high quality escapement data that account for escapement returns to hatcheries as well as those spawning in adjacent streams (Pers. Comm, Cam West, SEP, retired). We excluded all data without sex composition for fitting return age models for Coho and Chinook, since sex composition is needed to account for the older age-composition of female returns. This led to a much smaller dataset for return age models, with 4 hatcheries for Chinook and 8 hatcheries for Coho that had at least 20 CWT release events and return data to allow fitting hatchery and life-stage specific return age models (Fig CH.2, CO.2). All hatcheries release predominantly age-1 Coho smolts (yearlings) and age-0 Chinook smolts (sub-yearlings). A few facilities have also regularly released Coho fry (Puntledge River, Eagle River, Thompson River), Chinook fry (Eagle River, Terrace) and Chinook yearling smolts (Spius Creek, Terrace).

Smolt-to-adult survival

We define a release group as all hatchery-specific releases (i.e., release events) of the same stock that underwent the same rearing and release conditions, including the same day-of-release (as defined by midpoint day of release period) and weight-at-release.

The smolt-to-adult survival rate for each release group *i* was then calculated as:

$$S_i = \frac{1}{r_i}\sum_{a}^{A} R_{ai} = \sum_{a}^{A} C_{ai} + E_{ai}$$

where (a, A) are the minimum and maximum, respectively, ages-at-return, r_i is the total number of releases for group *i*, $C_{a,i}$ is the estimated catch-at-age (in number of fish) of group *i* fish in combined US and Canadian fisheries, $E_{a,i}$ is the estimated escapement-at-age of group *i* fish to their natal hatchery or stream, $R_{a,i}$ is the total number of returns-at-age calculated by summing CWT estimates of escapement and catch. There is considerable uncertainty (and possibly bias) in both catch and escapement for many of these stocks, which means the absolute scale of survival may not be reliable. Nevertheless, we assume that these survival rate indices are adequate reflections of the underlying hatchery release conditions. Assessment of catch and escapement uncertainties is beyond the scope of this particular paper.

We transform survival rate estimates to the log-odds (logit) scale for model fitting to linearize the response variable:

$$logit(S_i) = \log\left(\frac{S_i}{1 - S_i}\right)$$

Return ages

Return ages are calculated from CWT estimates of escapement and catch. The escapement numbers represent mature fish returning to their natal spawning sites and adjacent streams (hatcheries + natural spawners), while catch numbers typically include some unknown portion of immature fish.

For Chinook return age models, we calculate the mean age of return $\bar{a}_i$ for each release group *i* as:

$$\bar{a}_i = \frac{1}{R_{.i}} \sum_a^A R_{ai} a = \frac{1}{C_{.i} + E_{.i}} \sum_a^A (C_{ai} + E_{ai}) a$$

where a dot "." in place of the subscript *a* represents summation over that index. The proportion of females in total returns is calculated as:

$$\tilde{F} = \frac{1}{R_{.i}} \sum_a^A R_{ai} f_{ai}$$

where f_{ai} is the proportion of females from biological sampling of escapement-at-age of release group *i*.

For Coho return age models, we calculate the proportion of Jacks J_i (age-2 males) for each release group *i* as:

$$J_i = \frac{R_{2i}(1 - f_{2i})}{R_{.i}^M} = R_{2i}(1 - f_{2i}) \sum_a^A \frac{1}{R_{ai}(1 - f_{ai})}$$

where the superscript *M* is added to identify male returns and thus $R_{.i}^M$ is the estimated total male returns (e.g., catch + escapement) summed across all ages for release group *i*.

We transform the proportion of Jacks (J_i) to the log-odds (logit) scale for model fitting to expand the response variable bounds from 0,1 to $-\infty, +\infty$, which then allows a standard Gaussian linear modelling approach. We calculate the empirical log-odds by adding 0.5 to the numerator and denominator (Dunn and Smyth 2018) to allow computation of log-odds for samples with 0% or 100% Jacks and to reduce bias associated with low sample sizes:

$$\widehat{logit}(J_i) = \log\left(\frac{R_{.i}^M J_i + 0.5}{R_{.i}^M (1 - J_i) + 0.5}\right)$$

Hatchery and life-stage specific survival models

We use hatchery and life-stage (e.g., fry, sub-yearling, yearling) specific linear mixed effects models to investigate how weight-at-release and day-at-release potentially affect smolt-to-adult survival rates. Here we develop the model structure incrementally, starting with the simplest form:

(1) $Y_i = log\left(\frac{S_i}{1-S_{,i}}\right) = \alpha + \theta_1 W_i + \beta_1 D_i + \varepsilon_i$

where Y_i is the logit-transformed survival rate for release group *i*, α is the intercept or the hatchery average logit-survival before accounting for other covariates in the model, θ_1 is the coefficient or effect size for a continuous *Weight* (*W,* weight-at-release), β_1 is the coefficient for a continuous *Day* (*D*, day-at-release), and ε_i is an independent and identically distributed Gaussian residual (i.e., $\varepsilon_i \sim N(0, \sigma^2)$). We centered the *Day* covariate by subtracting the hatchery-specific mean Julian day-at-release. Thus, coefficient β_1 is interpreted as the change in logit-survival per 1-day deviation from the average day-at-release for a particular hatchery. We exclude the *Day* covariate from hatcheries where all releases occur within a 15-day window to reduce spurious relationships between survival and day-at-release.

Both weight-at-release and day-at-release may be non-linearly related to smolt-to-adult survival; therefore, we included quadratic terms for both weight- and day-at-release, i.e.,

(2) $Y_i = \alpha + \theta_1 W_i + \theta_2 W_i^2 + \beta_1 D_i + \beta_2 D_i^2 + \varepsilon_i$

Quadratic terms allow for a potential survival response that peaks at some optimal level.

The model defined by Equation (2) would be enough to model hatchery release experiments if we assume the error term ($\varepsilon_i \sim N(0, \sigma^2)$) was correct. In fact, we know from fisheries oceanography studies that such assumptions are almost never correct; instead, numerous potential confounding factors exist that mask or inhibit our ability to precisely estimate experimental effect sizes (θ, β). These could include structured patterns in the data such as long-term trends or periodic cycles (Malick et al. 2017, Malick et al. 2020) as well as short-term and localized events associated with the presence/absence of oceanographic features, predators, or prey (Malick et al. 2015, Chasco et al. 2017). Although these factors are not the primary interest in this study (we do pursue them further in multi-hatchery survival models), we do need to take them into account in a statistical way to extract the information we need. The simplest factor to include is a so-called *year-effect* in which the average survival jumps up or down at random for all release groups in a year independent of the experimental factors, i.e.,

(3) $Y_{it} = \alpha + \Delta_t + \theta_1 W_i + \theta_2 W_i^2 + \beta_1 D_i + \beta_2 D_i^2 + \varepsilon_i$

where Δ_t is the year-effect deviation in average survival. We assume these deviations follow a normal distribution $\Delta_t \sim N(0, \tau^2)$.

The model in Equation (3) is sufficient to account for random temporal effects on survival rates provided the normal distribution assumption about Δ_t is reasonable.

However, there may be some underlying structure to these temporal patterns, such as the trends or cycles mentioned above that could weaken such an assumption. Furthermore, it is not possible to draw inferences about trends from random year-effects alone. Instead, we can add a temporal trend covariate to the model that depends on year, i.e.,

(4) $$Y_{it} = \alpha + \Delta_t + \theta_1 W_i + \theta_2 W_i^2 + \beta_1 D_i + \beta_2 D_i^2 + \phi t_i + \varepsilon_i$$

where ϕ is the hatchery-specific trend coefficient and t_i is the ocean entry year since 1972. Now, if there is a strong positive/negative temporal trend in average survival for a particular hatchery, we will get positive/negative estimates of ϕ, lower variance terms on the random effects (which is good), and, hopefully, more precise estimates of the day-at-release and weight-at-release effect sizes.

When survival rate variation among release groups appears to follow a common pattern, the τ^2 term represents the inter-annual variation around the trend and σ^2 represents the variance in the model residuals from the experimental effects. The proportion of the total variance that is accounted for by the random year-effects can be quantified via the intra class correlation (ICC):

(5) $$ICC = \frac{\tau^2}{\tau^2 + \sigma^2}$$

Some hatcheries use multiple release sites and different stocks or hybrids, which may affect survival success via genetic predisposition (Bryden et al. 2004) or environmental conditions of the release site. Therefore, we add a stock and site effect to arrive at the full model,

(6) $$Y_{ist} = \alpha + \Delta_t + \rho_s + \theta_1 W_i + \theta_2 W_i^2 + \beta_1 D_i + \beta_2 D_i^2 + \phi t_i + \varepsilon_i$$

where ρ_s is a stock and release site-specific deviation from the intercept. We determine whether survival rates differ among different combinations of stocks and release sites within each hatchery (i.e., *Stock/Site* effects) via marginal mean (i.e., least-square means) survival rates from model fits, which account for unequal numbers of releases of different stocks or at different sites, as well as covariate effects.

Hatchery and life-stage specific return age models

We use a similar model structure to the survival models to investigate how hatchery treatments potentially affect return ages. We exclude the release day term since the majority of the data available for fitting return age models are from release events within +/- 15 days of the mean release date (Fig. CH.10 and CO.10).

We use the logit proportion of Jacks (i.e., age 2 males) as the response variable in Coho return age models:

$$(7) \qquad \widehat{logit}(J_{ist}) = \alpha + \Delta_t + \rho_s + \theta_1 W_i + \theta_2 W_i^2 + \phi t_i + \varepsilon_i$$

where $\widehat{logit}(J_{ist})$ is the logit proportion of Coho Jacks for release group *i*, stock and site *s*, and year *t.*

We use the mean age of returns as the response variable for Chinook return age models. Female returns tend to have older age compositions than males and so we also include the proportion of females in returns as a covariate:

$$(8) \qquad \bar{a}_{ist} = \alpha + \Delta_t + \rho_s + \theta_1 W_i + \theta_2 W_i^2 + \phi t_i + \lambda F_i + \varepsilon_i$$

where λ is the coefficient or effect size for a continuous predictor for *Females* (*F,* proportion of females in returns), and $\bar{a}_{ist}$is the mean age of returns for release group *i*, stock and site *s*, and year *t*.

Model selection procedure for hatchery and life-stage specific models

We fit the full models for return age and survival for each hatchery and then performed an all subsets selection procedure to fit all possible combinations of fixed effects. We evaluated model performance via the Akaike Information criterion corrected for small sample size (AICc) and the number of predictor terms included in the top model (Hurvich and Tsai 1989, Burnham and Anderson 2002). Models that include more predictor variables and are within 2 AICc units of the model with the lowest AICc (i.e., $\Delta\mathrm{AICc} < 2$) are not supported if the maximized log-likelihood is essentially the same as that of the top model (Burnham and Anderson 2002). The model with $\Delta AICc < 2$ and the fewest predictor variables was selected as the top model for each hatchery.

Multi-hatchery hierarchical modelling

Multi-hatchery hierarchical survival models were developed to investigate whether they could improve estimates of release strategy effects compared to single hatchery models.

Release strategies

We developed Bayesian hierarchical multi-hatchery models for both Coho and Chinook to see if pooling data from release events for multiple hatcheries across BC can provide improved estimates of release strategy effects on survival outcomes. The goals of the multi-hatchery models were five-fold. First, hierarchical models have more statistical power, which can have the dual effect of reducing uncertainty in estimated survival responses for experimental release conditions and reduce the chance of identifying spurious relationships (Myers and Mertz 1998, Malick et al. 2015). Second, by sharing information across all hatcheries in BC, the multi-hatchery models can accommodate a greater range of datasets that allows including hatcheries with fewer release events, which were excluded from the single-hatchery models due to their small sample size. Third, pooling data across all hatcheries provides more information to investigate any potential life-stage effects on survival, whereas single hatchery models had limited release data for multiple life-stages. Fourth, by using a common model across all hatcheries it allows for investigation of any spatial correlation among survival rates or release strategy effects on survival. Finally, the multi-hatchery model structure includes correlation between annual deviations in survival across hatcheries by estimating a common random year effect across all hatcheries or by including oceanographic covariates.

Similar to the single-hatchery models, we develop the multi-hatchery structure incrementally, starting with the simplest form:

(9) $Y_{ih} = log\left(\frac{s_{ih}}{1-s_{ih}}\right) = \alpha + \alpha_h + \varepsilon_{ih}$

where Y_{ih} is the logit-transformed survival rate for release group *i* and hatchery *h*, α is the intercept or the mean hatchery average logit-survival before accounting for other covariates in the model, and α_h is a hatchery-specific deviation from the mean logit-survival. The ε_{ih} term is an independent and identically distributed Gaussian residual (i.e., $\varepsilon_{ih} \sim N(0, \sigma_e^2)$).

We then add linear and quadratic terms for weight-at-release:

(10) $Y_{ih} = \alpha + \alpha_h + (\theta_1 + \theta_{1h})W_{ih} + (\theta_2 + \theta_{2h})W_{ih}^2 + \varepsilon_{ih}$

where θ_1 and θ_2 are the overall mean effect across all hatcheries for linear (*W*) and quadratic (W^2) terms for *Weight* effects, and θ_{1h} and θ_{2h} are the respective hatchery deviations from mean hatchery effects.

Similarly, we then add linear and quadratic terms for day-at-release:

(11) $Y_{ih} = \alpha + \alpha_h + (\theta_1 + \theta_{1h})W_{ih} + (\theta_2 + \theta_{2h})W_{ih}^2 + (\theta_3 + \theta_{3h})D_{ih} + (\theta_4 + \theta_{4h})D_{ih}^2 + \varepsilon_{ih}$

where θ_3 and θ_4 are the overall mean effect across all hatcheries for linear (*D*) and quadratic (D^2) terms for *Day* effects, and θ_{3h} and θ_{4h} are the respective hatchery deviations from mean hatchery effects.

We shorten the notation in equation 11 by including vectors for the mean coefficients ($\theta_j = \theta_1, \theta_2, \theta_3, \theta_4$), hatchery deviations ($\theta_{jh} = \theta_{1h}, \theta_{2h}, \theta_{3h}, \theta_{4h}$), and release strategy predictor variables for ($X_{jih} = X_{1ih}, X_{2ih}, X_{3ih}, X_{4ih}$=$W_{ih}$, W_{ih}^2, D_{ih}, D_{ih}^2) as follows:

(12) $Y_{ih} = \alpha + \alpha_h + \sum_{j=1}^{4} (\theta_j + \theta_{jh}) X_{jih} + \varepsilon_{ih}$

As in the single-hatchery models we also include a linear trend and random year effects for ocean entry year since 1972 to account for short or long-term changes to river and ocean conditions that might impact survival and limit our ability to estimate experimental release strategy effects:

(13) $Y_{ih} = \alpha + \alpha_h + \Delta_t + \sum_{j=1}^{4} (\theta_j + \theta_{jh}) X_{jih} + \phi t_i + \varepsilon_{ih}$

The linear trend (i.e., fixed year effect) will account for possible positive/negative temporal trends in survival across BC hatcheries over time, while the random year effect will allow for annual deviations from this trend. Both the linear trend and random year effect are common to all hatcheries and assume annual deviations from the mean hatchery survival are correlated across hatcheries.

The model in equation 13 includes all the same predictor and covariate terms as in the single-hatchery model (equation 6), with the exception of the ρ_s term for the stock and release site-specific deviation from the intercept. For the multi-hatchery models, we focus instead on release site conditions that might lead to site specific effects on survival. For example, the number of hatchery releases at each release site could lead to density-dependent effects on survival. Higher release numbers could have a negative effect on survival (i.e., negative density-dependence) due to increased competition for food sources or habitat (Buhle et al. 2009, Thorson et al. 2013, Walters et al. 2013, Scheuerell et al. 2019), or it could have a positive effect (i.e., positive density-dependence) on survival through predator swamping (Furey et al. 2016). The river outmigration distance might also have a positive or negative impact on survival. Shorter river migration distances might improve survival by reducing freshwater predation (Michel et al. 2015), while larger river systems may offer more high-quality habitat capacity for freshwater rearing that could improve survival (Nicholas et al. 2005, Buhle et al. 2009). Therefore, we add river migration distance and the total biomass of annual hatchery releases for all salmon species from each release site as covariates:

(14) $Y_{ih} = \alpha + \alpha_h + \Delta_t + \sum_{j=1}^{4} (\theta_j + \theta_{jh}) X_{jih} + (\theta_5 + \theta_{5h}) M_{ih} + (\theta_6 + \theta_{6h}) R_{ih} + \phi t_i + \varepsilon_{ih}$

where θ_5 and θ_6 are the overall mean effect across all hatcheries for the log river outmigration distance (*M*) and release biomass (*R*), respectively, while θ_{5h} and θ_{6h} are the hatchery deviations from mean hatchery effects. We added 1 km to all outmigration distances prior to log-transformation to allow transformation of zero values for ocean and estuary release sites. As in Equation 12, we shorten this notation by adding the river outmigration and release biomass terms to the vectors for mean coefficients ($\theta_j = \theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$), hatchery deviations ($\theta_{jh} = \theta_{1h}, \theta_{2h}, \theta_{3h}, \theta_{4h}, \theta_{5h}, \theta_{6h}$), and predictor variables ($X_{jih} = X_{1ih}, X_{2ih}, X_{3ih}, X_{4ih}, X_{5ih}, X_{6ih}$ =$W_{ih}, W_{ih}^2, D_{ih}, D_{ih}^2, M_{ih}, R_{ih}$):

(15) $Y_{ih} = \alpha + \alpha_h + \Delta_t + \sum_{j=1}^{6} (\theta_j + \theta_{jh}) X_{jih} + \phi t_i + \varepsilon_{ih}$

We ignore any potential stock effects from the multi-hatchery model, as the single-hatchery models only identified stock as a significant effect on survival for rarely used combinations of stocks and release sites (although in some cases stock and release site effects are confounded).

We fit multi-hatchery models using two different datasets for each species. We fit a single life stage model using only data from the most commonly released life stage (Chinook sub-yearling smolts, Coho yearling smolts) and multiple life stage model that included releases for all life-stages for Chinook (fry, sub-yearling smolts, yearling smolts) and Coho (fry, yearling smolts). For the data scenarios including multiple life-stages, we add a life-stage effect to account for any life-stage specific differences in survival that are not related to weight or day effects:

(16) $Y_{ihl} = \alpha + \alpha_h + \Delta_t + \omega_l + \sum_{j=1}^{6} (\theta_j + \theta_{jh}) X_{jih} + \phi t_i + \varepsilon_{ih}$

where ω_l is a life-stage specific deviation from the intercept.

Initial model fitting identified that hatchery-specific estimates for the quadratic weight effect ($\theta_2 + \theta_{2h}$) and quadratic day effect ($\theta_4 + \theta_{4h}$) had very small deviations from the overall hatchery mean effects (θ_2, θ_4) for Chinook models (Appendix Figure A.14). We found that the θ_{2h} and θ_{4h} coefficients were difficult to estimate and added little information to the models, so these were fixed as zero (i.e., no hatchery deviations) for subsequent Chinook model fits. Similarly, we found the hatchery-specific estimates for the linear day effect ($\theta_3 + \theta_{3h}$) and river migration ($\theta_5 + \theta_{5h}$) effect had small deviations from the overall hatchery mean effects (θ_3, θ_5) in Coho models (Appendix Figure A.15) and therefore we also fixed θ_{3h} and θ_{5h} at zero for Coho models.

For each data scenario (single life stage, multiple life-stage) and species, we fit the full models in equation 15 or 16, as well as models without the release site-dependent river outmigration distance (*M*), aggregate release biomass (*R*), or life-stage (ω_l) predictor terms.

Environmental effects

The second step of the multi-hatchery modelling was to evaluate whether including specific environmental indices to account for effects from oceanographic variability (Mueter et al. 2002, Malick et al. 2020) or localized predation (Chasco et al. 2017, Nelson et al. 2019) on survival rates could provide better model fits compared to using a random year effects Δ_t and the temporal trend ϕt. To account for oceanographic trends, we modified equation 16 to remove year effects and included environmental covariates for sea surface temperature (SST) and Pacific decadal oscillation (PDO):

(17) $Y_{ihl} = \alpha + \alpha_h + \ \omega_l + \sum_{j=1}^{6} (\theta_j + \theta_{jh}) X_{jih} + \gamma_1 S_i + \gamma_2 P_i + \ \varepsilon_{ih}$

where γ_1 and γ_2 are the average effect across all hatcheries for SST (*S*) and PDO (*P*) indices, respectively. The SST data captures regional variability in ocean temperatures spanning several hundred kilometres, while the PDO (Mantua 1999) is an index of ocean climate variability (pressure and temperature) for the North Pacific area spanning 1000s of kilometres (Malick et al. 2020). Monthly SST for 2° x 2° grid cells and PDO data were obtained from NOAA's National Centre of Environmental Information (NCEI) and are based on NOAA's extended reconstruction of SST (ERSSTv5, Huang et al. 2017). For each release site, we identified ocean entry points and a region of early ocean residence for juvenile salmon that was +/- 40 km in directions perpendicular to the shoreline and +/- 125 km in directions parallel to the shoreline. Average monthly SST for each release event were calculated based on the weighted proportion of ERSST grid cells that overlap with the ocean residence polygons. We used monthly values of PDO and 60-day weighted averages for SST corresponding to estimated dates of ocean arrival for each release event (See Appendix C for details on calculating ocean arrival dates and ocean entry sites). The 60-day weighted average SST is centered around the ocean arrival date to estimate an average SST for the period 30 days before and after ocean entry.

To account for localized predation, we modified equation 16 to remove year effects and include Harbour Seal predation on juveniles (Chasco et al. 2017, Nelson et al. 2019) and Killer Whale predation on returning adults (Chasco et al. 2017), as follows:

(18) $Y_{ihl} = \alpha + \alpha_h + \ \omega_l \sum_{j=1}^{6} (\theta_j + \theta_{jh}) X_{jih} + (\theta_7 + \theta_{7h}) H_{ih} + (\theta_8 + \theta_{8h}) K_{ih} + \ \varepsilon_{ih}$

where θ_7 and θ_8 are the overall mean effect across all hatcheries for Harbour Seal abundance (*H*) and Killer Whale abundance (*K*) respectively, while θ_{7h} and θ_{8h} are the hatchery deviations from mean hatchery effects. As in Equations 12 and 15, we shorten this notation by adding the predator abundance terms to the vectors for mean coefficients ($\theta_j = \theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7, \theta_8$), hatchery deviations ($\theta_{jh} = \theta_{1h}, \theta_{2h}, \theta_{3h}, \theta_{4h}, \theta_{5h}, \theta_{6h}, \theta_{7h}, \theta_{8h}$), and predictor variables ($X_{jih} = X_{1ih}, X_{2ih}, X_{3ih}, X_{4ih}, X_{5ih}, X_{6ih}, X_{7ih}, X_{8ih}$ $= W_{ih}, W_{ih}^2, D_{ih}, D_{ih}^2, M_{ih}, R_{ih}, \ H_{ih}, \ K_{ih}$):

(19) $Y_{ihl} = \alpha + \alpha_h + \ \omega_l \sum_{j=1}^{8} (\theta_j + \theta_{jh}) X_{jih} + \varepsilon_{ih}$

We used Harbour Seal numbers in the ocean entry year and Killer Whale numbers for the mean return year of each release event for model fitting. Harbour seal abundance estimates for Strait of Georgia and the rest of the BC coast (i.e., Haida Gwaii, North Coast, Central Coast, Queen Charlotte Strait, Discovery Passage, West Coast Vancouver Island) for 1970-2020 were estimated from logistic models using parameter estimates from Olesiuk et al. 2010 (Figure A.20). We used Strait of Georgia seal numbers for hatcheries in Strait of Georgia, while the time series for the BC outer coast was used for hatcheries in Northeast Vancouver Island, Central Coast, Northern BC and West Coast Vancouver Island (Quinsam River, Terrace, Toboggan Creek, McLaughlin Creek, Robertson Creek). Both Northern Resident (Chasco et al. 2017, Towers et al. 2020) and Southern Resident (Centre for Whale Research Data) Killer Whale numbers were used for hatcheries in Strait of Georgia and Vancouver Island hatcheries, while Northern Resident numbers only were used for North and Central Coast hatcheries (Toboggan Creek, Terrace, McLaughlin Creek).

We standardized all predictor variables (i.e., X_{jih}, E_{ijh}) to have a mean of zero and unit variance by subtracting the mean and dividing by the standard deviation, which facilitates model fitting and comparing effect sizes. Therefore, the coefficient θ_j can be interpreted as the effect size on logit survival from a 1 standard deviation increase in predictor variable *j*. All of the hatchery-specific deviation terms (θ_{jh}, α_h) and the year effect deviation (Δ_t) are treated as random effects with assumed normal distributions with mean zero and variance $\sigma^2_{\theta_j}$, σ^2_{a}, and $\sigma^2_{\Delta_t}$. We use a gamma prior with shape parameter $\alpha = 2$ and rate parameter β=0.1 to constrain the hatchery and year effect deviation variance (Chung et al. 2013)

We use leave-one-out cross-validation information criterion (LOOIC) for comparing predictive performance of Bayesian models (Vehtari et al. 2017) to determine if the life-stage, river migration, biomass of releases, and environmental predictors improved model performance. The LOOIC is similar to other information criterion, such as AICc used for single hatchery model comparison, where models with the lowest LOOIC have the best predictive performance.

All models were developed using the Template Model Builder package (TMB, Kristensen et al. 2016) within R version 3.6.3 (R Core Team 2020). Posterior distributions of parameter estimates were generated using a Hamiltonian Monte Carlo method in the tmbstan package in R (Monnahan and Kristensen 2018) and LOOIC calculations were done using the loo package in R.

Hatchery returns for release strategies with maximum survival rates

The multi-hatchery survival models were used to estimate the expected increases in hatchery returns that could be achieved by modifying weight- and day-at-release to improve survival rates relative to the survival for average weight and day-at-release strategies used over the last 20 years.

For each species and hatchery, we estimated total returns for average annual releases from 2000-2020 for the following release strategies:

a) average release weight and release day from 2000-2020 ($\bar{W}$, $\bar{D}$)
b) average 2000-2020 release weight and release day for maximum survival ($\bar{W}, D_S$)
c) release weight for maximum survival and average 2000-2020 release day ($W_S, \bar{D}$)
d) release weight and release day for maximum survival (W_S, D_S)

The release weight (W_S) and day (D_S) for maximum survival are the values within the central 95% distribution of historical releases that are expected to maximize survival for the life-stage most commonly released at each hatchery.

Variance component analysis

We computed conditional $R^2_{logit(c)}$ (Nakagawa and Schielzeth 2013) to quantify the proportion of variance in logit-transformed survival explained by different models using environmental effects, random year effects, and/or temporal trends, via the following:

(20) $$R^2_{logit(c)} = \frac{\sigma_f^2 + \sigma_r^2}{\sigma_f^2 + \sigma_r^2 + \sigma_\varepsilon^2}$$

(21) $$\sigma_f^2 = \mathrm{var}\left(\alpha + \omega_l + \sum_{j=1}^{6} \theta_j X_{ji} + \phi t_i\right)$$

(22) $$\sigma_r^2 = \sigma_{\Delta_t}^2 + \sigma_a^2 + \sum_{j=1}^{p} \sigma_{\theta_j}^2$$

(23) $$\sigma_\varepsilon^2 = \sigma_e^2 + \pi^2/3$$

where σ_f^2 is the variance in logit-transformed survival owing to fixed effects, σ_r^2 is the variance of the random effects, and σ_ε^2 is the unexplained residual variance. The total random effects variance (σ_r^2) is the sum of the variance of random year effects ($\sigma_{\Delta_t}^2$), random effects for hatchery-specific deviations in average logit survival (σ_a^2), and random effects for hatchery deviations ($\sum_{j=1}^{p} \sigma_{\theta_j}^2$) for *p* predictor variables (i.e., release strategies and marine mammals). Residual variance (σ_ε^2) is composed of the residual variance on the logit-scale (σ_e^2) and distribution-specific variance for the logit link ($\pi^2/3$, Nakagawa and Schielzeth 2010, Nakagawa and Schielzeth 2013)

We also fit a model without any random year effects, temporal trend, or environmental effects, i.e.:

(24) $Y_{ihl} = \alpha + \alpha_h + \omega_l \sum_{j=1}^{6} (\theta_j + \theta_{jh}) X_{jih} + \varepsilon_{ih}$

The increase in $R^2_{logit(c)}$ for different models relative to eqn 24 is used to estimate the proportion of additional variance explained by including random year effects, temporal trend, and environmental effects in models, while including random hatchery effect terms.

Estimates of hatchery-specific variance components for random year effects and fixed effects from the multi-hatchery hierarchical survival models are provided in Appendix E.

Results

The top models are shown in Tables CH.1 & CO.1 for single hatchery survival models, CH.2 & CO.2 for return age models, and CH.3-4 & CO.3-4 for multi-hatchery survival models. In the subsequent sections, we summarize the main findings for survival and return age models for different hatchery release strategies across BC and reference figures displaying model fits on the natural scale. Single-hatchery model results were developed in initial stages of the project and their findings were used to inform the hierarchical multi-hatchery model structure. For completeness and documentation of the analysis done, we include both single-hatchery survival (Figs CH.15-CH.22, CO.15-CO.22) and multi-hatchery survival model results (Figs CH.29-CH.38, CO.29-CO.38) in this report; however greater emphasis should be placed on the outcomes of the multi-hatchery models for reasons described in the multi-hatchery models methods section (e.g., improved statistical power, information sharing, increased hatcheries and observations for model fitting, common year effects across hatcheries).

Model fits on the scale of the estimation model (e.g., logit survival and logit proportion of Jacks) are shown in Appendix A Figures A.2-A.13. The raw data inputs, single-hatchery model fits, and residual plots for each hatchery are summarized in Appendix F for Chinook and Appendix G for Coho. Note some figures include project names for some hatcheries, for which the corresponding hatchery names are:

- Heiltsuk: McLaughlin Creek Hatchery
- Powell R: Lang Creek Hatchery
- Terrace: Deep Creek Hatchery
- Thompson R N: Dunn Creek Hatchery

Chinook survival models

Single-hatchery models

Among the top 17 model fits for 16 different hatcheries (separate models were fit for fry and yearling at Terrace), the highest average survival rate occurs at the Chilliwack River hatchery (3.4%, 95%CI = 0.90-11.6%) and the lowest survival rate at Quesnel River (0.06%, 95%CI=0.01-0.2%). The range of survival rates is narrower across the other hatcheries, ranging from 0.1%-1.0% (Figure CH.15). Deep Creek (Terrace) was the only hatchery with sufficient observations to fit separate models for multiple life stages, which found higher average survival rates for yearling releases (0.9%, 95%CI=0.4-2.2%) than fry (0.2%, 95%CI=0.03-0.6%).

Weight and *Day* were the most important covariates associated with survival and were each included in 9 of the 17 models for Chinook hatchery releases (Table CH.1, Figures CH.16-17). In contrast, 8 out of 17 models (47%) did not find *Weight* or *Day* effects on survival. A declining temporal trend in average survival was included in models for 7 out of 17 models. (Table CH.1), while *Stock/ Site* effects were included in 6 out of 17 models (Figure CH.18).

Models with *Weight* effects included a positive linear response for logit survival at 4 hatcheries (i.e., increasing survival with increasing weight) and a concave down quadratic response for 5 hatcheries (i.e., increasing survival up to an optimal weight then decreasing, Figure CH.16. For sub-yearling models with a quadratic response, the weight-at-release that maximized expected survival varied from approximately 6-10 g across 4 hatcheries. The linear logit responses also showed increasing survival rates up to the maximum range of weights released at each hatchery (8-17 g), although there are few sub-yearling releases at weights greater than 8 g at most hatcheries other than Quinsam River. Fry released at Terrace also had a quadratic response indicating increased survival from increasing weights from 1.5 g up to 3 g. Additionally, there were 5 hatcheries releasing sub-yearling (Snootli, Nanaimo, Chilliwack, Quesnel, Shuswap), 2 hatcheries releasing yearling (Terrace, Spius Creek) and 1 hatchery releasing fry (Eagle), where weight at-release was not an important predictor for survival.

Models with *Day* effects included a negative linear response for logit survival for 5 hatcheries (i.e., decreasing survival for fish released at later dates relative to average release day) and a concave down quadratic response for 4 hatcheries (i.e., increasing survival up to an optimal day then decreasing, Figures CH.17 and A.3). Some hatchery release events all occur within 30-36 days (Little Qualicum, Spius Creek) and others have release events that are 3 months apart (Big Qualicum River, Quesnel River, Cowichan). With the exception of Quinsam and Cowichan, the hatcheries with a *Day* effect indicated improved survival could be expected for earlier release dates relative to the historical mean day-at-release. The release day with highest survival for Cowichan is the mean historical release day (mid-May), while models for Quinsam indicate the highest survival occurs approximately 10 days later than the current mean historical release date.

The *Stock/Site* effect was included in the top models for 5 hatcheries releasing sub-yearling smolts (Capilano River, Cowichan River, Puntledge River, Quinsam River, Snootli Creek) and 1 hatchery releasing yearling smolts (Spius Creek). Tukey's multiple pair-wise comparison tests of the marginal mean logit-survival revealed differences in survival rates (Figure CH.18) among:

- 8 stock/site combinations for sub-yearling reared at Capilano Hatchery
- 9 stock/site combinations for sub-yearling reared at Puntledge Hatchery
- 4 stock/site combinations for sub-yearling reared at Snootli Creek Hatchery
- 2 stock/site combinations for yearling reared at Spius Creek Hatchery
- 5 release sites for sub-yearling reared at Cowichan Hatchery
- 3 release sites for sub-yearling reared at Quinsam Hatchery

We found evidence of lower survival for Cowichan Lake sub-yearling releases relative to the other 4 release sites for Cowichan River hatchery (Fig. CH.18 & B.2). At Quinsam, we found lower survival rates for Orange Point relative to those at Taku Lodge and Campbell Estuary; however, these release sites are rarely used (Fig. CH.18 & B.5). There was no difference in survival rates for Quinsam River and Discovery Pass seapen release sites that are most frequently used. The lack of factorial treatment structure meant that we could not distinguish between a release site or broodstock effect for most release events at the other 4 hatcheries (Capilano, Puntledge, Snootli Creek, Spius Creek). While many of the survival differences seen were for rarely used stock/site combinations; we summarize a few of the survival differences for stock/site combinations more frequently used. For the Spius Creek hatchery, the combination of Nicola River broodstock released at Nicola River had greater survival rates than Salmon River broodstock released at Salmon River. At the Puntledge hatchery, Quinsam River stock released at Puntledge River had lower survival than Puntledge River Fall stock released at Puntledge River and in the Courtenay Estuary. Finally, at Capilano we found that Chilliwack River Fall stock released at Capilano River had higher survival than Big Qualicum stock released in Deep Cove.

Release strategies did not appear to affect Chinook survival for 4 hatchery/life-stage combinations (Nanaimo River sub-yearlings, Eagle River fry, Shuswap R sub-yearlings, Terrace yearlings), where the top model fits only include a declining temporal trend in survival or random *Year* effects.

Multi-hatchery models

The multi-hatchery model with all life-stages provided estimates of release strategy effects on Chinook survival for 21 hatcheries compared to 16 single-hatchery models (Fig. CH.28). The increased number of hatcheries included in the multi-hatchery models was made possible due to information sharing across BC hatcheries and pooling multiple life-stages in one model. The hierarchical approach for multi-hatchery models allowed inclusion of hatcheries with only 5 years of release data, whereas the single-hatchery models needed at least 16 years of data for model fitting. Additional observations were also gained by fitting the model with multiple life-stages (Table CH.3), whereas the single-hatchery models fit separate models for each life-stage because most hatcheries predominantly release one life-stage with limited information to model multiple life-stages (See Table A.2 in appendix for the smolt-only hierarchical model).

The coefficient estimates from the multi-hatchery Chinook survival model have similar precision to estimates from single-hatchery models for the 9 hatcheries with *Weight* effects and the 8 hatcheries with *Day* effects (Fig. CH.29, CH.30). In some cases, precision is greatly improved (e.g., Spius Creek *D* coefficient, Robertson Creek D^2 coefficient, Big Qualicum D^2 coefficient). For the most part, the precision of the mean release strategy effects across all hatcheries (i.e., vertical black lines in Fig CH.29) is higher compared to hatchery-specific estimates from multi-hatchery and single-hatchery models, with the exception of single hatchery model estimates for Quinsam for *W* and *D* coefficients. The higher precision from the single-hatchery model estimates for smolt releases at Quinsam is not surprising given the large number of release observations (n=386) for a wide range of weights (3-19 g) and days at-release (mid-April to mid-July) available for model fitting.

The posterior median from multi-hatchery model fits suggests an overall hatchery-average maximum expected survival at a release weight of 20 g (95% credible interval: 14-47 g) with hatchery specific estimates of 3.4 g, 5-16 g, and 14-18 g for historical release strategies for fry, sub-yearling and yearling smolts, respectively (Fig. CH.31, CH.33). The hatchery-specific estimates indicate that increased survival would be expected across all hatcheries for increasing the weights-at-release relative to the historical average release weight for the dominant life-stage released at each hatchery (Fig CH.33). The model optimum weights for maximizing sub-yearling survival in the multi-hatchery models are higher than the 6-10 g range identified in the 4 single hatchery models with quadratic weight responses for sub-yearlings (Table A.4). The difference is likely related to the limited range of weight observations available for fitting single-hatchery models, with most weights-at-release below 10 g. The single hatchery models that included observations of larger release weights up to 15-20 g (i.e., Big Qualicum, Cowichan, Quinsam) estimated linear *Weight* effects, indicating higher survival for increasing weights at-release up to at least 15-20 g.

The multi-hatchery models found that for the same weights-at-release, sub-yearling smolts had higher survival rates than both fry and yearling smolts; however, there is more evidence and a bigger effect size for the latter. Posterior distributions of life-stage survival coefficients indicate a 79% probability of higher sub-yearling survival relative to fry releases at the same weight and 96% probability of higher sub-yearling survival relative to yearling releases at the same weight (Fig. CH.34). Sub-yearling survival was 1.2 (95% credible interval: 0.8-2.0) times that of fry and 2.2 (95% credible interval: 0.9-5.4) times that of yearling smolts (Fig CH.31, CH.34). For example, the average survival for a 3.6 g release weight is 0.3% (95% CI = 0.2-0.6 %) for fry and 0.4% (95%CI= 0.2-0.8%) for sub-yearling smolts, while the average survival for a 9.9 g release weight is 1.0% (95% CI = 0.5-2.0%) for sub-yearling smolts and 0.5% (95% CI = 0.2-0.9 %) for yearling smolts. The inclusion of the life-stage effect did not lead to improved model fitting; models without the life-stage effect had LOOIC within 0.30 units of the model with a life-stage effect (Table CH.3).

The hatchery average optimal day-at-release estimated for the multi-hatchery model is May 10 (95% CI= April 21 - May 24) or Julian day 130 (95% CI=111-144), which is 12 days earlier than the historical mean release date, May 22, across all hatcheries (Fig. CH.32). The hatchery-specific estimates for hatcheries using a sub-yearling release strategy suggest that survival improves for releases more than 6-27 days earlier than the average historical release date for 13 hatcheries, while 3 hatcheries (Cowichan R, Eagle R, Inch Creek) had maximum survival for releases within 3 days of the mean historical release date (Fig. CH.33, Table A.4). Quinsam River hatchery was the only hatchery where we found improved sub-yearling survival for releases more than a week later (12 days) than the historical mean release date. These are similar findings to the *Day* effects identified for single-hatchery models, which identified improved sub-yearling survival for release days 15-25 days earlier relative to the average hatchery release date for 6 out of 7 hatcheries with a *Day* effect. The exception to this was Quinsam River, for which both single hatchery and multi-hatchery models indicated improved survival for later release dates relative to the average release date. For the Deep Creek hatchery that most commonly releases fry, multi-hatchery models found improved survival for releases 14 days later than the average release date. Similarly, Penny Creek and Spius Creek hatcheries most commonly release yearling and had improved survival for releases 10-12 days later than their average release dates. At Toboggan Creek, we found improved survival for releases 10 days earlier than the historical mean release date, which occurs at the end of April (Fig CH.33).

We found that the inclusion of different release site conditions improved model performance, although the 95% credible intervals overlapping with zero indicates their effects are not statistically significant (Table CH.3). The log river outmigration distance had a non-significant positive correlation with average hatchery Chinook survival (Fig. CH.34) with a mean posterior estimate of 0.33 (95% credible interval: -0.05,0.72). In contrast, hatchery release biomass had a non-significant negative correlation with hatchery average survival with a posterior mean estimate of -0.32 (95% credible interval: -0.80,0.19). Hatchery-specific estimates varied for both release site condition effects. There were 5 hatcheries (Spius Creek, Chilliwack, Capilano, Snootli Creek, Quinsam) with significant positive migration distance effects on survival, while only Robertson Creek had a significant negative effect (Fig CH.35). The hatchery release biomass had weaker effects on survival and only estimates for 3 hatcheries (Capilano, Big Qualicum, Quinsam R) had significant negative effects on survival (Fig. CH.35). The hatchery average coefficient estimates for *Weight* and *Day* effects were relatively insensitive to the inclusion of release site condition effects (Table CH.3).

All the environmental covariates (Harbour Seals, Killer Whales, SST, PDO) had significant negative correlations with Chinook Survival (Fig. CH.36); however, their inclusion in models instead of year effects (Fig. CH.37) did not improve model predictive performance. Models with environmental effects had LOOIC values ranging from 278-555 units from the top model with year effects (Table CH.4) and explained an additional 6-19 % of variance relative to a model without any environmental or year effects. The seal abundance covariate had the best performance among the environmental models and the largest negative effect on Chinook survival. Hatchery-specific estimates for seal predation (Fig. CH.38) showed significant negative effects on survival for 9 out of 21 hatcheries (Toboggan Creek, Quinsam River, Robertson Creek, Capilano River, Big Qualicum, Cowichan, Nanaimo, Penny Creek, Eagle River).

We found that modifying weight- and day-at-release to improve survival rates relative to the survival for average weight and day-at-release strategies has potential to generate large increases in returns at many hatcheries. Median posterior estimates of increases in hatchery Chinook returns range from 6-245% for the different hatcheries using release weight and day for maximum survival (W_S, D_S), relative to average release strategies $(\overline{W}, \overline{D})$ from the last 20 years (Fig. CH. 39, Table D.1). The median increases in hatchery returns were over 80% for 5 hatcheries (Robertson Cr, Capilano R, Penny Cr, Puntledge R, Quinsam R) and over 200% for 2 hatcheries (Big Qualicum, Nanaimo R). The other 14 hatcheries had increases in returns ranging from 6-62%. The large increase in predicted returns for Big Qualicum and Nanaimo R are primarily due to increases in weight-at-release, as modifying only the day-at-release led to modest 4% increases in returns for both hatcheries. Increases in weight-at-release led to greater improvements in survival than changes to day-at-release for 13 hatcheries, while modifying day-at-release led to greater improvements in survival than increases to weight-at-release for 6 hatcheries. At Inch Creek, there was a 3% median increase in returns for both changes to weight-at-release and day-at-release. The absolute values for survival rates and estimated returns for average annual releases at each hatchery are provided in appendix D (Tables D.2, Fig. D.1-D.2) for the different combinations of weight- and day-at-release.

Chinook return age models

Among the return age models for smolt releases at 4 hatcheries, Quinsam River had oldest average age of returns (4.0 years, 95% CI= 3.8-4.2) and Puntledge River had the youngest (3.0 years, 95%CI =2.7-3.2, Figure CH. 23). The other 2 hatcheries (Robertson Creek and Big Qualicum) had mean return ages of 3.3-3.7 years.

The *Weight* covariate is only included in the top models for Puntledge River smolt releases (Table CH.2, Figure CH.24) and a release site effect was included in the top model for Quinsam (Table CH.2, Figure CH.25). The proportion of *Females* effect was included for 3 hatcheries (Puntledge, Quinsam, Robertson Creek), indicating increasing ages with increasing proportions of females. There was no underlying temporal trend in return ages over time.

The *Weight* effect for Puntledge River has a quadratic response with mean return ages declining as release weights increase from 3-7g and return ages increasing as release weights increase from 7-10 g.

Tukey's multiple pair-wise comparison tests of the marginal mean age of return indicated that returns from smolts released at Discovery Pass were on average younger (3.77 years, 95% CI=3.70-3.84) compared to those released at Quinsam River (3.98 years, 95% CI=-3.92-4.04)

Coho survival models

Single-hatchery models

Among the top 14 models at 12 hatcheries (separate models were fit for fry and yearling at Puntledge and Thompson River), the highest average Coho survival rates occur for yearlings released at the Capilano River (11.0%, 95%CI = 5.0-22.4%). Survival rates for yearling releases at the other 11 hatcheries ranged from 1.0-6.8%, while survival rates for fry releases at 3 hatcheries ranged from 0.5-0.9% (Figure CO.15)

The *Weight* and *Day* covariates are included in 5 and 4, respectively, of the 14 models for Coho hatchery releases (Table CO.1, Figures CO.16-17). In contrast, 9 out of 14 models (64%) and 10 out of 14 models (71%) did not find *Weight* or *Day* effects, respectively, on survival. None of the models had a stock effect and only the Quinsam River hatchery included a release *Site* effect (Figure CO.18). The majority of models (10 out of 14) included a declining temporal trend in survival (Table CO.1, Figures CO.19-21)

Models with *Weight* effects showed a variety of different survival responses (Figure CO.16), including:

- a positive linear response for logit survival for Big Qualicum yearlings and Eagle River fry (i.e., increasing survival with increasing weight)
- a negative linear response for logit survival for Puntledge River yearlings (i.e., decreasing survival with increasing weight)
- a concave down quadratic response for Capilano River yearlings (i.e., increasing survival up to an optimal weight then decreasing)
- a concave up quadratic response for Quinsam River yearlings (i.e., increased survival for both smaller and larger weights at-release relative to the average)

Models with *Day* effects included a positive linear response for logit survival for Puntledge River yearlings (i.e., increasing survival for fish released at later dates), and a concave down quadratic response for yearling reared at Capilano, Inch Creek, and Quinsam River hatcheries (i.e., increasing survival up to an optimal day then decreasing,

Figure CO.17). The range of release days for hatchery models with a *Day* covariate varies, with some hatcheries releasing most fish within 1 month (Puntledge River) and others releasing fish over 2-3 months (Capilano River, Inch Creek, Quinsam River). The top models for Inch Creek and Puntledge River indicated improved survival rates for fish released 15-40 days later relative to the average historical release timing. In contrast, model fits for Capilano River indicate improved survival for releasing fish approximately 10 days earlier relative to the historical average release date in early June. The Quinsam River model indicated that peak survival occurs around the historical average release timing in the middle of May.

Release strategies did not appear to affect Coho survival for 8 hatchery/life-stage combinations (McLaughlin Creek yearlings, Robertson Creek yearlings, Tenderfoot Creek yearlings, Puntledge fry, Chilliwack yearlings, Thompson River fry, Thompson river yearlings, Spius Creek yearlings) where the top model fits only include a declining temporal trend in survival or random *Year* effects.

Multi-hatchery models

The multi-hatchery model with all life-stages provided estimates of release strategy effects on Coho survival for 16 hatcheries compared to 13 in the single-hatchery models (Fig. CO.28). The increased number of hatcheries included in the multi-hatchery models was made possible due to information sharing across BC hatcheries and pooling multiple life-stages in one model. The coefficient estimates from the multi-hatchery survival model have similar precision to most estimates from single hatchery models for the 5 hatcheries with *Weight* effects and the 4 hatcheries with *Day* effects (Fig. CO.29, CO.30). For some hatcheries, precision is greatly improved (e.g., Puntledge River *W* and *D*, Quinsam River D^2, Inch Creek *D* coefficients) and for a couple hatcheries there was decreased precision in the estimated *Weight* effects (Eagle River *W*, Capilano River *W* and W^2).

The posterior median from multi-hatchery model fits suggest an overall hatchery-average maximum expected survival at a release weight of 22 g (80% credible interval: 18 - 36 g) with hatchery specific estimates ranging from 2-11 g and 17-33 g for historical release strategies for fry and yearling smolts, respectively (Fig. CO.31, CO.33). The hatchery-specific estimates indicate that increased survival would be expected for larger yearling weights-at-release for the majority of hatcheries relative to their historical average release weight (Fig CO.33), with the exception of four hatcheries (McLaughlin Creek, Robertson Creek, Lang Creek, Puntledge R) where lower yearling weights-at-release are expected to improve survival.

The hatchery average optimal day-at-release estimated for the multi-hatchery model is June 10 (80% credible interval: May 30 - July 5) or Julian day 161 (80% credible interval: 150-186), which is 13 days later than the historical mean release date across all hatcheries of May 28 (Fig. CO.32). The hatchery-specific estimates for hatcheries using a yearling release strategy suggest survival improves for releases at least 8-33 days later than the average historical release date at 12 hatcheries (Fig CO.33). Similarly, Rosewall Creek hatchery had improved fry survival for later releases, with maximum survival for releases 15 days after the average release date. The release date for maximum survival occurs at the mean historical release date for Capilano yearling (June 5th) and Eagle River fry (July 2nd). This is noteworthy since 95% of historical releases span a period from early May to early July for Capilano and mid-May to mid-October for Eagle River. An optimal release date was not identified for Toboggan Creek due to a positive coefficient estimates for D^2, which indicates increasing survival for later release dates. None of the hatcheries showed improve survival for earlier releases relative to the mean historical release date. The multi-hatchery findings for *Day* effects are similar to the single-hatchery model estimates for Inch Creek and Puntledge, which identified improved survival for releases 40 and 15 later, respectively, than their mean release date. In contrast, the estimated maximum survival for yearling at Quinsam River from the multi-hatchery model occurs for releases in early June, whereas single-hatchery models indicated maximum survival occurred for releases on May 19. Multi-hatchery model estimates for the optimal release date for Capilano River were also later, with maximum survival occurring for releases 10 days later than the single-hatchery model.

The multi-hatchery models found that for the same weights-at-release, yearling smolts had higher survival rates than fry. Posterior distributions of life-stage survival coefficients indicate a 79% probability of higher yearling survival relative to fry releases at the same weight (Fig. CO.31). The inclusion of the life-stage effect did not lead to improved model fitting; the model without the life-stage effect had the lowest LOOIC value and the model with a life-stage effect was within 2.1 LOOIC units (Table CH.3).

In contrast to Chinook models, the hatchery release biomass *R* had a greater effect on survival than the log river migration distance *M* (Table CO.3). LOOICc metrics indicated the inclusion of hatchery release biomass improved model performance, while the river migration effect (*M*) did not. Similar to the Chinook models, we found that hatchery release biomass had a non-significant negative effect on Coho survival with a posterior mean estimate of -0.13 (95% credible interval: -0.48,0.18) indicating negative density dependence, while the log river migration distance (*M*) had a non-significant positive effect on survival with a mean posterior estimate of 0.07 (95% credible interval: -0.16, 0.30, Fig CO.34). Among the hatchery-specific estimates for the release biomass effect, only Robertson Creek had a significant negative effect on survival with mean posterior of -0.45 (95% credible interval: -0.68,-0.22, Fig. CO.35). The hatchery average coefficient estimates for *Weight* and *Day* effects were not sensitive to the inclusion of release site condition effects (Table CO.3).

All the environmental covariates (Harbour Seals, Killer Whales, SST, PDO) had significant negative correlations with Coho survival (Fig. CO.36); however, their inclusion in models instead of year effects (Fig. CO.37) did not improve model predictive performance. Models with environmental effects had LOOIC values ranging from 43-224 units from the top model with year effects (Table CO.4) and explained an additional 2-18 % of variance relative to a model without any environmental or year effects. Similar to Chinook, the seal abundance covariate had the best performance among the environmental models and the largest negative effect on Coho survival. Hatchery-specific estimates for seal predation (Fig. CO.38) showed significant negative effects on survival for 12 out of 16 hatcheries (Quinsam, Capilano, Lang Creek, Tenderfoot Creek, Big Qualicum, Goldstream, Puntledge, Chilliwack, Inch Creek, Spius Creek, Eagle River, Thompson River).

We found that modifying weight- and day-at-release to improve survival rates relative to the survival for average weight and day-at-release strategies has potential to generate large increases in returns at some hatcheries. Median posterior estimates of increases in hatchery Coho returns range from 5-160% for the different hatcheries using release weight and day for maximum survival (W_S, D_S) relative to average release strategies ($\overline{W}$, $\overline{D}$) from the last 20 years (Fig. CO. 39, Table D.3). The expected increases in hatchery returns were greatest for Dunn Creek at 160% (95% CI: 8-141%) and were over 60% for another 3 hatcheries (Eagle R, Inch Cr, Lang Cr). In contrast, another 10 hatcheries had increases in returns ranging from 5-34%. Increases in weight-at-release led to greater improvements in survival than changes to the day-at-release for 11 hatcheries, while modifying the day-at-release led to greater improvements than increasing weight-at-release for only 3 hatcheries (McLaughlin Cr, Robertson Cr, Tenderfoot Cr). The absolute values for survival rates and estimated returns for average annual releases at each hatchery are provided in appendix D (Table D.4, Fig. D.3-D.4) for the different combinations of weight- and day-at-release.

Coho return age models

Among the 8 model fits for age-2 Coho returns at 7 hatcheries (separate models were fit for fry and yearlings released at Puntledge), the highest average proportion of age 2-males was for Quinsam River yearlings (33.8%, 95%CI = 14.8-60.0%) and the lowest average proportion of Jacks was for Capilano yearling (7.1%, 95% CI= 3.1-15.3%) and Puntledge fry (7.8%, 95%CI = 4.0-14.6%). Yearling releases from Quinsam River, Big Qualicum River, and Puntledge River hatcheries had more younger males in returns with mean proportions of Jacks ranging from 25.3-33.7%, while yearling releases from Robertson Creek, Capilano, Inch Creek, and Chilliwack hatcheries had older males in returns with mean Jack proportions ranging from 7.0-11.2% (Figure CO. 23).

The *Weight* covariate was included in 3 of the top models for yearling releases (Big Qualicum, Puntledge, and Quinsam) and in the top model for Puntledge River fry release (Figure CO.24). A temporal trend showing increasing proportion of Jacks over time (i.e., younger male returns over time) was included in the top models for yearling released at Quinsam River, Big Qualicum, and Inch Creek hatcheries (Table CO.2, Figures CO.26). A release *Site* effect was also included in top models for Puntledge fry and Quinsam yearling (Figure CO.25).

Models with *Weight* effects showed a variety of responses for the proportion of age-2 fish in male returns (Figure CO.24), including:

- a positive linear response on logit-scale for Puntledge yearling with increasing proportion of age-2 males (i.e., younger male returns) with weights increasing from 18 to 29 g.
- a negative linear response on logit-scale for Puntledge fry with decreasing proportion of age-2 males (i.e., older male returns) as weights increase from 2-7 g
- a concave down quadratic response for yearlings released at Big Qualicum and Quinsam hatcheries (i.e., increasing proportion of age-2 males with increasing weight and then decreasing)

Quadratic responses indicated the highest proportion of age-2 males in returns for release weights of 22 g for Big Qualicum and 28 g for Quinsam hatcheries. For Puntledge fry releases there are only 2 release events for weights greater than 4.5 g and for Big Qualicum yearling there is only 1 release event with weights greater than 24 g. The model fits for higher weight ranges (e.g., 23-30 g for Big Qualicum, 4.5-7 g for Puntledge) will be sensitive to these single observations.

The *Site* effect indicated the proportion of Jacks in returns from Quinsam yearling released at Discovery Pass was greater than those released at Quinsam River; however, there is only 1 release event from Discovery Pass used to fit that model. More Discovery Pass releases are needed to provide greater understanding of a *Site* effect and to ensure this is not confounded with weight-at- or day-at-release. Despite the *Site* effect in the top model for Puntledge fry, the Tukey multiple comparison did not provide evidence of differences in the proportion of Jacks among the different release sites for Puntledge fry (Figure CO.25).

Release strategies did not appear to affect the proportion of age-2 males in Coho returns for yearling smolt releases at 4 hatcheries (Robertson Creek, Capilano, Inch Creek, and Chilliwack), where the top model fits only include a temporal trend or random *Year* effects.

Discussion

We evaluated the extent to which experimental hatchery release strategies (weight-at-release, day-at-release, life-stage, stock, and release site) potentially affect smolt-to-adult survival rates and return ages of Chinook and Coho for 25 hatcheries releasing fish at multiple life stages and release sites in BC. Our results provide information on whether changes to release strategies can improve survival rates for specific hatcheries. In particular, we found that i) Chinook and Coho survival rates in BC increase for larger weights-at-release up to 20 g and 22 g, respectively, ii) Chinook survival was highest for releases in early May and could be improved by releasing fish 1-4 weeks earlier than the historical average release timing at most hatcheries, iii) Coho survival was highest for releases in mid-June and could be improved by releasing fish 1-4.5 weeks later than the historical average release timing at most hatcheries, and iv) release site-specific conditions for river migration distance and biomass of hatchery releases were positively and negatively correlated, respectively, with both Chinook and Coho survival rates, but had little effect on the optimal weights and days-at-release for survival.

Weight-at-release effects on survival

We found that the expected survival of hatchery releases was greater for larger weights at-release compared to the historical average release weights for the dominant life stage release at all of the 21 hatcheries releasing Chinook and a majority of the hatcheries releasing Coho (11 out 16). This is consistent with a 'bigger is better' hypothesis, in which larger juveniles within the same cohort gain a competitive advantage for survival over their smaller counterparts through mechanisms such as, improved predator avoidance, better tolerance for variable environments, and competition for food and habitat (Sogard 1997, Rhodes and Quinn 1998, Naish et al. 2007). Increasing survival for increasing sizes at release is consistent with previous findings for hatchery Coho (Bilton et al. 1982, Irvine et al. 2013), hatchery Chinook (Hankin 1990) and out-migrating wild salmon (Reimers 1973).

There was little change in average survival across hatcheries for increasing Chinook release weights beyond 15 g and Coho weights beyond 17 g. The quadratic survival response indicates that survival increases up to 20 g and 22 g release weights for Chinook and Coho, respectively, and then declines. For Chinook, we found that the biggest increase in average hatchery survival occurred for increasing weights from 2 to 17 g, after which survival tended to level off for weights in the 17-23 g range. Coho survival responses also showed increased survival for increasing weights from 2 g to 17 g with the highest survival rates in the 17-27 g range; however, there was a steeper decline in survival for weights greater than 27 g. One explanation for the reduced survival for larger sizes could be related to preferential size selectivity by bird, fish, and Harbour seals, which tend to favour fish at sizes greater than 100 mm (Nelson et al. 2019). Alternatively, it is possible that weight at-release has an asymptotic effect on survival for these larger weight ranges, particularly for Chinook where the quadratic response looks nearly asymptotic for weights greater than 17 g. The quadratic response could also be sensitive to limited data for larger release weights (< 5% of Chinook release events have weights greater than 16 g, < 5% Coho release events have weights greater than 30 g). If estimating survival differences for the upper 95% of release weights is a priority for hatchery managers, then experimental releases at the tails of the weight distribution could improve our understanding of survival differences for Chinook > 16 g and Coho > 30 g.

Sub-yearling Chinook and yearling Coho release strategies are most common for BC hatcheries. The Chinook yearling release strategy was mainly used by facilities in the upper Fraser (Penny Creek, Spius Creek), central coast (Deep Creek) and north coast (Toboggan Creek). The weights-at-release for maximizing survival for historical release strategies varied across hatcheries, with weights ranging from 5-16 g for Chinook sub-yearling, 14-18 g for Chinook yearling, and 17-33 g for Coho yearling. The historical release weights that maximize Chinook survival occur at the upper 95% of the historical distribution of release weights for the life-stage most commonly released at nearly all hatcheries. The only exception are yearling releases at Spius Creek, which have a model optimum release weight of 18 g and where the 97.5th percentile of release observations is 19 g. For all other hatcheries, the model optimum release weights for Chinook exceeded the 97.5th percentile of weight observations for the dominant life-stage release strategy. This indicates there may be potential to improve Chinook survival at most hatcheries by using larger sub-yearling release weights than historically were used and by releasing sub-yearling near their maximum size. The upper range of weights released at BC hatcheries varies; the 97.5th percentile of sub-yearling release weights at hatcheries in the Lower Fraser (Chehalis, Chilliwack, Inch Creek) and Rosewall Creek were in the 6-7 g range, which are smaller than the 97.5th percentile of release weights (8-14 g) for other hatchery releases into the Strait of Georgia (Capilano, Lang Creek, Big Qualicum, Little Qualicum, Cowichan, Nanaimo, Quesnel, Shuswap). In contrast, the range of historical release weights for yearling Coho include the model optimum weight at several hatcheries (Capilano, McLaughlin Creek, Puntledge, Robertson Creek, Tenderfoot Creek). A majority of Coho hatcheries indicated increasing weights relative to the mean release weight would improve survival; however, a few hatcheries (McLaughlin Creek, Lang Creek, Robertson Creek, Puntledge River) had maximum survival for smaller release weights of 17-18 g relative to the average.

Some of the variability in optimal release weights may be related to the range of weight observations available for model fitting within hatcheries, but it might also be explained by hatchery specific environmental conditions or predator size preferences. For example, some hatcheries might have lower productivity environments or have data for predominantly low productivity years (e.g., McLaughlin Creek, Lang Creek), whereby larger weights may be mostly beneficial to survival (Woodson et al. 2013). The extent to which survival is positively correlated with larger sizes at release or faster growth rates may be dependent on the environmental conditions during residence time (e.g., 25-100 days) in freshwater and estuaries prior to ocean entry, which may be particularly important during low recruitment years (Woodson et al. 2013). Alternatively, larger sizes might be less beneficial for survival at hatcheries with greater predation rates and size-selective predation for larger smolts. For example, we estimated a lower weight-at-release for maximum survival (18 g) relative to the hatchery average for Coho yearling at Puntledge, which could be related to size-selective predation by Harbour Seals on out-migrating smolts (Lance et al. 2012, Thomas et al. 2017, Nelson et al. 2019; Olesiuk et al. 1996, Yurk and Trites 2000). Evidence for size-selective predation by Harbour seals on salmon smolts has also been documented at Big Qualicum (Allegue et al. 2020), but hatchery specific estimates of Coho survival responses for Big Qualicum indicate increasing survival for weights up to at least 28 g. It is interesting that we observe opposite trends in survival rates for Coho yearling releases greater than 18 g that are released at Big Qualicum and Puntledge River, both of which are in areas with high seal densities (Olesiuk et al. 2010). Possible explanations could be related to differences in the number of seals feeding in each area, hatchery release numbers (i.e., potential predator swamping), availability of alternative prey, varying predator size selectivity, or different predation rates. There is some evidence for the latter, as Harbour seals feeding on out-migrating salmon smolts are particularly efficient predators at Puntledge River using the lighting at two bridges to assist with feeding at night. The seals have been observed to float side by side in the river to form a barrier to intercept out-migrating smolts (Yurk and Trites 2000). The lack of suitable haul out sites near Big Qualicum estuary is another factor (Olesiuk et al. 2010, Allegue et al. 2020) that might lead to reduced predation. There could also be large variability in terms of seal prey specialization for different areas. For example, Allegue (2017) identified 4 different foraging behaviours for Harbour Seals and that only half of seals were feeding on Coho smolts out-migrating from Big Qualicum hatchery.

Weight-at-release effects on return ages

Only smolts released at 4 hatcheries (Puntledge, Quinsam, Big Qualicum, Robertson Creek) had enough sex composition data to fit the single hatchery return age models for Chinook. All 4 hatcheries released most smolts in the 4-9 g range and have similar median weights-at-release (5.3-6.1 g, Fig. CH.13), yet the mean return age is different for the 4 hatcheries ranging from 3.0 years for Puntledge to 4.0 years for Quinsam River (Figure CH.23). We only identified a weight effect on return-age for Puntledge releases, which indicated that the mean age of returns decreased (i.e., younger ages at maturity), as the weights-at-release increased from 3 g to 7 g. This is consistent with previous research that has found earlier maturation for hatchery releases at larger sizes (Hankin 1990) and for wild stocks out-migrating at larger sizes (Neilson and Geen 1986, ODFW 2000). However, the model fits indicated older return ages as weights-at-release increased from 7 g to 10 g. This may be a spurious relationship as there are only 3 observations for weights greater than 7.1 g and the model fit is sensitive to these observations (Figure CH.24). More data for releases greater than 7 g for both Puntledge River Fall and Summer stocks are needed to better understand the relationship between release weights and return ages at Puntledge River. The lack of a weight effect at the other 3 hatcheries could be related to low statistical power to detect the effect, otherwise it might suggest that other factors (e.g., genetics, release site, environment) than weight-at-release have a greater influence return age.

The results for Coho return age modelling showed similar trends to Chinook with a greater proportion of younger males in returns for larger yearling released up to 22 g for Big Qualicum, 28 g at Quinsam, 29 g at Puntledge. It is interesting that there were quadratic responses showing a decline in the proportion of Jacks (i.e., more older males) for weights increasing from 22-30 g at Big Qualicum and 28-37 g at Quinsam. More data from yearling releases larger than 23 g at Puntledge, larger than 24 g at Big Qualicum, and larger than 28 g at Quinsam would provide greater confidence for understanding effects on return ages for larger weights-at-release. This is particularly the case for Big Qualicum, which only had 1 release event (after data filtering) larger than 24 g.

The current analyses assumed that sex composition estimates from escapement sampling was representative of sex composition in catch. Different size- or sex-selectivity (e.g., preference for larger females) in the fisheries catch compared to escapement could affect our results. Another limitation with the return age analyses that is important to note is the potential for immature fish in the catch that would not have returned to spawning grounds otherwise. There is currently no maturity data for catch, so we could not account for this in the present analyses and thus all catch was included in return age analyses. Future sampling of the catch for sex composition and maturity data would provide improved information for evaluating age at maturity of hatchery releases.

Day-at-release effects on survival

We expected that each species and hatchery would have an optimal release period for survival, which may be influenced by prey availability, predation, ocean conditions, and freshwater rearing conditions that could be hatchery, regional, or release site specific (Bilton et al. 1982, Mathews and Ishida 1989). Our multi-hatchery model results support this with optimal release dates varying across hatcheries from late April to mid-June for Chinook and mid-May to early July for Coho. Historically, the average release timing for sub-yearling Chinook has been slightly later (mid-May to early June) than those for yearling Coho (early to mid-May) at most hatcheries. It is interesting that for the hatcheries releasing both Coho yearling and Chinook sub-yearling (Inch Creek, Chilliwack, Puntledge, Big Qualicum, Lang Creek, Capilano, Robertson Creek, Quinsam), we see slightly earlier optimal release dates for Chinook. Some hatcheries have shifted the average release date for Chinook and Coho over time, although it is unclear whether the shift in release dates at certain hatcheries is an attempt to improve survival rates or achieve some other management goal. There has been a trend to release Chinook earlier in the Spring for Strait of Georgia hatcheries, which have been releasing Chinook in mid-May since 2000-2015 compared to average release dates in mid-June for the 1960s and 1970s (Nelson et al. 2019). For Coho, most yearling releases have historically been in mid-May; however, several hatcheries (e.g., Quinsam River, Robertson Creek) have shifted release timing over the years. For example, Quinsam River had experimental releases of Coho yearlings that were staggered on multiple dates (Fig. CO.8) between April and June in some periods (1978-1981,2003-2017), while other years almost exclusively released yearling in late May/early June (1982-2002).

Intra and interspecies competition may also play a role in release timing. For example, juvenile salmon compete for habitat, whereby larger sizes and earlier residents have a competitive advantage for defending territories (Rhodes and Quinn 1998). In the wild, this favours larger sizes and earlier emerging fry, which have more opportunities to establish territories and better ability to defend them compared to fry emerging at later dates (Naish et al. 2007). This is an important consideration for hatcheries, as strategies to increase hatchery survivals might lead to greater competition between wild and hatchery fish that are counter-productive to hatchery conservation or rebuilding objectives (Nickelson et al. 1986).

The uncertainty for the average optimal release timing across all hatcheries was larger for Coho (90% credible interval: May 27 - August 2) than for Chinook (95% Credible interval: April 21 - May 24). The lower bound (May 27) for the Coho optimal release is much closer to the optimal release date (June 10) than the upper bound (August 2) of the 90% credible interval, which may be related to 2 hatcheries (Dunn Creek, Toboggan Creek) with optimal release timing later than other hatcheries. The estimates for the quadratic *Day* coefficients at Toboggan Creek and Dunn Creek are near zero, indicating increasing survival for the later days in the year.

Predicted returns for release strategies with maximum survival rates

We found that modifying weight- and day-at-release has potential to generate increases in returns ranging from 6-245 % for Chinook and 5-160% for Coho for the different hatcheries. Our estimates of increased returns for different weight- and day-at-release strategies provides information for hatchery managers to evaluate whether modifying release strategies is worthwhile for achieving hatchery objectives and to conduct intentional experiments (see consideration 1) to test model predictions.

The difference across hatcheries in survival rates for maximum survival days and weight (W_S, D_S) relative to survival from average weight and day release strategies ($\overline{W}$, $\overline{D}$) is due to a combination of i) model fits and ii) historical release strategies. The former relates to the different survival responses estimated for each hatchery for changing weight-at-release and day-at-release (i.e., W,W^2,D, and D^2 coefficients from multi-hatchery models). The latter is related to the mean historical release day and weight ($\overline{W}$, $\overline{D}$) from the last 20 years, as well as the range of historical release observations. For example, most Chinook hatcheries release sub-yearling at weights well below the model optimum (Table A.4); however, some hatcheries (Snootli Cr, Chehalis, Chilliwack, Inch Creek, Eagle R) have a very narrow range of historical release weights with maximum weights less than 7 g. While model optimums suggest survival would be maximized for weights much higher than this (i.e., 18-23 g), we do not use these model optimum values to avoid extrapolating model predictions beyond the range of observed data at each hatchery. Instead, the maximum survival weight (W_S) used to estimate predicted returns is the value within the 95% central distribution of historical releases that maximizes survival (Tables A.4-A.5). Hatcheries with a narrow range of small weight observations (e.g., 5-7 g) will have small increases (e.g., 1-2 g) for W_S, which generates smaller increases in survival than hatcheries with large increases for W_S relative to $\overline{W}$. For these hatcheries, intentional experimental designs with weights or days-at-release closer to model optimums could be used to evaluate whether greater improvements in survival would be achieved using release strategies outside the range of historical observations.

Life stage and age effects

The multi-hatchery Chinook models indicate that after accounting for weight effects, sub-yearling smolts had survival rates 2.2 times that of yearlings and 1.2 that of fry. It is possible that this is a spurious effect, given that i) we found little difference in model fits with and without the life-stage variable, and ii) there is limited overlap of weight ranges for different life stages. Alternatively, one mechanism for a life-stage effect might be related to decreased survival for older fish related to a reduced adaptability for seawater during smolting. Foote et al. 1990 found that the ability of yearling Chinook to adapt to seawater started to decline after the early spring (mid-April) in their 2^{nd} year for Nicola River stream-type Chinook reared at Spius Creek hatchery. This was particularly the case for precocious males who started growing at faster rates in mid-April. There is limited overlap in the weights-at-release for different life stages at most hatcheries, with the exception of Eagle River, and pooling information across hatcheries using the hierarchical model was needed to investigate potential life-stage effects on survival. If life-stage at release is an important consideration for future release strategies, then future experiments could deliberately try to release multiple life-stages at similar weights (e.g., 3-4 g and 10-12 g) to provide more information to evaluate life-stage effects.

Release site effects

Differences in survival rates for different release sites were not detected in the single-hatchery models for a majority of hatcheries. It could be that for most hatcheries the alternative release site has little effect on survival, or there may not be adequate statistical power to detect an effect due to low sample sizes or the experimental design (See consideration 1 below). There were 4 hatcheries (Capilano, Puntledge, Snootli Creek, Spius Creek) where we found that the combination of some stocks and release sites led to different Chinook survival rates, but the lack of factorial treatment structure meant we could not estimate a release site or stock effect separately. We only identified a specific release site effect on Chinook survival (independent of stock effects) at select sites for Quinsam River (Orange Point, Taku Lodge, Campbell Estuary) and Cowichan River (Cowichan Lake) hatcheries.

Our models didn't indicate a difference in survival for seapen release sites relative to the majority of other release site or stock/site combinations within a hatchery; however, there were limited CWT release observations for seapens (Quinsam River Chinook at Discovery Pass, Capilano Chinook at Deep Cove, and Heiltsuk Coho in McLoughlin Bay) for model fitting. It is difficult to infer much about differences in survival rates for Capilano releases at Deep Cove given the different combinations of stock and release sites there. In contrast, Quinsam hatchery provides a good dataset to evaluate the seapen effect since it has released the same stock at Quinsam River and Discovery Pass Seapens in most years since the mid-1980s (Figure CH.18, groups 12).

While we defer speculation on why some stocks may differ in average survival, our multi-hatchery models estimate how release site-specific conditions, such as river outmigration distances and hatchery release biomass might affect survival rates. Most hatcheries did not show strong evidence for river migration or release biomass effects on Chinook or Coho survival, which may mean there aren't strong release site effects at these hatcheries or could be related to low statistical power. The majority of hatcheries release Coho at only 1 location, which is why hatchery-specific estimates for river outmigration effects could not be estimated for Coho. The 4 hatcheries (Spius Creek, Chilliwack, Capilano, Snootli Creek) with significant positive effects from river migration distance on Chinook survival indicate longer river migrations might improve survival, possibly due to more high quality habitat for freshwater rearing (Nicholas et al. 2005, Buhle et al. 2009). In contrast, Robertson Creek had a negative significant effect from river migration distance on Chinook survival that might be related to predation or poorer river conditions for survival, whereby longer migrations do not improve survival outcomes (Michel 2015). The aggregate biomass of hatchery releases tended to have weaker negative correlations with survival for most hatcheries and only the effects for Robertson Creek Coho, Capilano River Chinook, and Big Qualicum Chinook were significant (i.e., negative density dependence).

Multi-hatchery vs single-hatchery models

In general, the multi-hatchery model estimates of weight- and day-at-release effects were consistent with trends identified in the single hatchery models with a few exceptions that are likely related to a narrow range of weight or day observations for single hatchery modelling (e.g., Chehalis Chinook Sub-yearling, Terrace Chinook Fry, Robertson Creek Chinook smolts, Puntledge Coho yearling). This is not surprising, given that some facilities have few experimental releases, but rather try to maintain consistent weights- and days-at-release related to hatchery objectives (e.g. assessment). The exclusion of weight and day predictors in some of the single hatchery models may also be related to the experimental designs or low sample sizes (i.e., low statistical power, see consideration 1) to detect weight or day-at-release effects. The model fitting approach for single hatchery models excludes predictor variables that did not improve model fits based on AICc criterion in favour of selecting the simpler model, which excluded coefficients where the 95% CIs overlapped with zero (i.e. non-significant effects). The lack of weight or day effects in models means that that weight and day coefficients are treated as zero; however, they are not really zero but have a probability distribution of estimated coefficients (e.g., Figs CH.29, CH.34, CO.29, CO.34). In contrast to the single hatchery models, the Bayesian approach used for the hierarchical models is to include the weight and day effects for all hatcheries and to integrate over the uncertainties.

Environmental effects on survival

While we found that regional oceanographic indices and marine mammal predator abundance were correlated with Chinook and Coho survival, attempts to estimate their effects did not improve model predictive performance relative to models that accounted for interannual sources of variability using year effects. There are numerous environmental factors that may potentially influence salmon survival for any given year, which might include interannual or interdecadal variability in oceanographic conditions, predation, prey, or disease (Mueter et al. 2002, Miller et al. 2014, Malick et al. 2015, Chasco et al. 2017, Malick et al. 2017, Nelson et al. 2019). The environmental factors influencing survival may be confounding (Miller et al. 2014), time-varying (Malick et al. 2020), data-limited (e.g., primary productivity) or unknown, making it difficult to estimate their effects in isolation. Instead of modelling these numerous factors independently, the inclusion of a year effect allows the model to account for all environmental effects simultaneously and estimate their net effect on average annual survival. This is sufficient for this study, since we do not need to estimate the environmental effects independently but rather account for them so that we can reliably estimate the release strategy effects of interest.

Temporal trends in survival

The multi-hatchery models estimated that survival rates have declined at an average rate of 5.6% per year for Chinook during 1972-2015 ocean entry years. Declines in survival rates for Coho were similar, with an estimated average rate of decline of 5.8% per year for 1973-2017 ocean entry years. Single hatchery models also showed negative temporal trends at most hatcheries; however, they were more prevalent for Coho (71%, 10 out of 14 models) than Chinook (41%, 7 out of 17 models). This phenomenon is not unique to hatchery releases as declines in marine survival for the Strait of Georgia have been observed for some wild coho stocks since the 1970-1980s (Cole 2000, Simpson et al. 2001, Beamish et al. 2010, Zimmerman et al. 2015) and some Chinook stocks since the 1990-2000s (PSC 2019). The single hatchery models found that all hatcheries releasing Coho into the Strait of Georgia and Johnstone Strait had declining survival over time with the exception of yearling releases from Spius Creek and fry releases from Thompson River that have shorter time series. The only other ocean entry sites for Coho survival models were for Robertson Creek (Southwest Vancouver Island) and McLaughlin Creek (Central Coast). Interestingly, single hatchery models for Robertson Creek and McLaughlin Creek did not have declining survival over time, despite having longer time series of data from 1978-2017 and 1987-2005, respectively. For Chinook releases in the Strait of Georgia and Johnstone Strait, we found that about half (6 out of 13) of the single hatchery models hatcheries had declining temporal trends in survival. Model fits for Chinook survival for hatcheries with ocean entry sites in Terrace (Skeena) and Central Coast (Snootli Creek) did not have declining survival trends, although the Snootli Creek dataset is a short time series from 2009-2014. In contrast to the Coho survival models, Chinook smolts released from Robertson Creek did have a declining trend in survival for 1974-2014 ocean entry years.

Considerations for future experiments and research

1) Develop experimental designs with factorial treatment structures and power analyses to detect release strategy effects

In this study, we used a hierarchical Bayesian model with information sharing across hatcheries, which provided improved statistical power to estimate release strategy effects (weight-at-release, day-at-release, release site, life-stage) that could not otherwise be estimated for some hatcheries using single hatchery models. Many of the hatchery datasets we used were not generated from intentional release experiments, which in many cases made it difficult to isolate specific effects (e.g., seapens, release site, stock) on survival. For example, some hatcheries release different stocks at different sites (e.g., Snootli Creek, Spius Creek, Capilano), which makes it difficult to distinguish between release site and stock effects. The appropriate experimental design will differ depending on whether hatchery-specific objectives are to estimate the effects of a combination of release conditions (e.g. weight + site at release) or specific strategy (e.g., weight effect, release site effect) on survival outcomes. For example, if the objective is to evaluate release site (e.g., Capilano River vs Sandy Cove Seapen) effects on survival rates of sub-yearling smolts, then an experimental design with two release site treatments that keeps all other variables constant (weight-at-release, day-at-release, life-stage, stock) would yield the greatest power. This would involve releasing sub-yearling smolts at Capilano River and Sandy Cove at the same size and on the same date over multiple years. Alternatively, if a hatchery wants to evaluate weight-at-release with 2 treatment levels (e.g., 5 g and 10 g) and release site with 2 treatment levels (e.g., river and seapen) in the same experiment, then a factorial treatment structure (i.e., all combinations of each factor and levels within the experiment) would be an appropriate design, i.e.:

1. 5 g sub-yearling release weight, seapen release site
2. 5 g sub-yearling release weight, river release site
3. 10 g sub-yearling release weight, seapen release site
4. 10 g sub-yearling release weight, river release site

When designing an experiment, it is important to know ahead of time what size of survival effect the hatchery wishes to detect. For example, do hatchery managers want to know whether survival is 10% higher for river release sites compared to seapens or is it only important to know whether survival rates are over 100% higher. Generally, the smaller the effect size, the larger the sample size required to detect it with the same probability (i.e., statistical power). A power analysis can be done during the experimental design phase to identify the appropriate sample size (number of release events) needed to detect a release strategy effect of a specific size, if it exists. This ensures that resources are not wasted in experiments with sample sizes that are too low to detect the desired effect (underpowered study) or by using higher sample sizes than needed (overpowered study, Green and MacLeod 2016).

2) Adjust marine survival rates to account for age-compositions of returns

Differences in return age composition among stocks or within stock/hatchery combinations can also contribute to differences in average marine survival rates, because older fish (i.e., ages 4, 5, 6) are exposed to additional years of at-sea mortality. Here, we focused on fry- and smolt-to-adult survival rates without accounting for differences in age-composition of returns. This is unlikely to have much effect on Coho models where the majority of returns are 3 years old, while outcomes for Chinook survival could be affected where abundances of 3-, 4-, and 5-year-olds in returns vary across release events (and possibly in response to experimental factors).

One approach to dealing with differences in age-composition of returns is to re-scale all adult returns to a single reference age-class (i.e., age-3 Chinook) to account for additional years of natural mortality experienced by older fish. This requires assumptions (PSC 2015, Hankin and Logan 2010) or an approach for estimating ocean mortality rates on different age-classes (Pardo and Hutchings 2020). For example, the Pacific Salmon Commission Chinook Model assumes mortality rates of 40% for age 2, 30% for age 3, 20% for age 4, and 10% for age 5 or greater (PSC 2015). This could improve comparisons of survival outcomes among hatcheries and rearing/release conditions by accounting for additional at-sea mortality experienced in the 4th and 5th year at sea for the older returns.

3) More information for evaluating regional trends

There are limited CWT data for Chinook and Coho hatchery releases outside of the Strait of Georgia, which makes it difficult to compare release strategy effects or survival trends across regions (e.g., North Coast, Central Coast, West Coast Vancouver Island). For example, there was only one hatchery for WCVI (Robertson Creek), two hatcheries for the North Coast (Toboggan Creek, Terrace), and two hatcheries for the Central Coast (McLaughlin Creek, Snootli Creek) with sufficient CWT data to include in model fitting. If a better understanding of regional differences in release strategies and hatchery survival rates is of interest moving forward, then future work might consider deploying more CWTs for hatcheries outside of the Strait of Georgia. Alternatively, it might be possible to include more information for other areas in BC if survival estimates from thermal marking data are available and could be added to the multi-hatchery survival models.

4) Life-stage specific and time-varying periods of optimal release

The period of optimal release for survival could vary from year-to-year depending on large-scale oceanographic features or more local conditions associated with river temperatures, discharge, predation, or prey availability (Mathews and Ishida 1989, Nelson et al. 2019). For example, Irvine et al. (2013) found that estimated relationships between Coho survival and day-at-release changed for different periods from 1980-

2005 at Big Qualicum and Puntledge, possibly indicating shifting periods of optimal release.

There could also be different optimal release periods for maximum survival of fry and smolt releases. This could be influenced by inter or intraspecies competition with other hatchery releases and wild stocks in the same river system. For example, larger sizes and earlier releases give individuals a competitive advantage to occupy habitats first and defend territory from later hatchery releases or later emerging wild fry (Rhodes and Quinn 1998, Naish et al. 2007), in which case an earlier optimal release date for fry might be expected compared to smolts.

Future efforts could investigate whether modelling life-stage specific and interannual survival responses (i.e., shifting optimal release periods) for day-at-release improves model fits.

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Chinook Figures

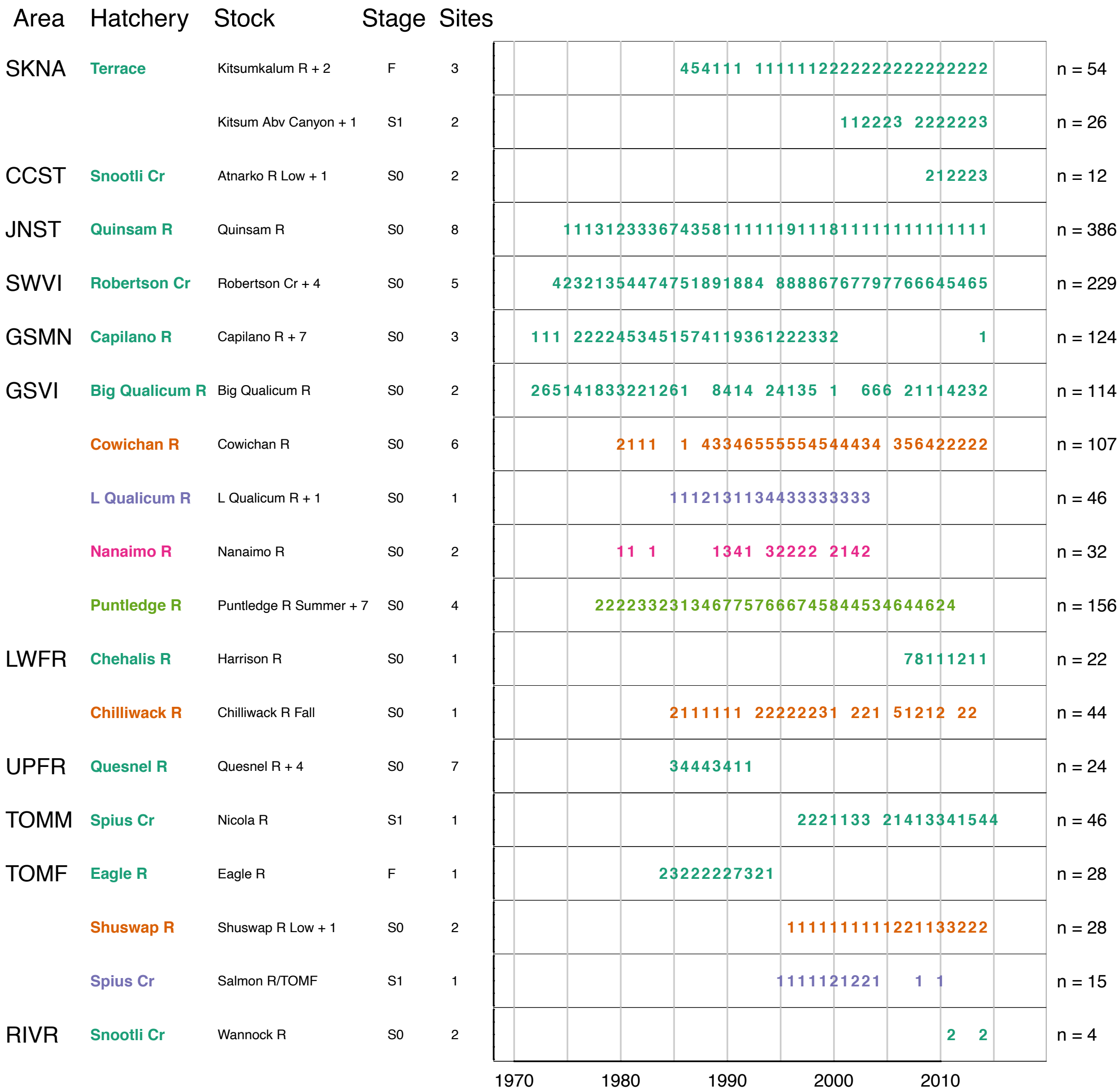


Figure CH.1: Chinook CWT fry (F), smolt (S0), and yearling (S1) releases by ocean entry year used for fitting individual hatchery and life-stage **survival models**. Releases are grouped by hatchery and release site sub-areas (CCST=Central Coast, RIVR=Rivers inlet, SKNA = Skeena River, JNST= Johnstone Strait, SWVI=Southwest Vancouver Island, GSMN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, UPFR = Upper Fraser, LWFR = Lower Fraser, TOMM= Lower Thompson, TOMF= Upper Thompson). Different colours are used to distinguish different hatchery releases in each sub-area.

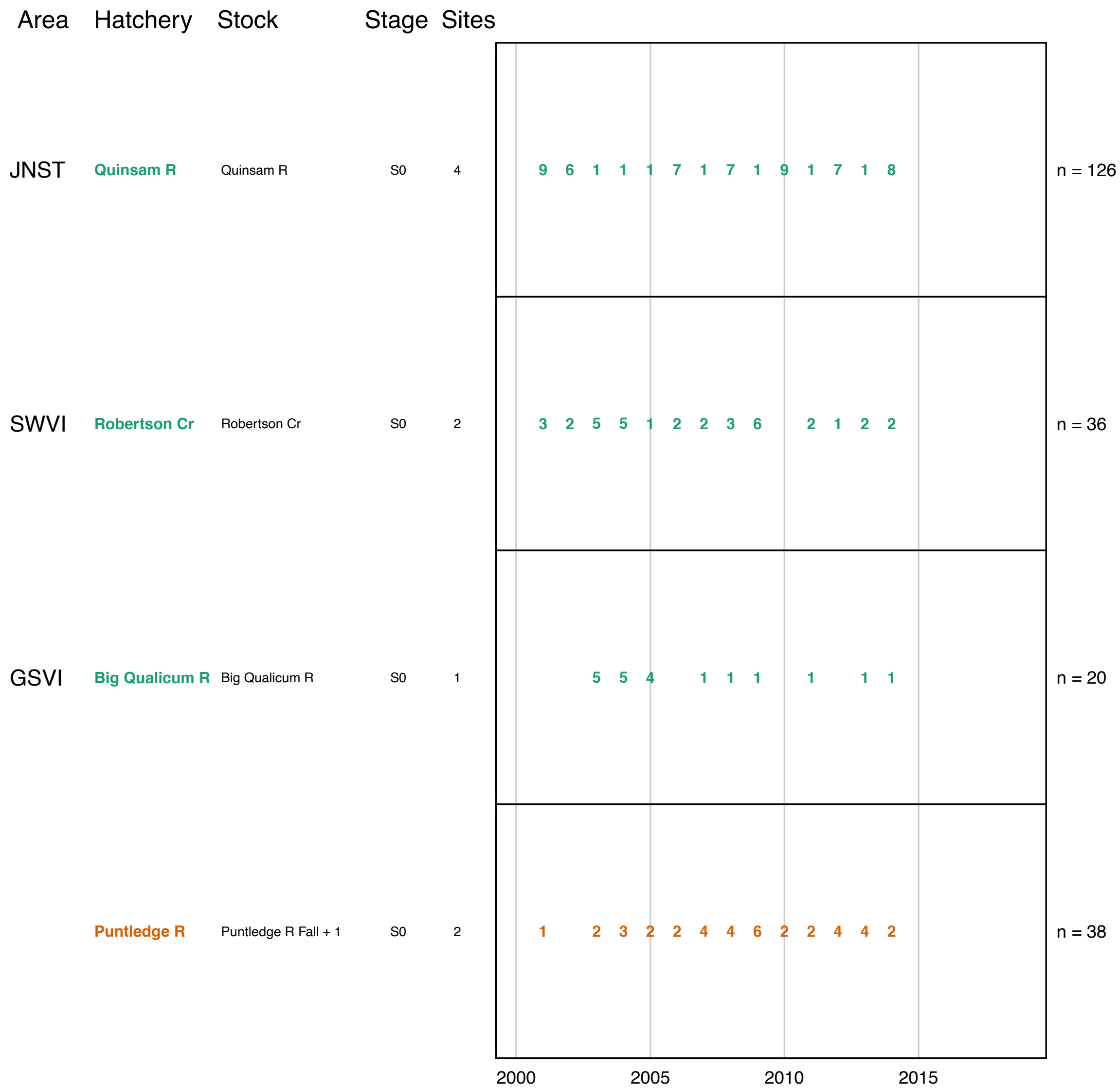


Figure CH.2: Chinook CWT smolt (S0) releases by ocean entry year used for fitting individual hatchery and life-stage **return age models**. Releases are grouped by hatchery and release site sub-areas (JNST= Johnstone Strait, GSVI = Strait of Georgia Vancouver Island). Different colours are used to distinguish different hatchery releases in each sub-area.

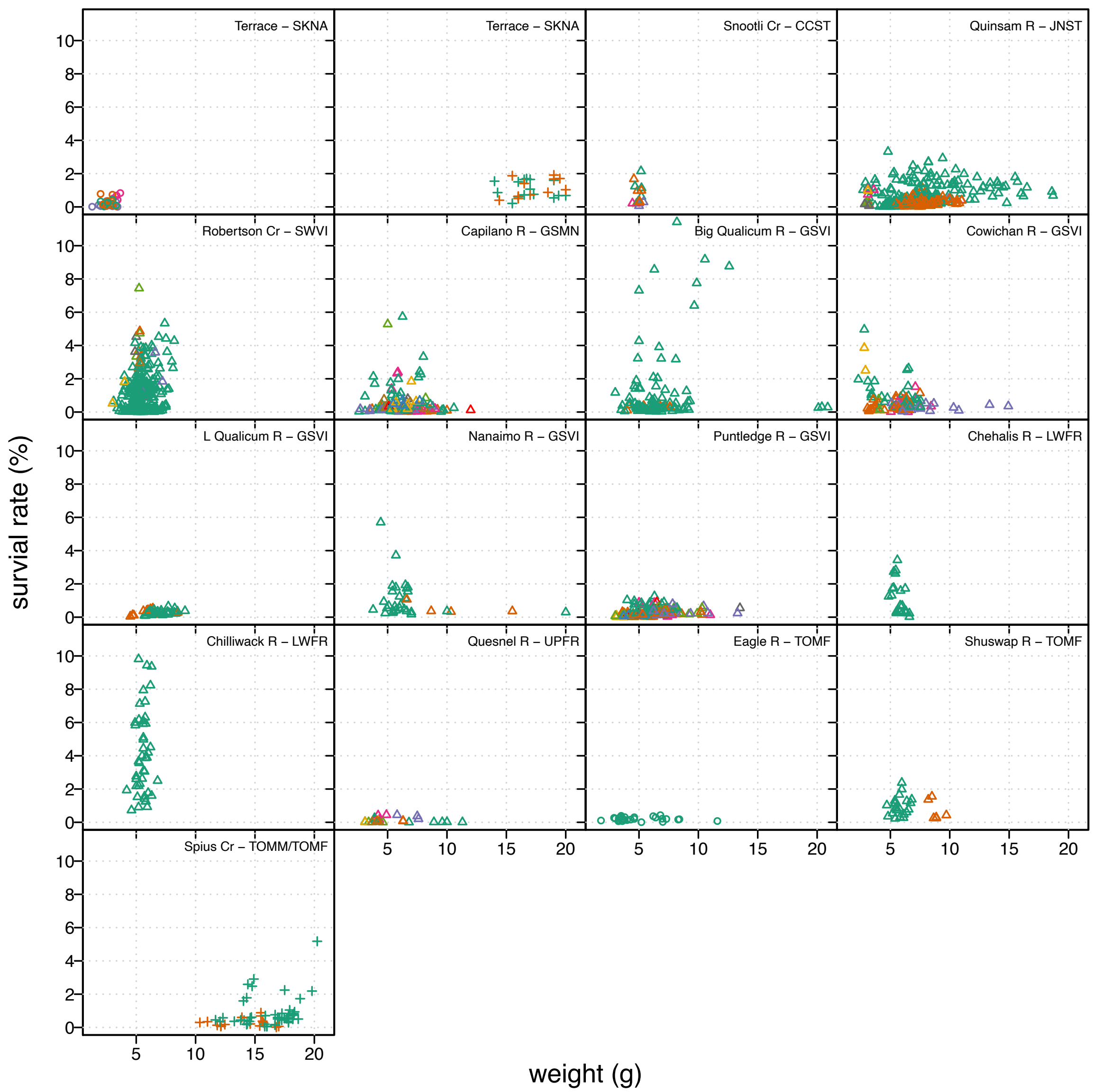


Figure CH.3. Smolt-to-adult **survival** rates (%) by weight-at-release for fry (○), smolt (△), and yearling (+) CWT Chinook hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

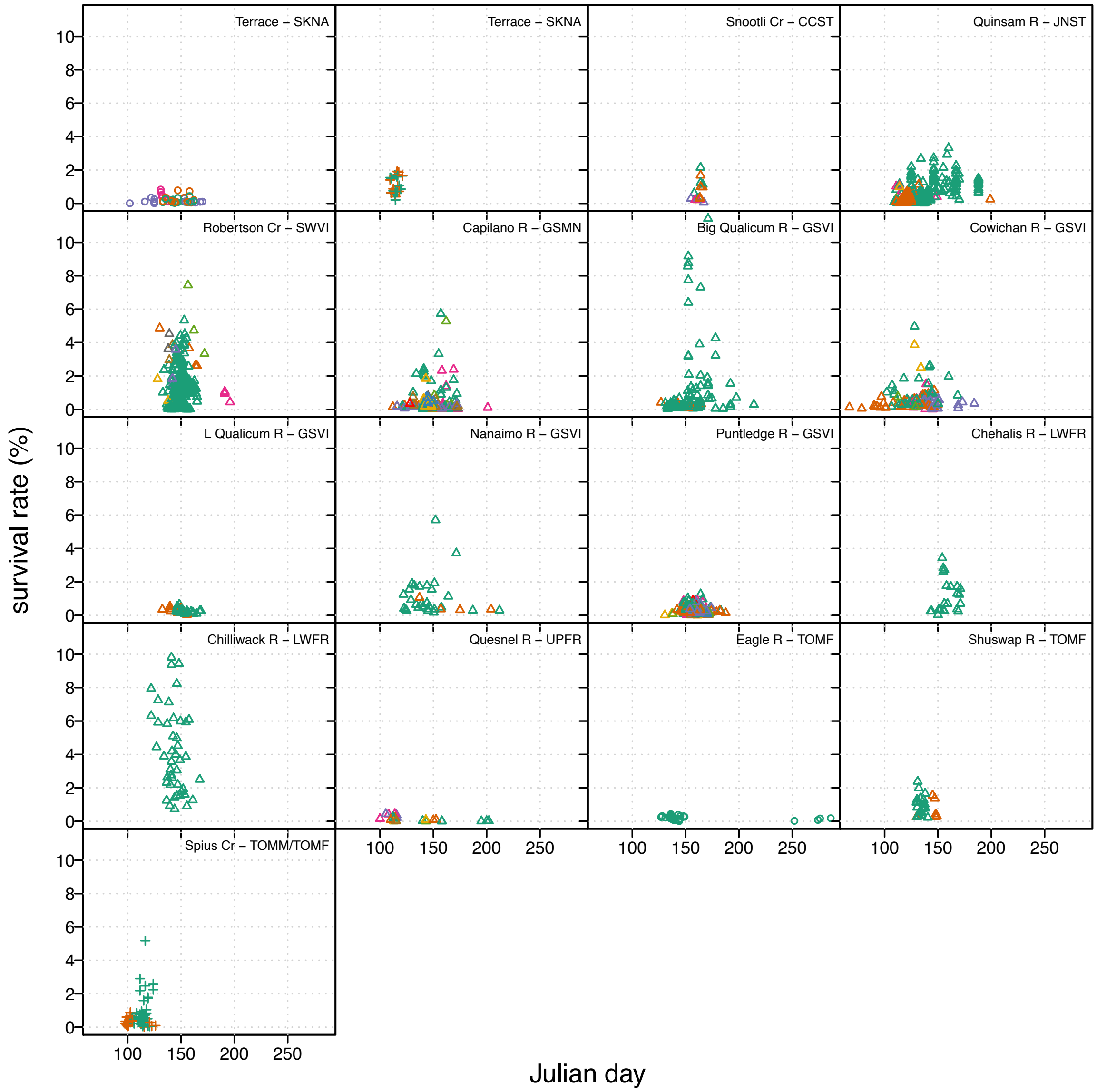


Figure CH.4. Smolt-adult **survival** rates (%) by Julian day for fry (○), smolt (△), and yearling (+) CWT Chinook hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

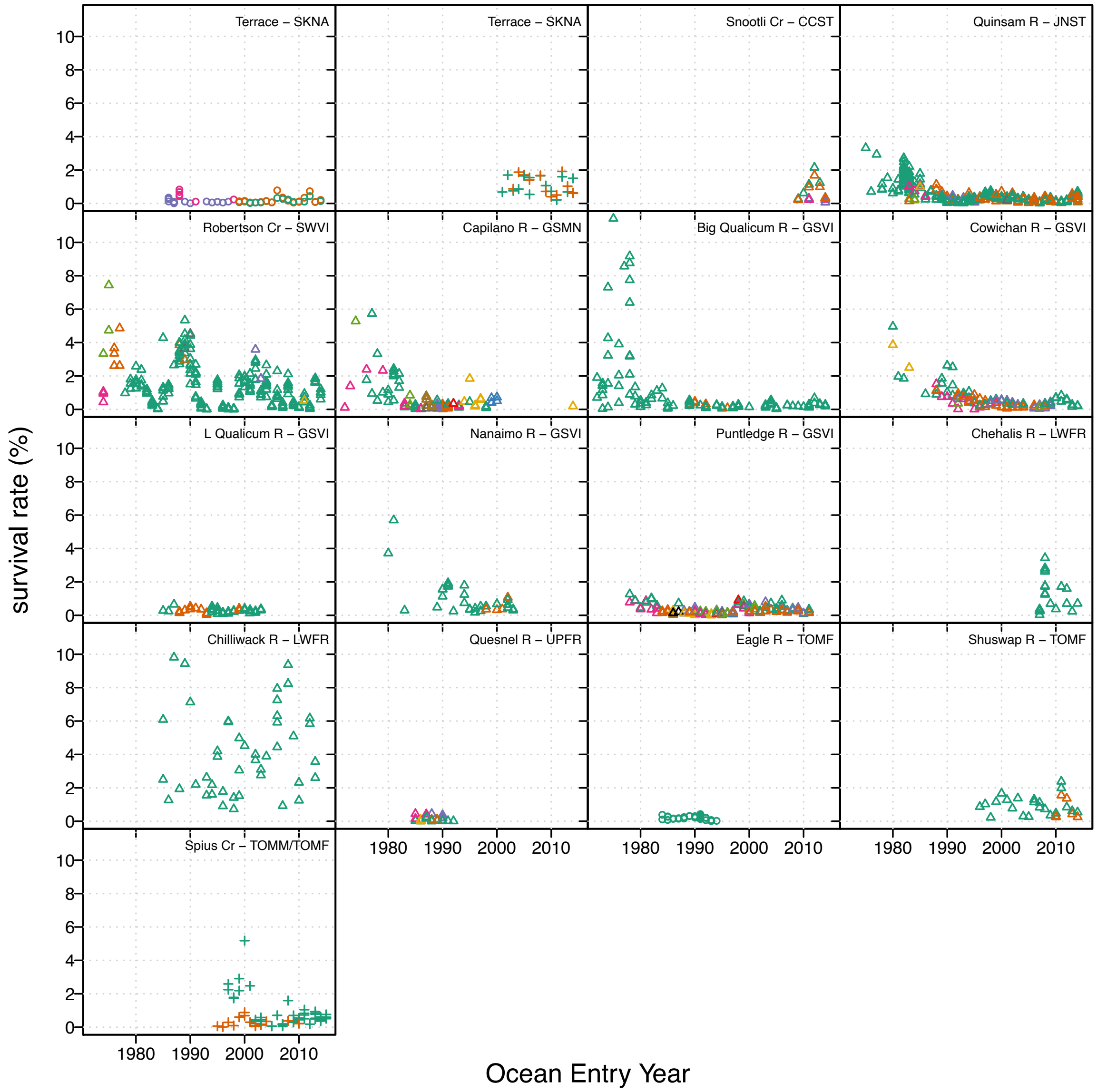


Figure CH.5. Smolt to adult **survival** rates (%) by ocean entry year for fry (○), smolt (△), and yearling (+) CWT Chinook hatchery releases included in survival model fitting. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

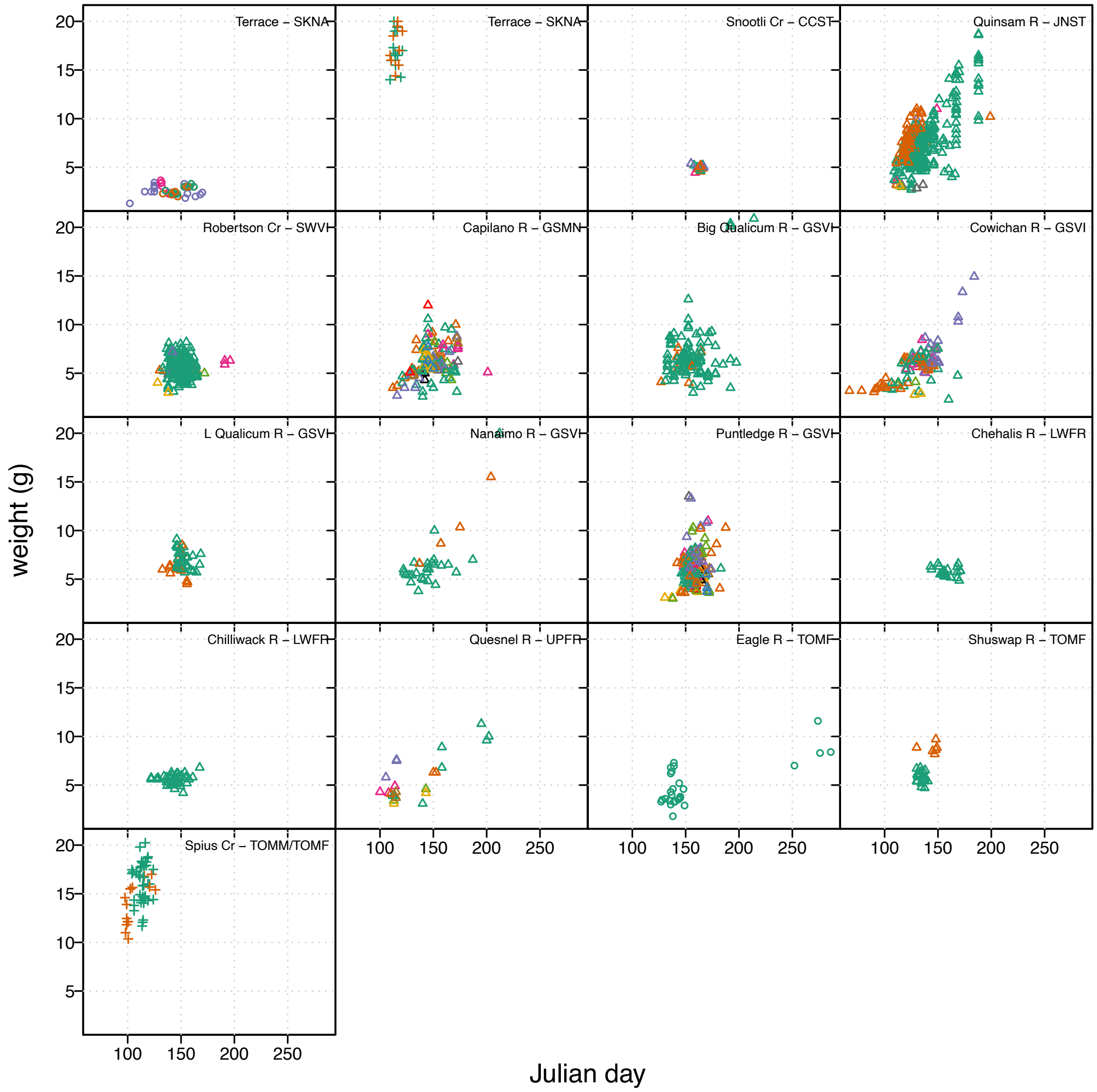


Figure CH.6. Weight-at-release by Julian day for fry (○), smolt (△), and yearling (+) CWT Chinook hatchery releases included in **survival** model fitting. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

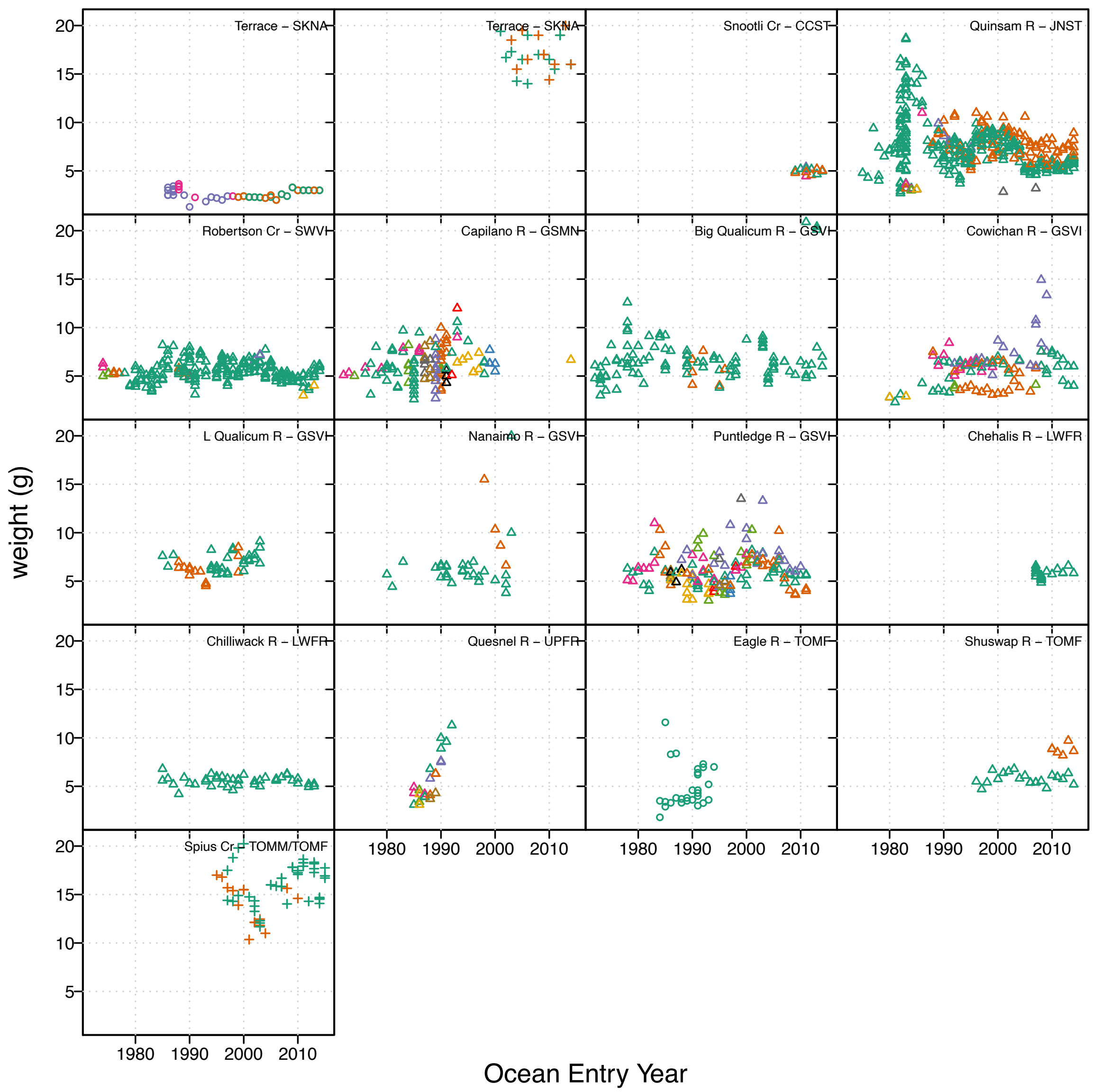


Figure CH.7. Weight-at-release by ocean entry year for fry (○), smolt (△) and yearling (+) CWT Chinook hatchery releases included in **survival** model fitting. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

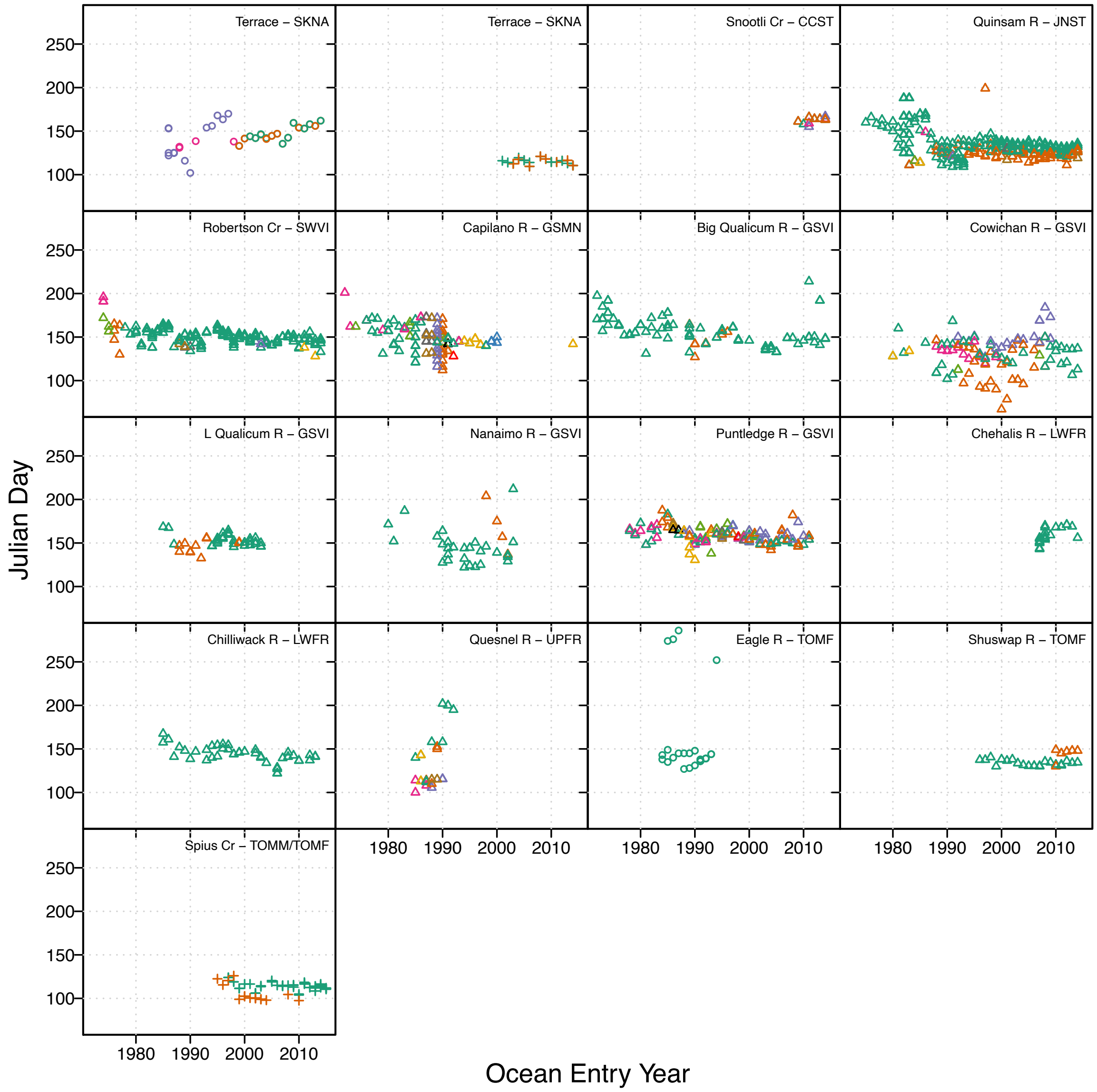


Figure CH.8. Julian day-at-release by ocean entry year for fry (○), smolt (△) and yearling (+) CWT Chinook hatchery releases included in **survival** model fitting. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

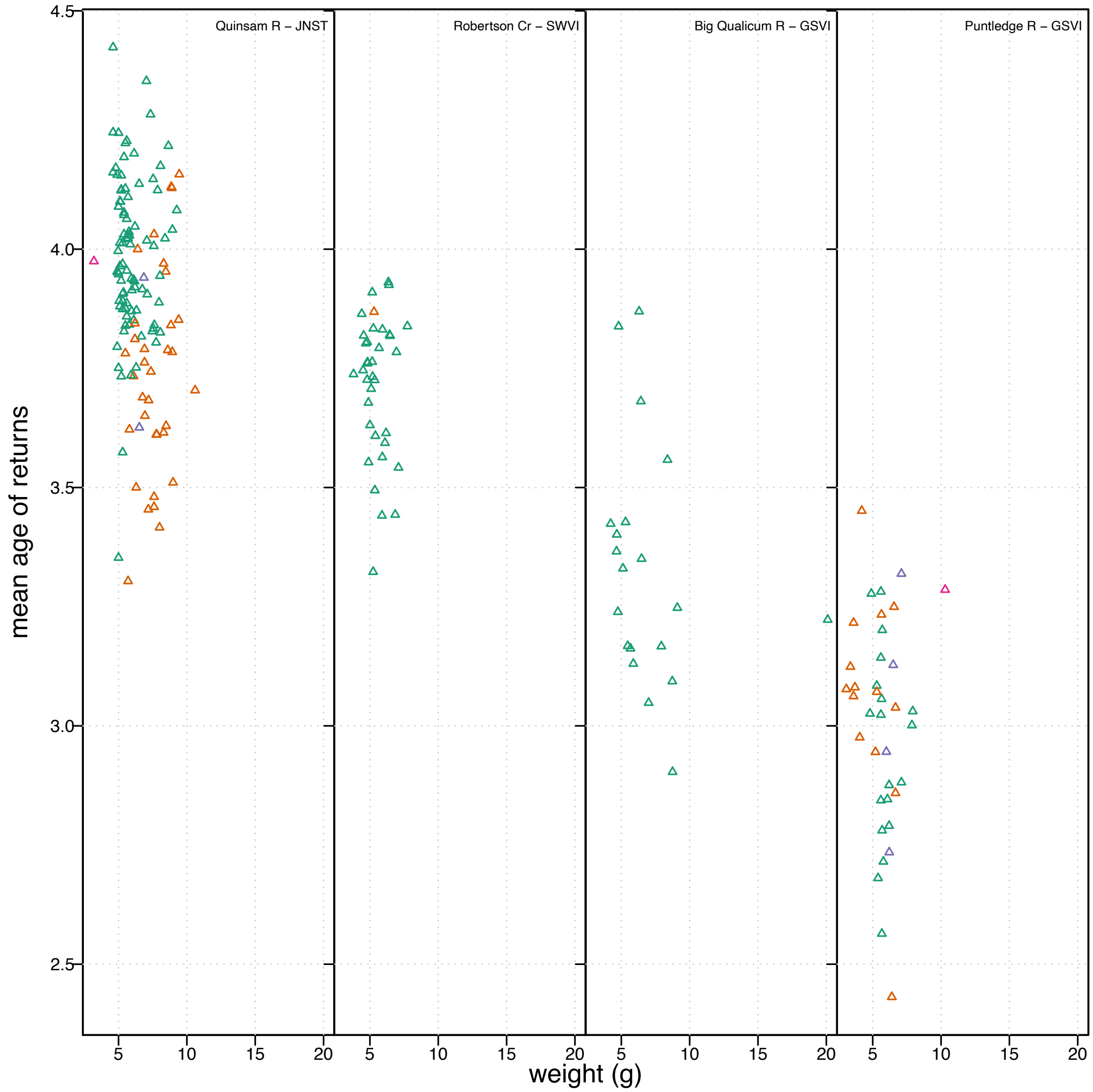


Figure CH.9. Mean age of returns by weight-at-release for smolt (△) CWT Chinook hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

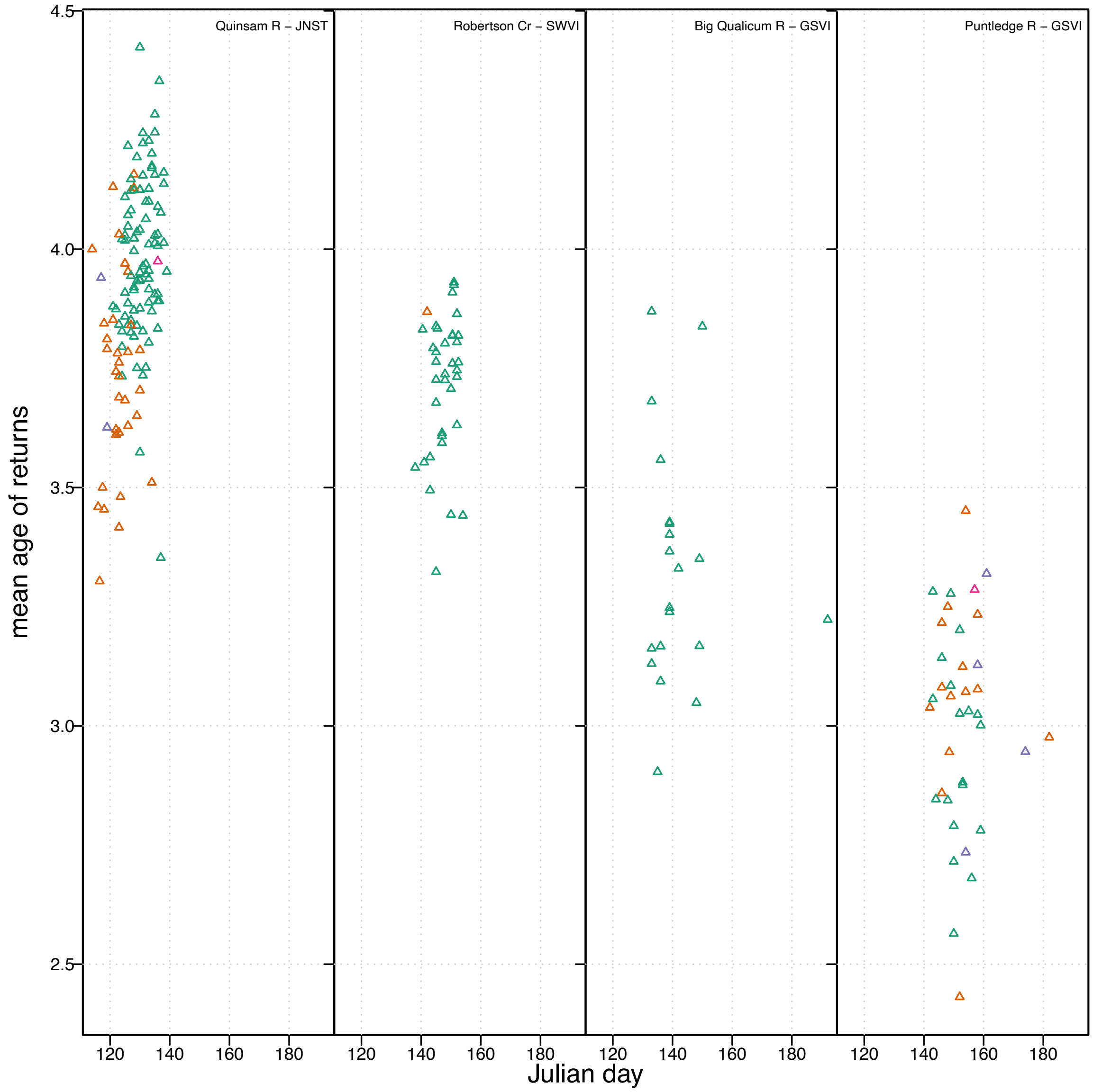


Figure CH.10. Mean age of returns by Julian day for smolt (△) CWT Chinook hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

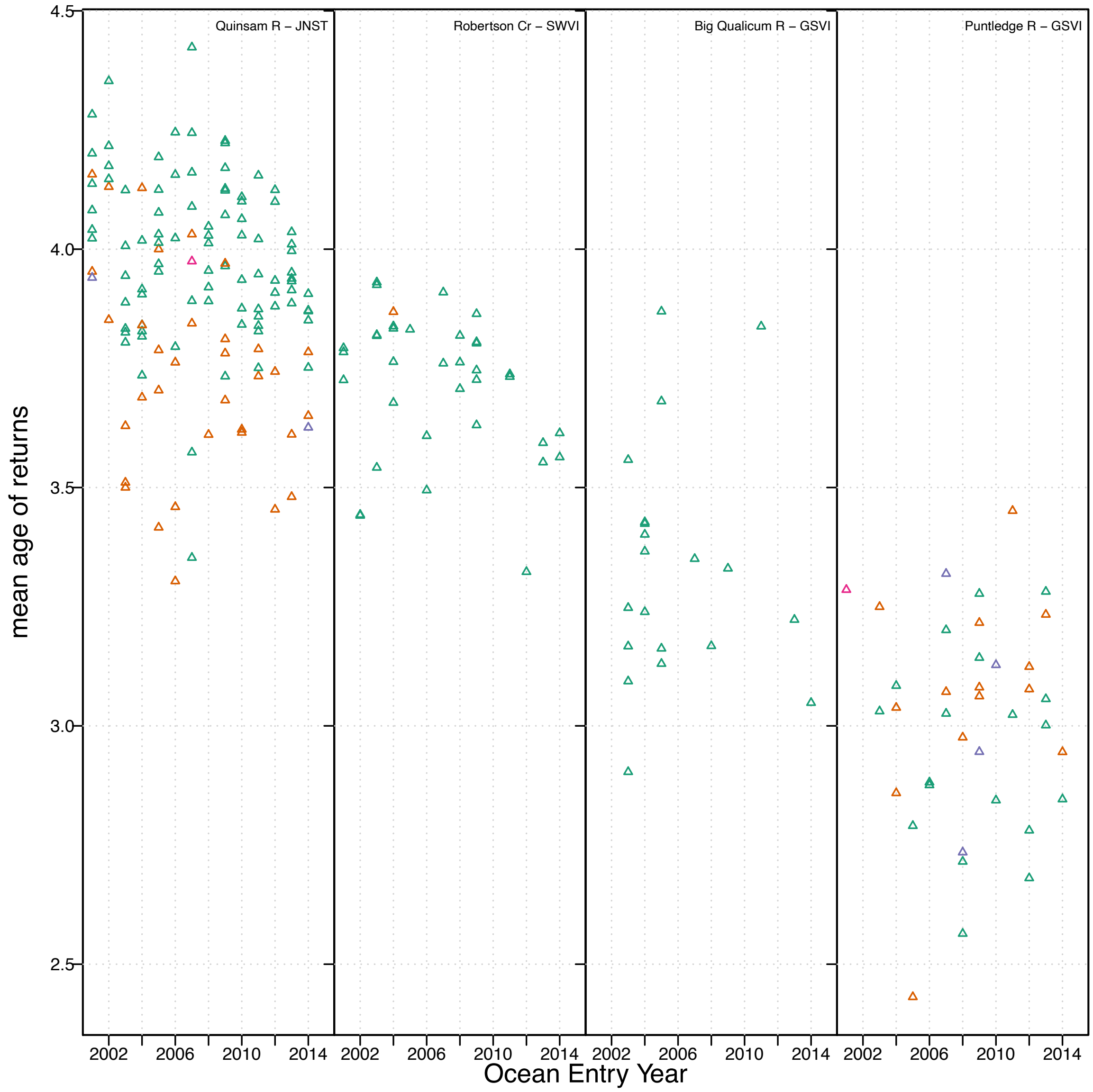


Figure CH.11. Mean age of returns by ocean entry year for smolt (△) CWT Chinook hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

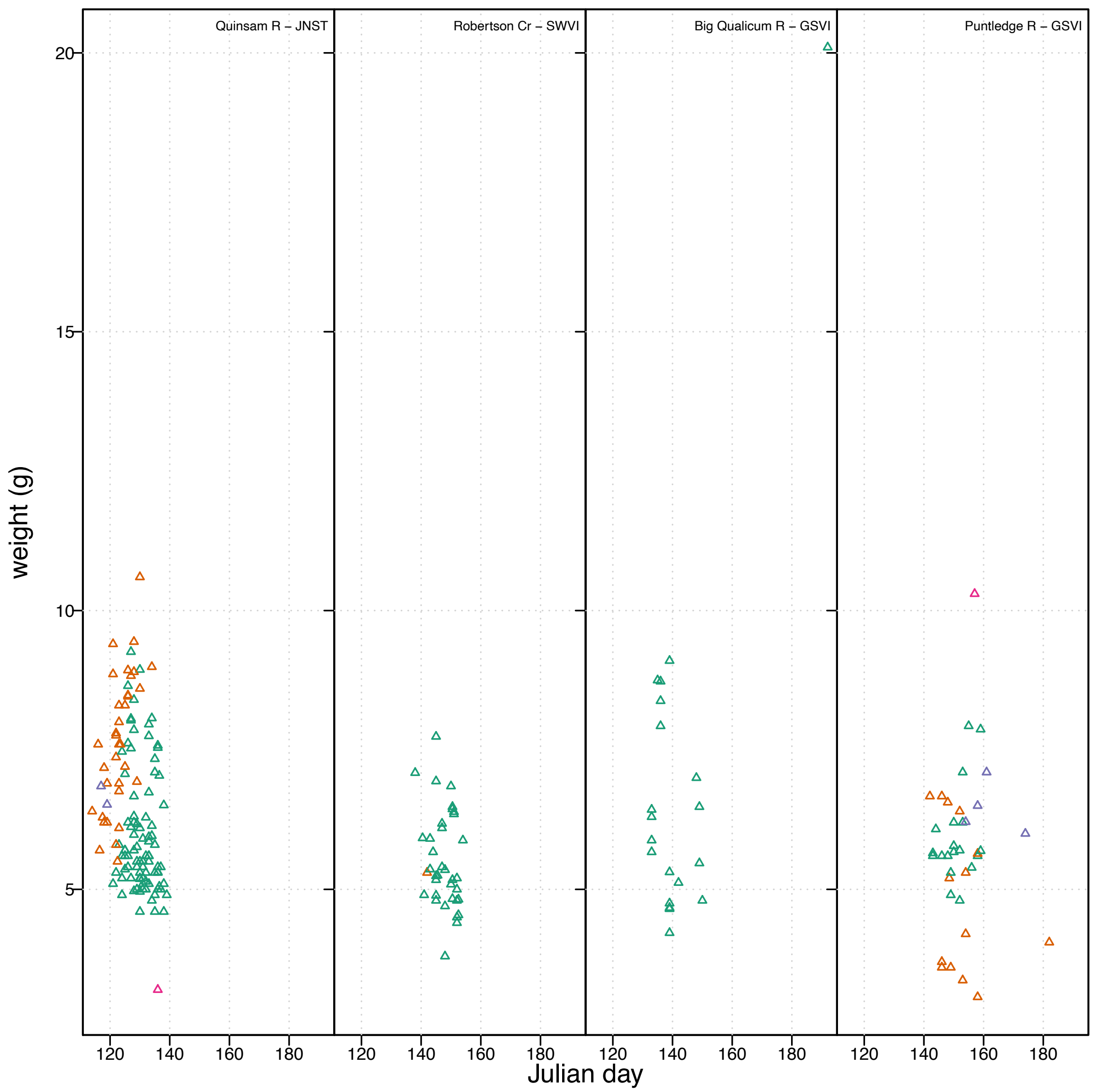


Figure CH.12. Weight-at-release by Julian day for smolt (△) CWT Chinook hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

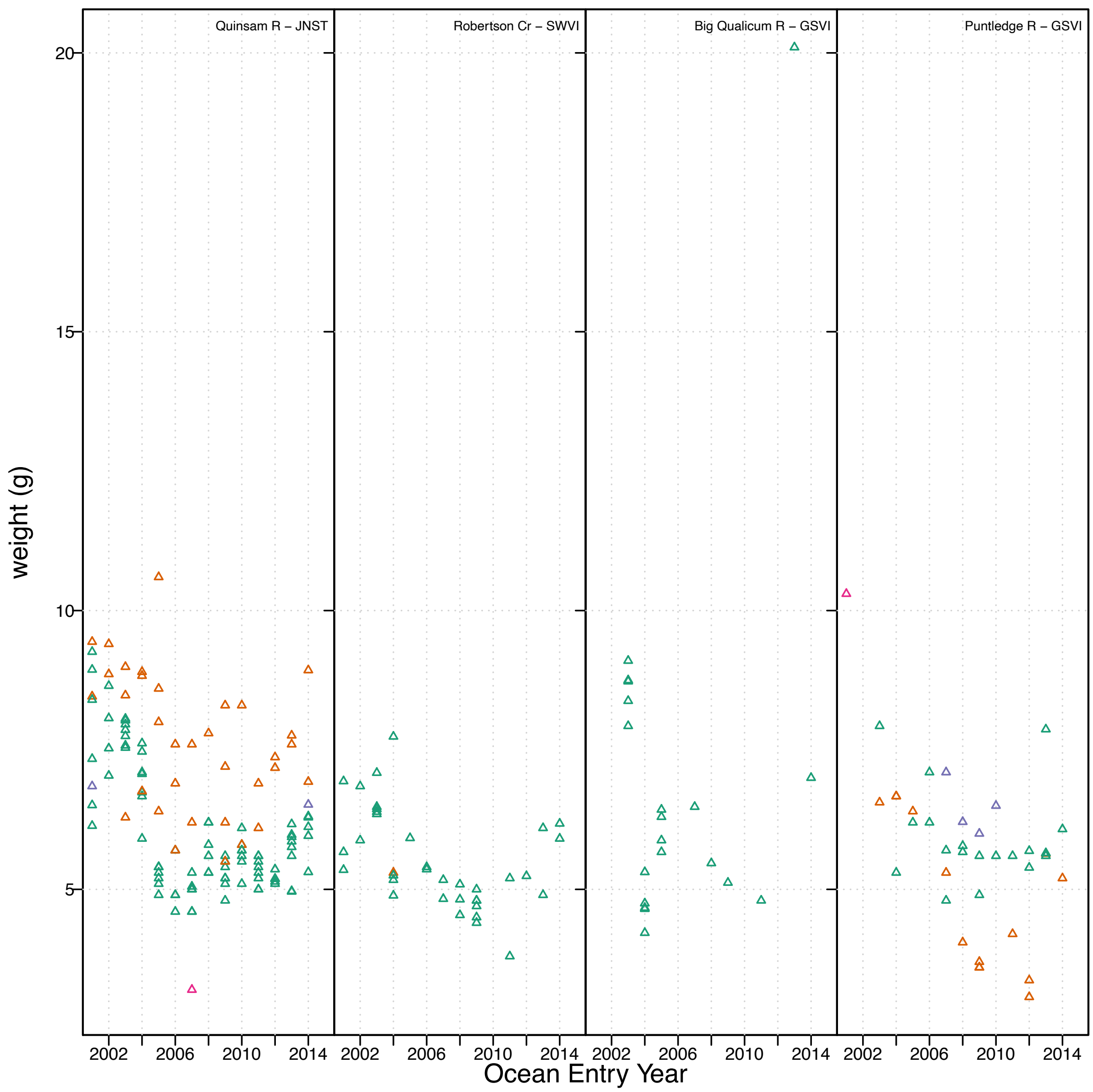


Figure CH.13. Weight-at-release by ocean entry year for smolt (△) CWT Chinook hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

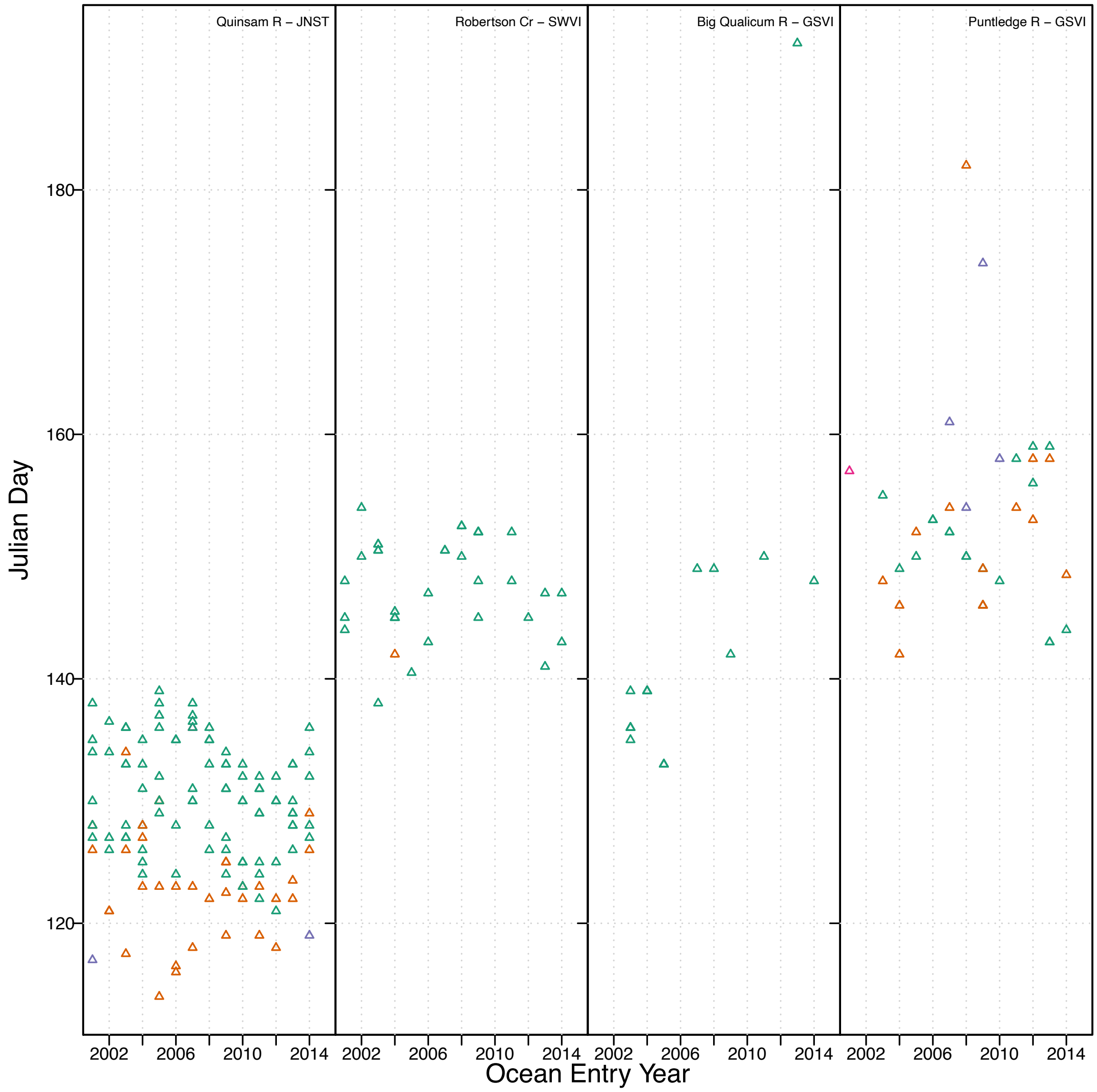


Figure CH.14. Julian day-at-release by ocean entry year for smolt (△) CWT Chinook hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

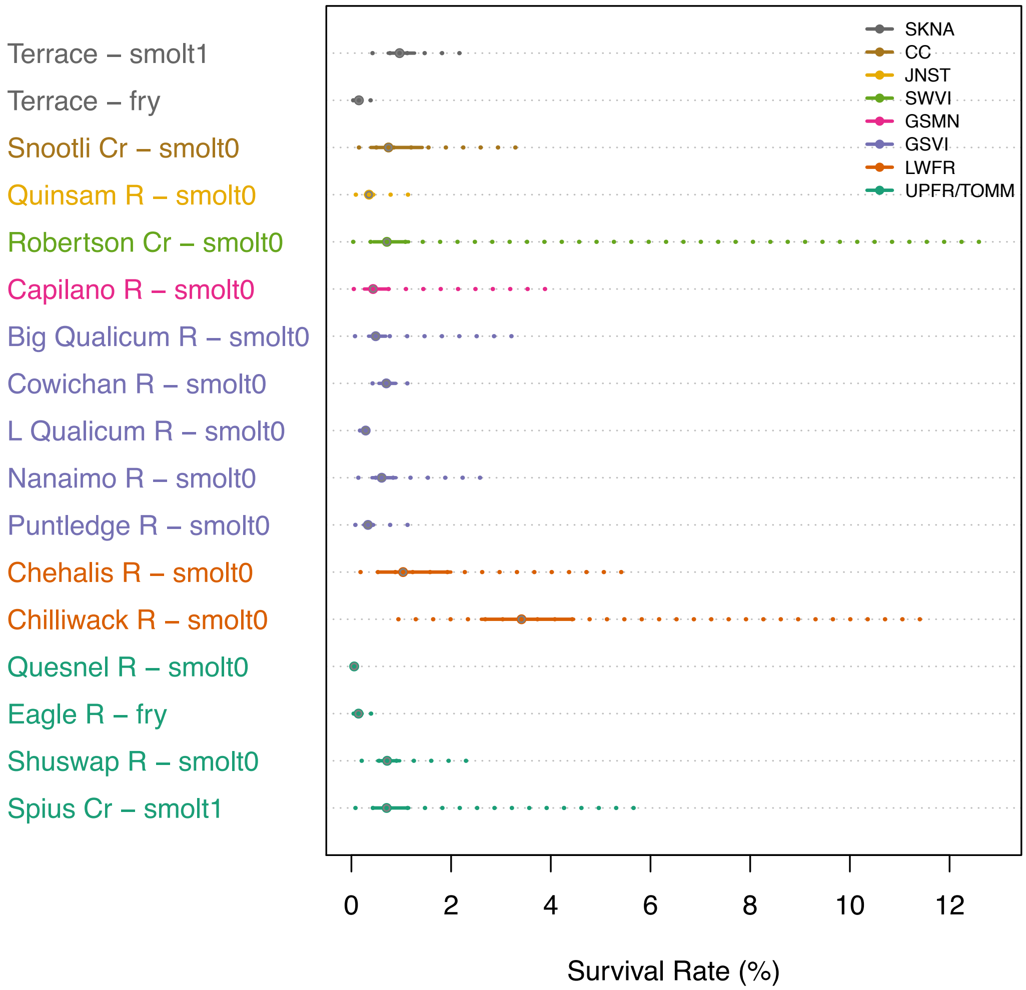


Figure CH.15. Mean Chinook **survival** rates and 95% confidence intervals accounting for uncertainty in both fixed and random effects for top model fits for each hatchery. Solid lines indicate uncertainty due to fixed effects, while the dotted lines indicate uncertainty from both fixed and random year effects. The survival rates reflect estimated survival for the average values of covariates. For models with a stock effect (Capilano R, Cowichan R, Puntledge R, Quinsam R, Snootli Cr, Spius Cr) the survival rates are shown for the most common stock and release site. Smolts < 1 year old at release are indicated as 'smolt0' and smolts > 1 year old at release (i.e., yearling) are indicated as 'smolt1'.

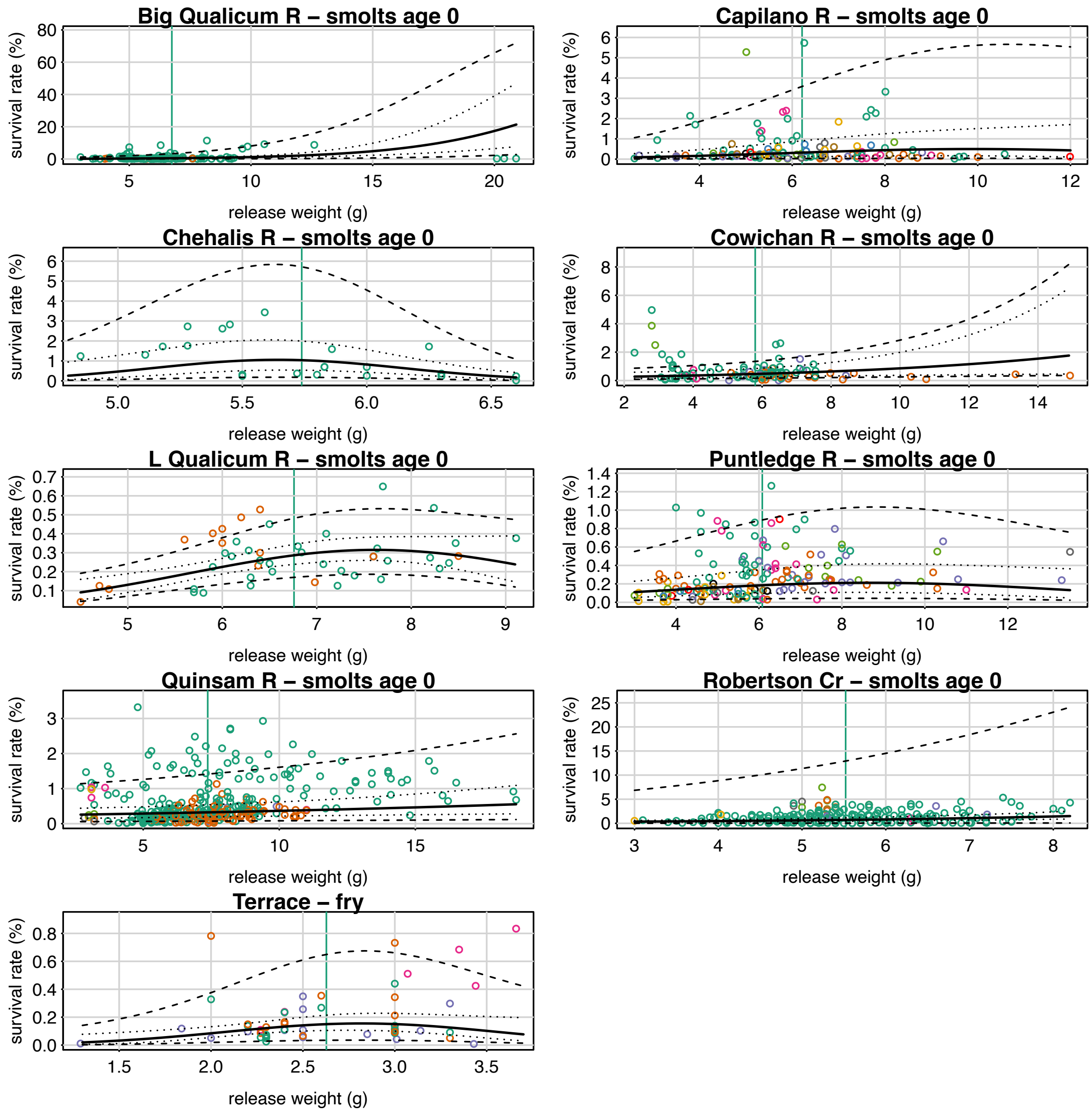


Figure CH.16. Mean **survival** (solid line) for Chinook at different release weights for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). Different colours indicate different combinations of stocks and release sites, while the solid green vertical line indicates the mean weight-at-release. Hatcheries without *Weight* effects in top models are not shown.

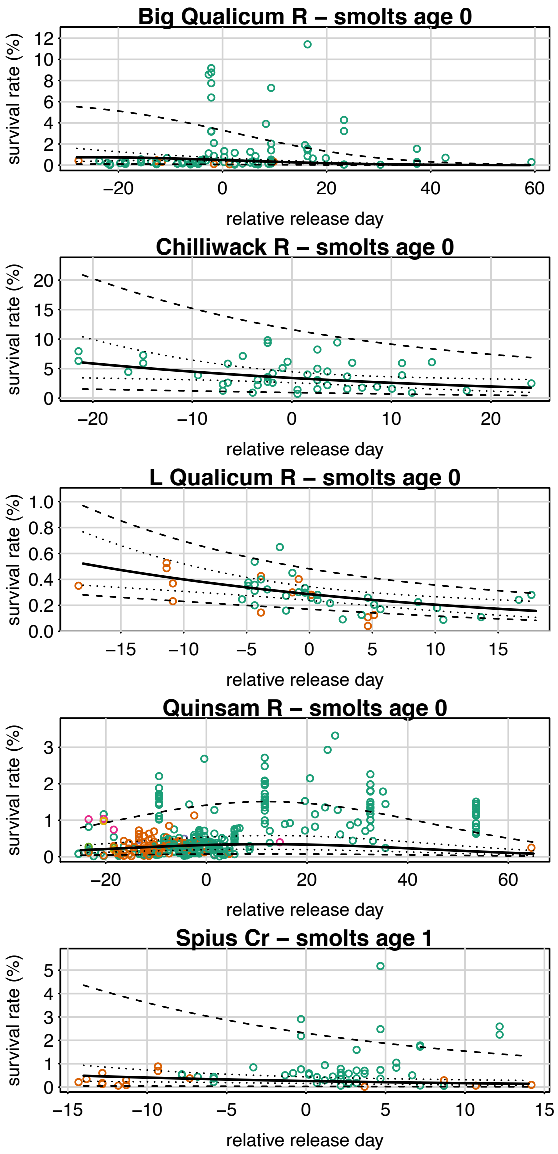


Figure CH.17. Mean **survival** (solid line) for Chinook at release days for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). The zero day indicates the mean release date for a hatchery, while different colours indicate different combinations of stocks and release sites. Hatcheries without *Day* effects in top models are not shown.

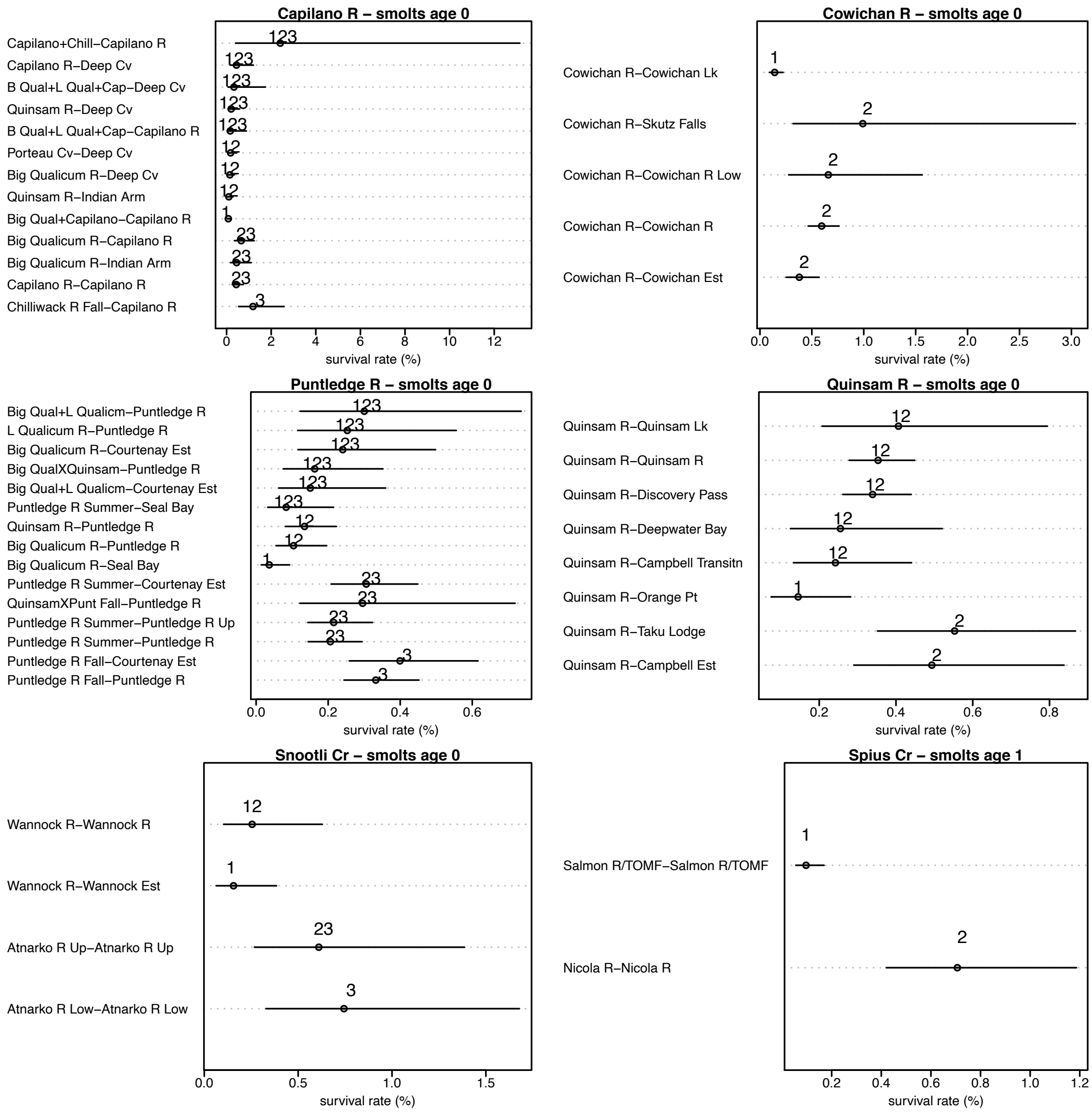


Figure CH.18. Estimated marginal mean Chinook **survival** rates for hatcheries including a stock or release site effect in the top model. The numbers indicate groups whose survival rates are significantly different from one another (i.e., group 1 is different from group 2, but there is no difference between group 12 and 1 or group 12 and 2). Error bars are shown for 95% confidence intervals of fixed effects. For each hatchery, the y-axis shows the stock(s) released followed by a dash and the release site. The + symbol indicates different stocks that were reared together and tagged with the same code, while the X symbol indicates stocks that were crossed during spawning to create a hybrid. Seapen releases are used at Capilano (Deep Cove, Indian Arm), Cowichan (Cowichan Estuary), Puntledge (Courtenay Estuary), Quinsam (Orange Point, Discovery Pass, Taku Lodge), and Snootli Creek (Wannock Estuary). Release site locations are shown in Appendix B.

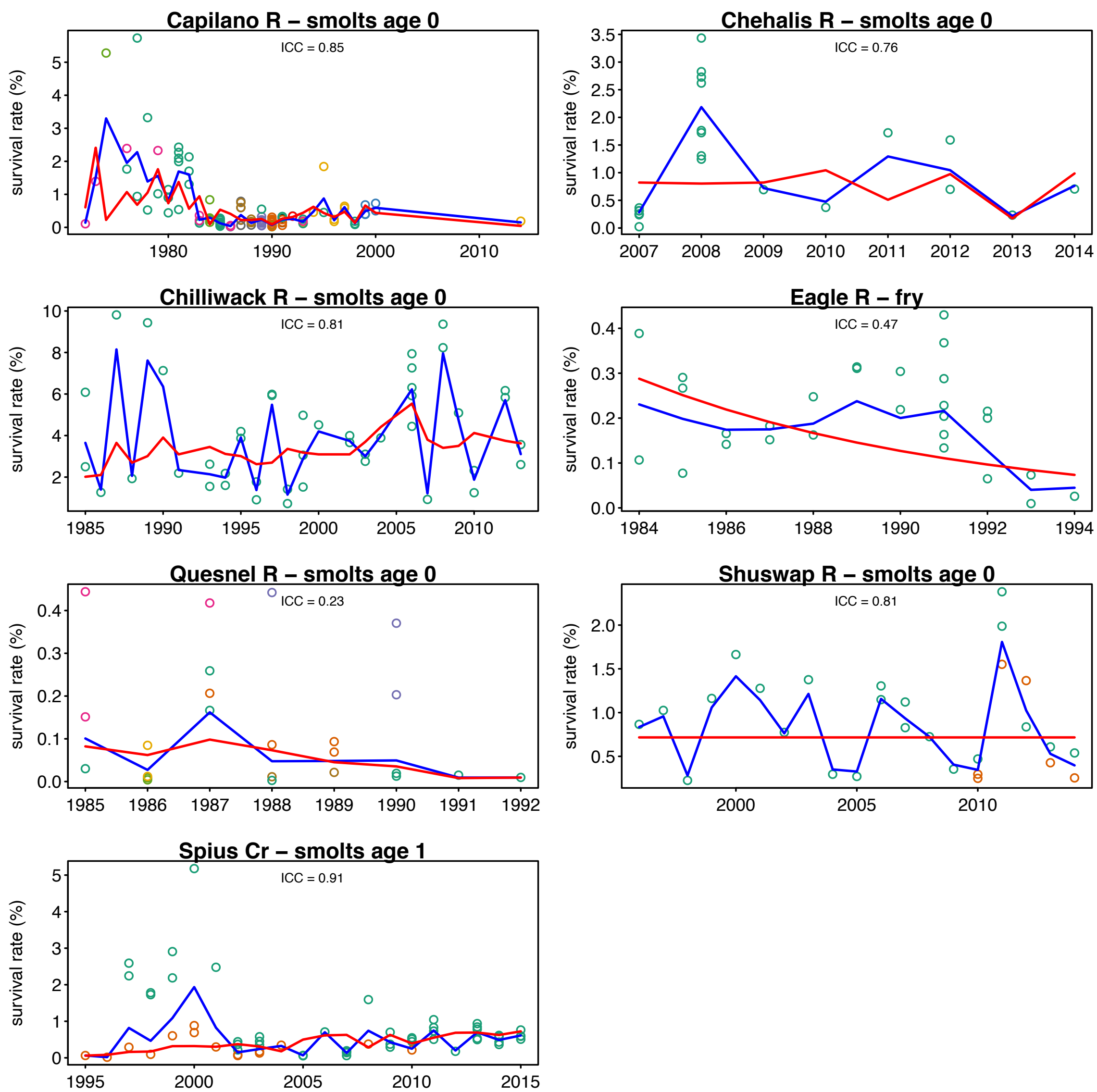


Figure CH.19. Top model fits for Mainland BC hatcheries' average Chinook **survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects. Different colors indicate different combinations of stocks and release sites for each hatchery with green indicating the most frequent stock released and release site.

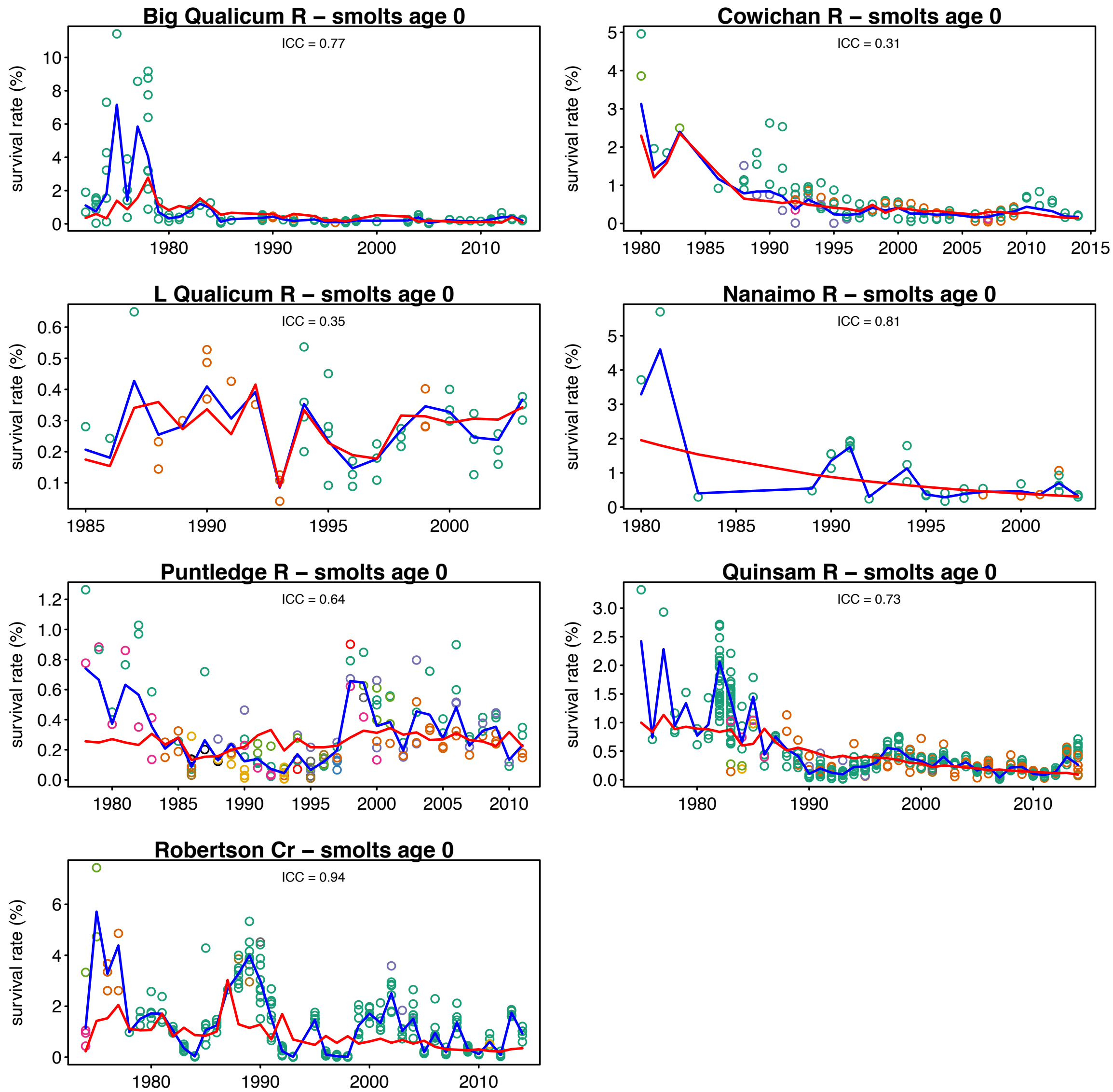


Figure CH.20. Top model fits for Vancouver Island hatcheries' average Chinook **survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects. Different colors indicate different combinations of stocks and release sites for each hatchery with green indicating the most frequent stock released and release site.

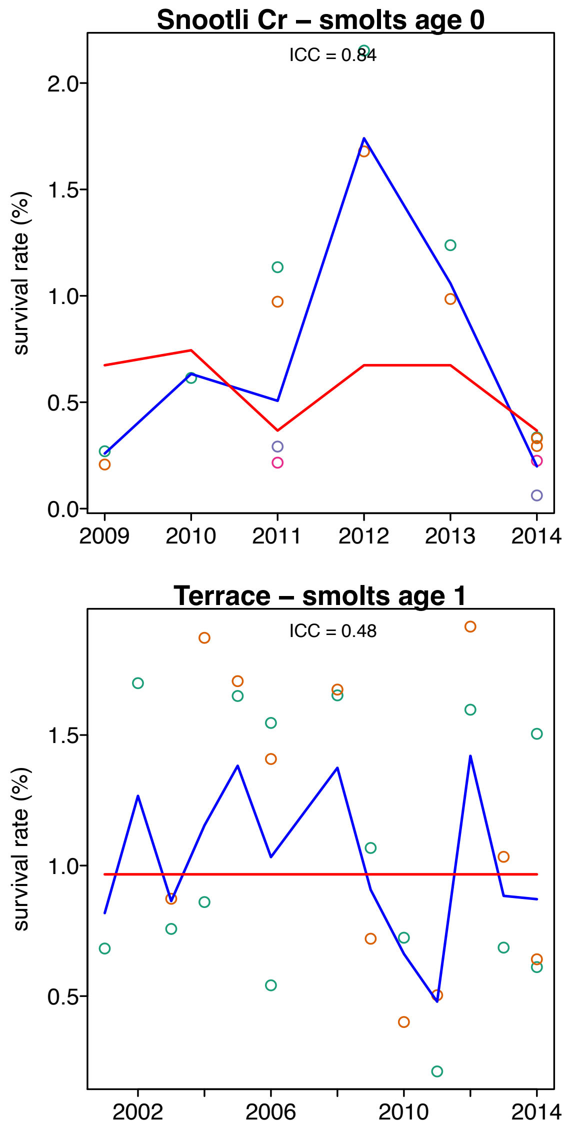


Figure CH.21. Top model fits for Northern BC hatcheries' average Chinook **survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects. Different colors indicate different combinations of stocks and release sites for each hatchery with green indicating the most frequent stock released and release site.

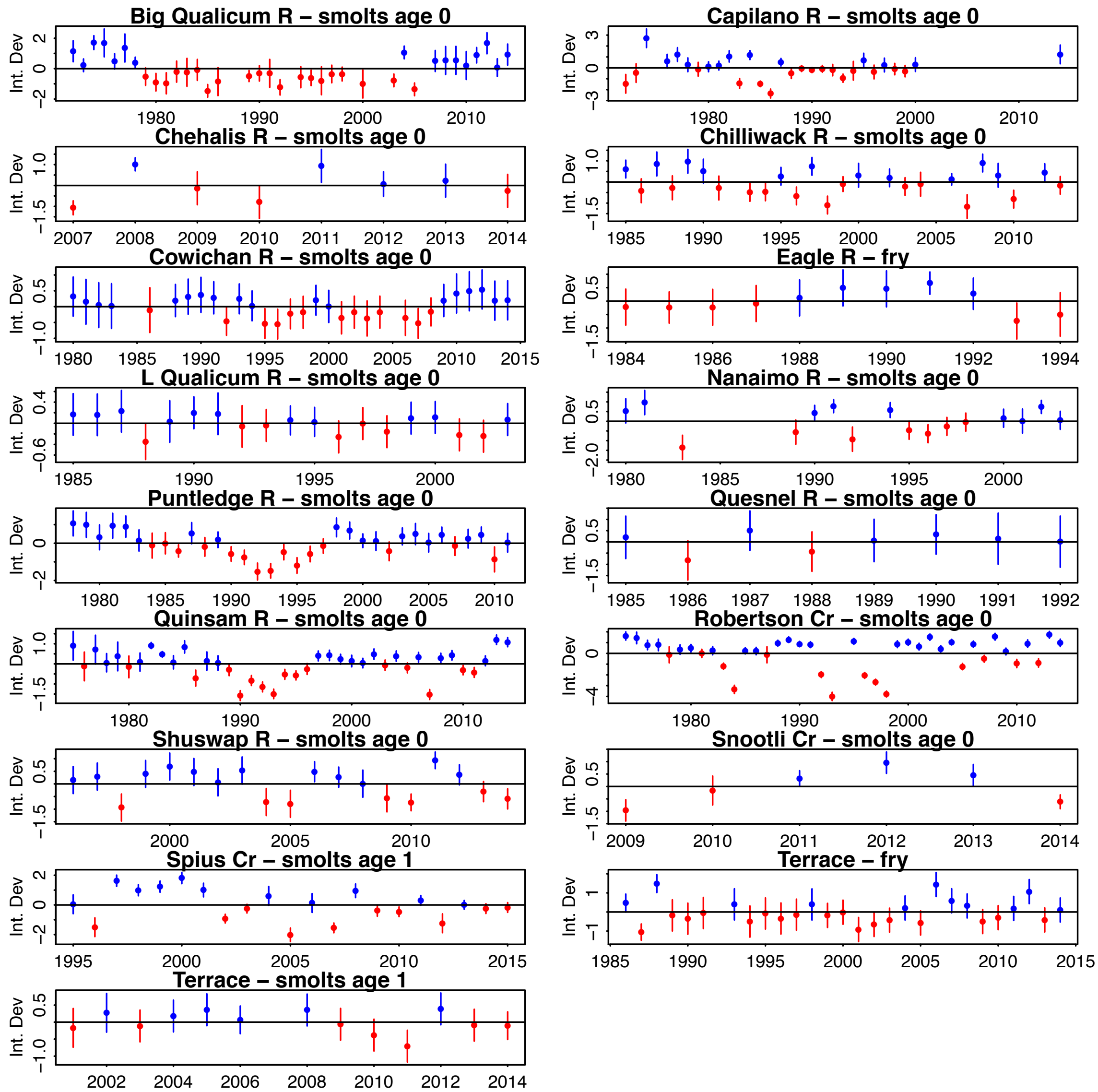


Figure CH.22. The ocean entry year-effect deviation in average Chinook **logit survival** (i.e., Δ_t) for each hatchery and life-stage model. Negative (red) values indicate a year effect below the average and positive (blue) values indicate a year effect above the average.

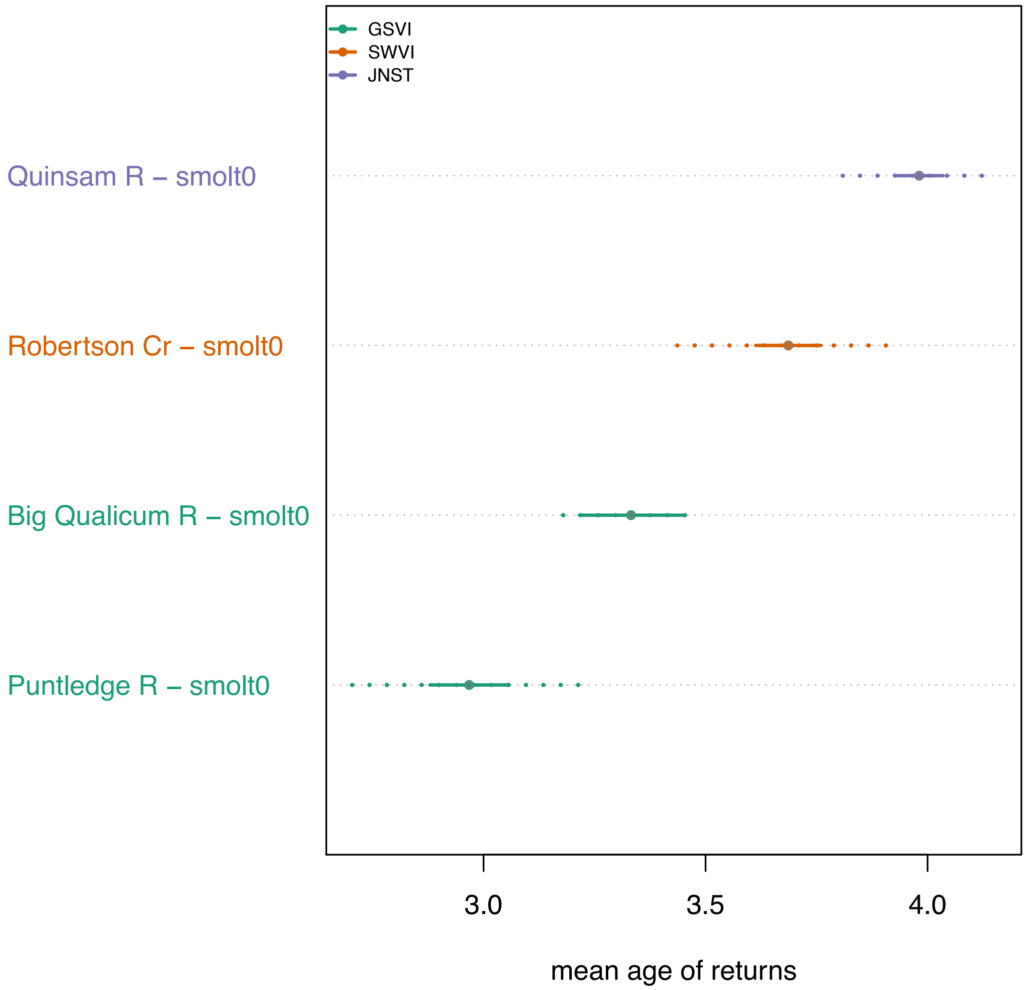


Figure CH.23. Mean Chinook **return ages** and 95% confidence intervals accounting for uncertainty in both fixed and random effects for top model fits for each hatchery. Solid lines indicate uncertainty due to fixed effects, while the dotted lines indicate uncertainty from both fixed and random year effects. The mean ages reflect estimated survival for the average values of covariates.

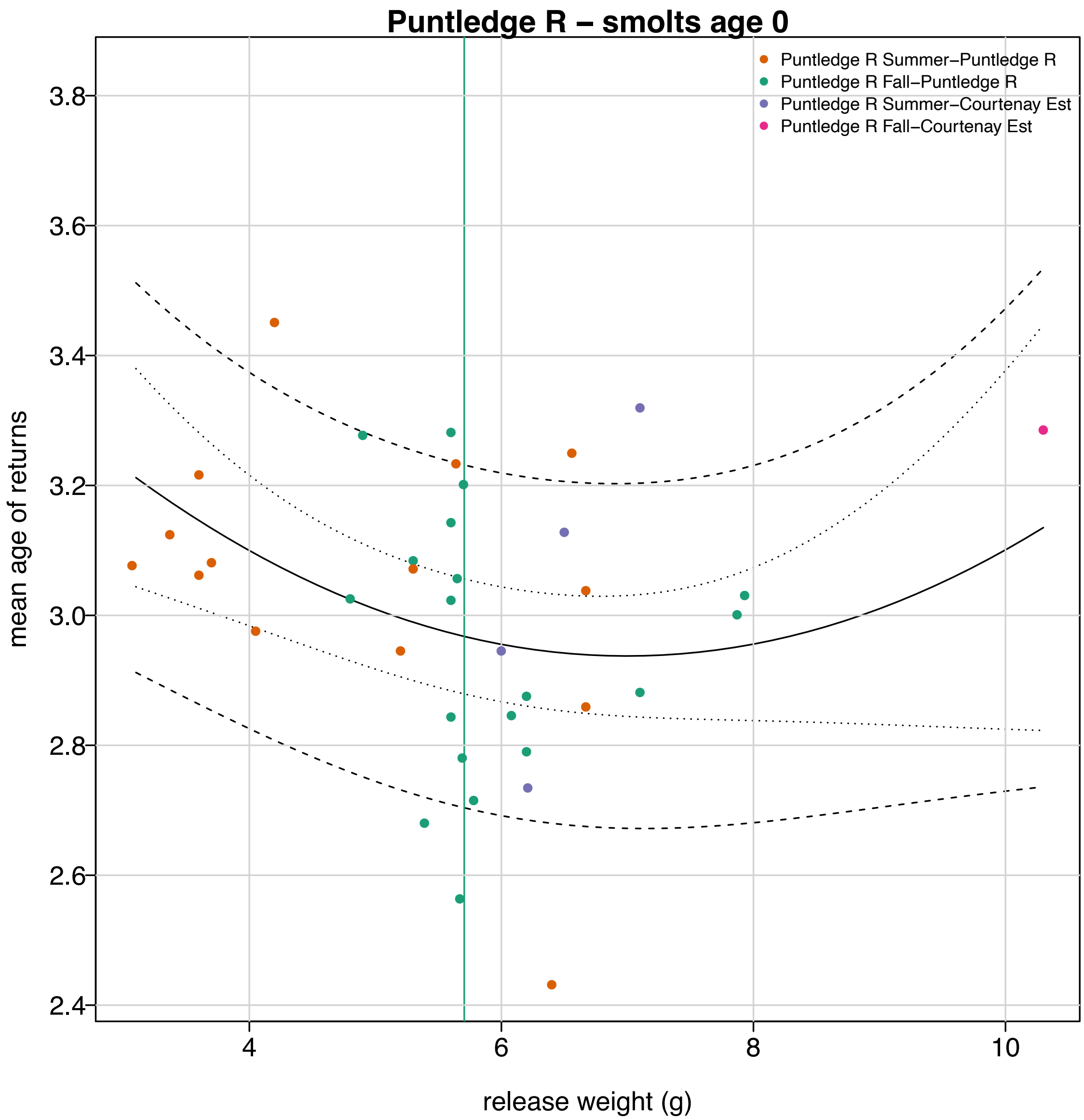


Figure CH.24. Mean **return age** (solid line) for Chinook at different release weights for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). Different colours indicate different combinations of stocks and release sites, while the solid green vertical line indicates the mean weight-at-release. Hatcheries without *Weight* effects in top models are not shown.

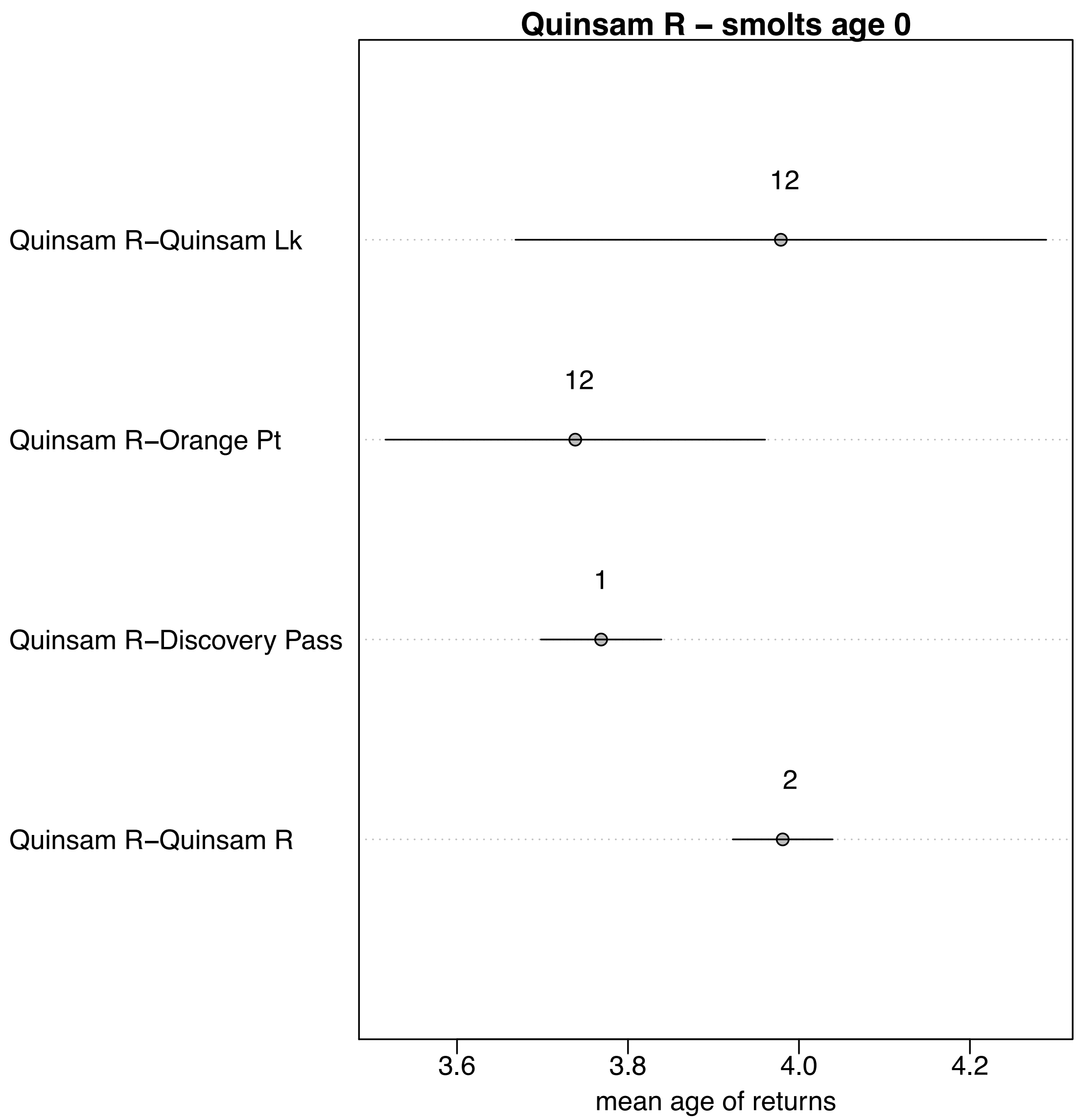


Figure CH.25. Estimated mean **return age** for Chinook returns from Quinsam hatchery smolt releases. The numbers indicate groups where the proportion of Jacks are significantly different from one another (i.e., group 1 is different from group 2). Error bars are shown for 95% confidence intervals of fixed effects. The y-axis shows the stock released followed by a dash and the release site. Orange Point and Discovery Pass are seapen sites.

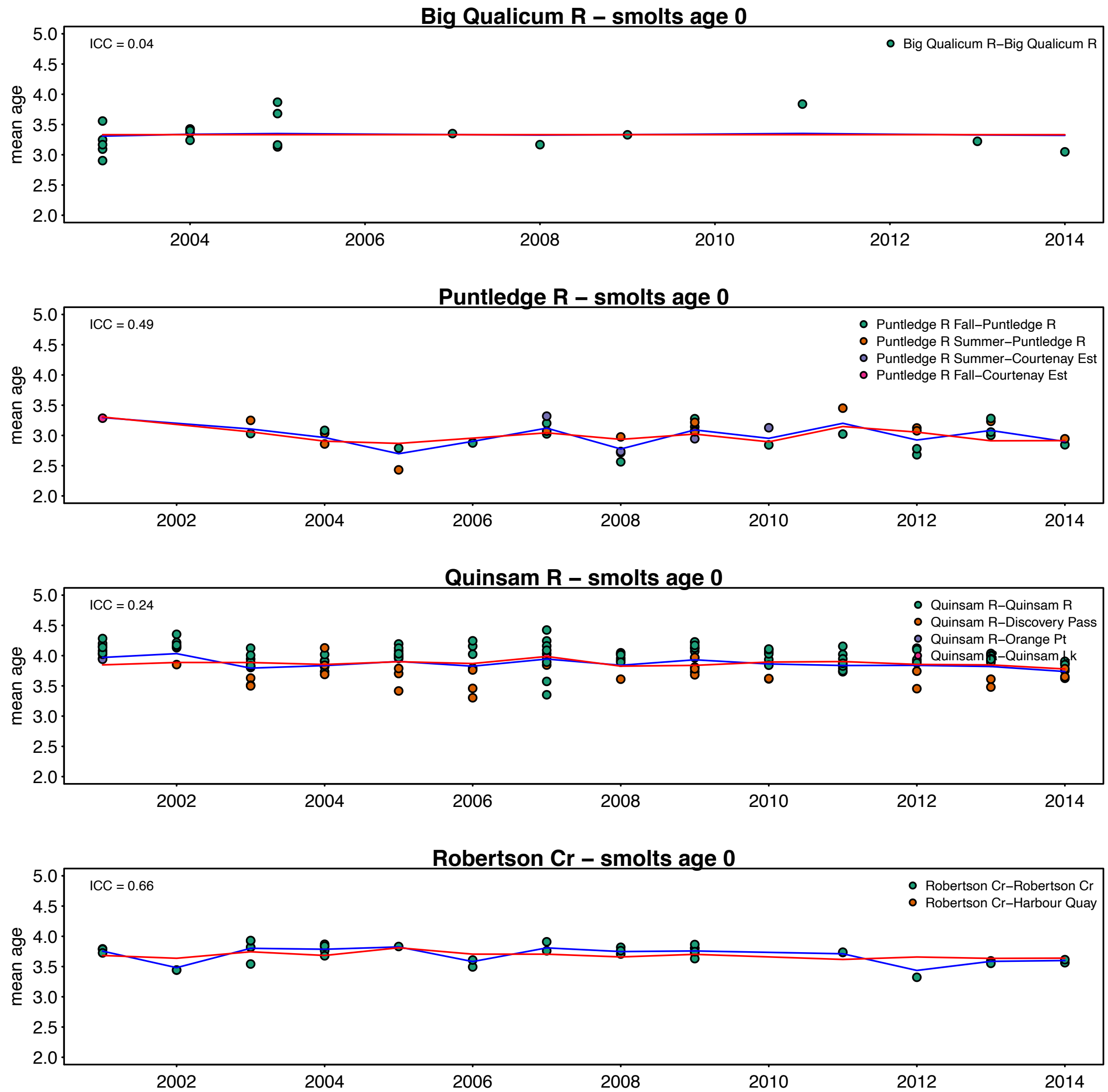


Figure CH.26. Top model fits for BC hatcheries' mean Chinook **return age** over time, accounting for all predictors (e.g. weight, proportion of females, stock and release site) with (blue) and without (red) random year effects.

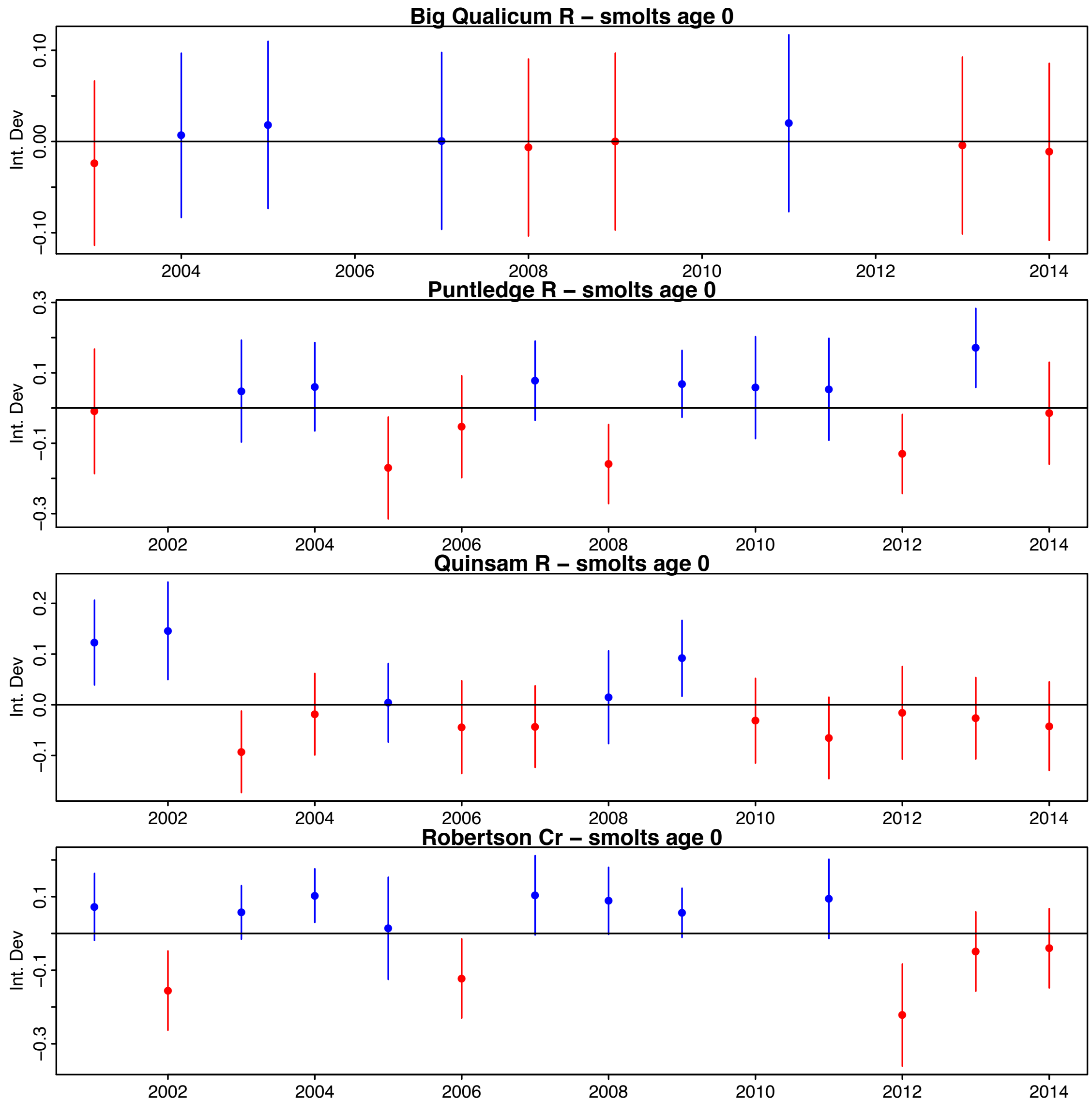


Figure CH.27. The ocean entry year-effect deviation in average Chinook **age of returns** (i.e., Δ_t) for each hatchery and life-stage model. Negative (red) values indicate a year effect below the average and positive (blue) values indicate a year effect above the average.

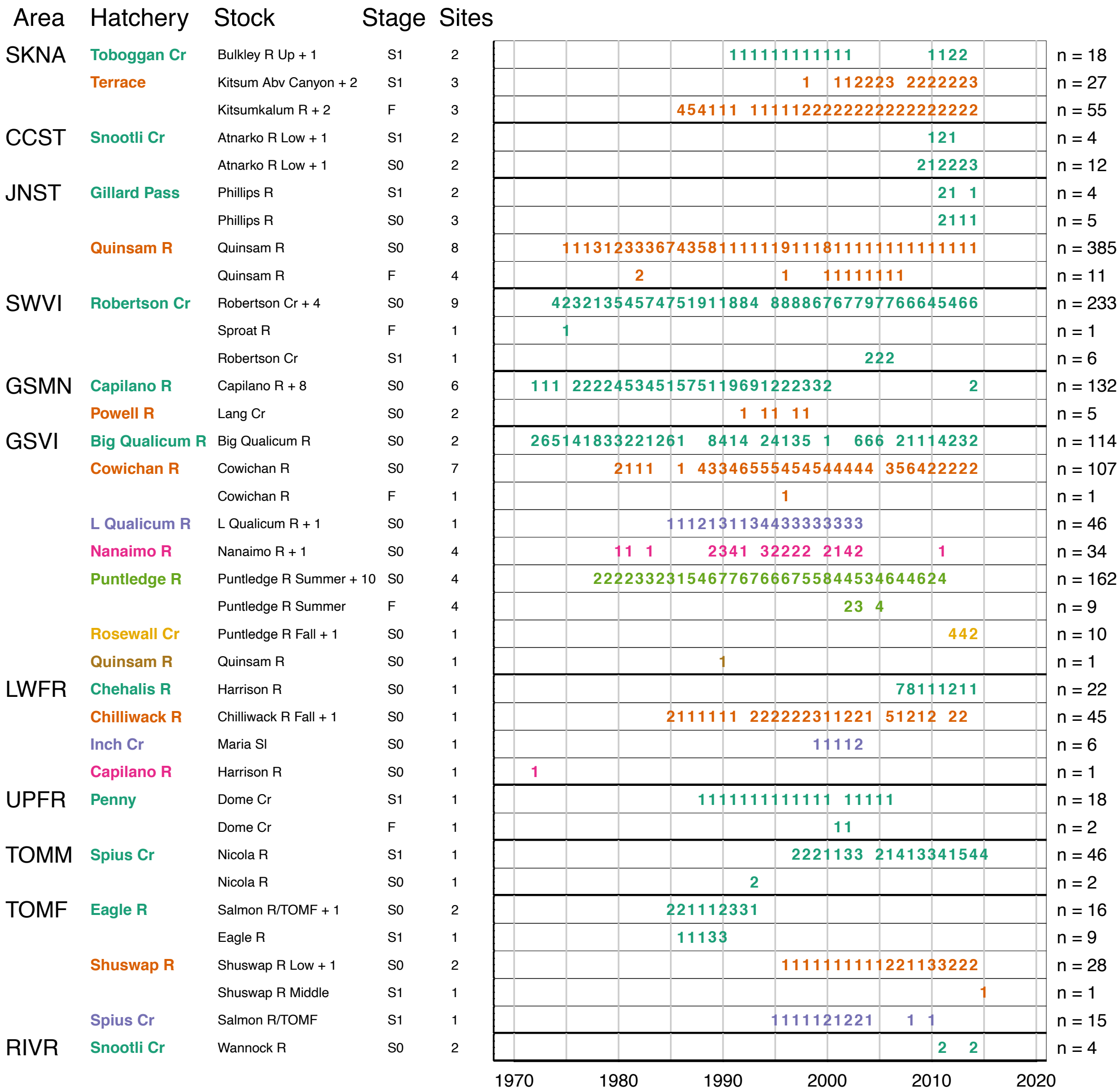


Figure CH.28: Chinook CWT fry (F), sub-yearling smolt (S0), and yearling smolt (S1) releases by ocean entry year used for fitting multi-hatchery survival models with all life-stages. Releases are grouped by hatchery and release site sub-areas (CCST=Central Coast, RIVR=Rivers inlet, SKNA = Skeena River, JNST= Johnstone Strait, SWVI=Southwest Vancouver Island, GSMN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, UPFR = Upper Fraser, LWFR = Lower Fraser, TOMM= Lower Thompson, TOMF= Upper Thompson). Different colours are used to distinguish different hatchery releases in each sub-area.

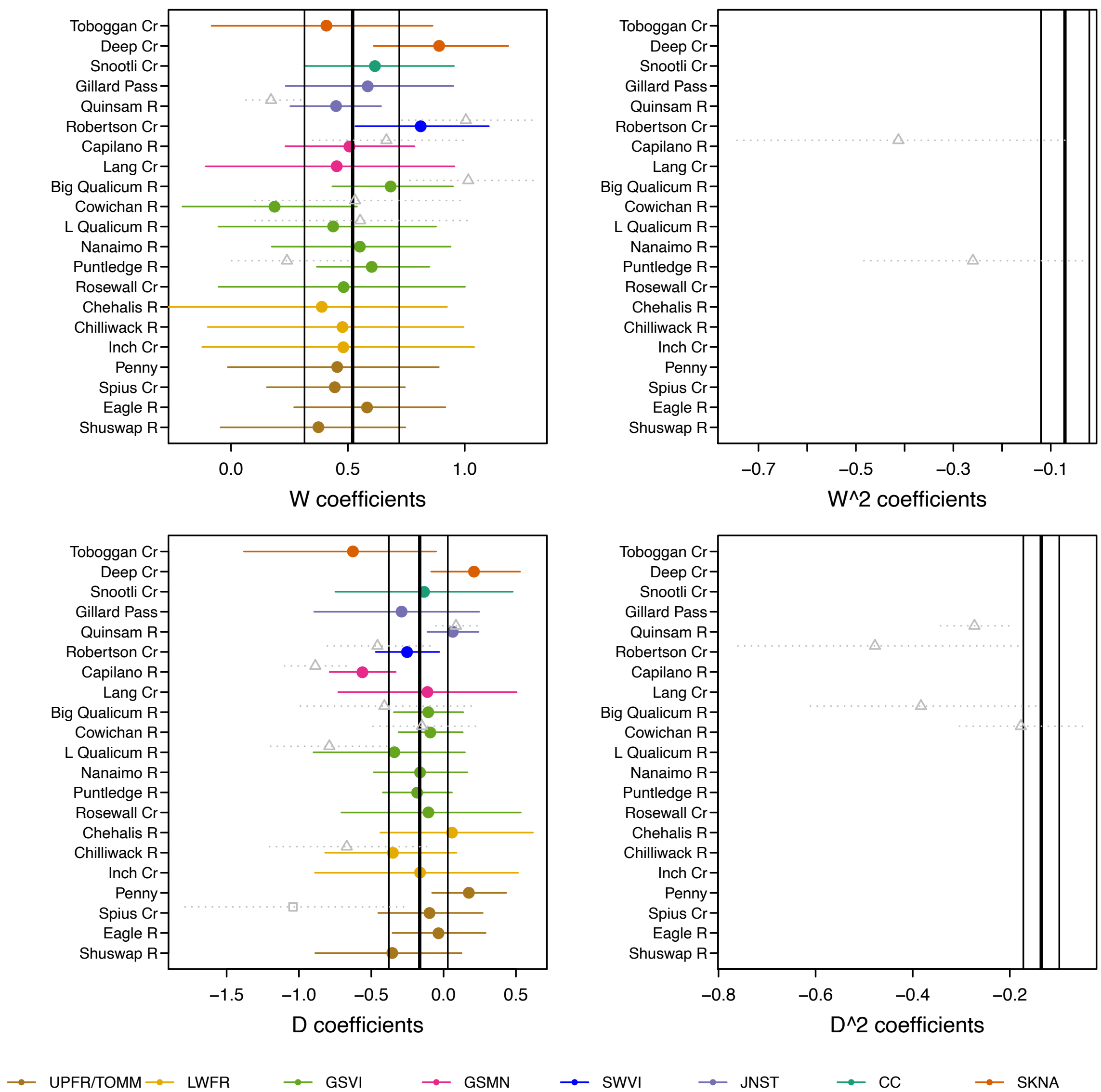


Figure CH. 29. Multi-hatchery Chinook survival model coefficient estimates for linear and quadratic terms for *Weight* (*W*, *W^2*) and *Day* (*D*, *D^2*) at-release. The circles indicate hatchery specific mean posterior estimates along with 95% credible intervals, while the vertical lines indicate the mean posterior for the average effect across all hatcheries (thick black line) with 95% credible intervals for the posterior distribution (thin black lines). Single-hatchery estimates and 95% CIs are shown in grey for sub-yearling smolt (△) and fry (□) life-stage models. Note *W* and *W^2* estimates for Terrace Fry (*W* = -27.4 (SE= 11.8), *W^2* = -11.7 (SE= 4.8)) and Chehalis Smolts (*W* = -19.8 (SE= 4.4), *W^2* = -25.8 (SE= 6.3)) are not shown due to scale.

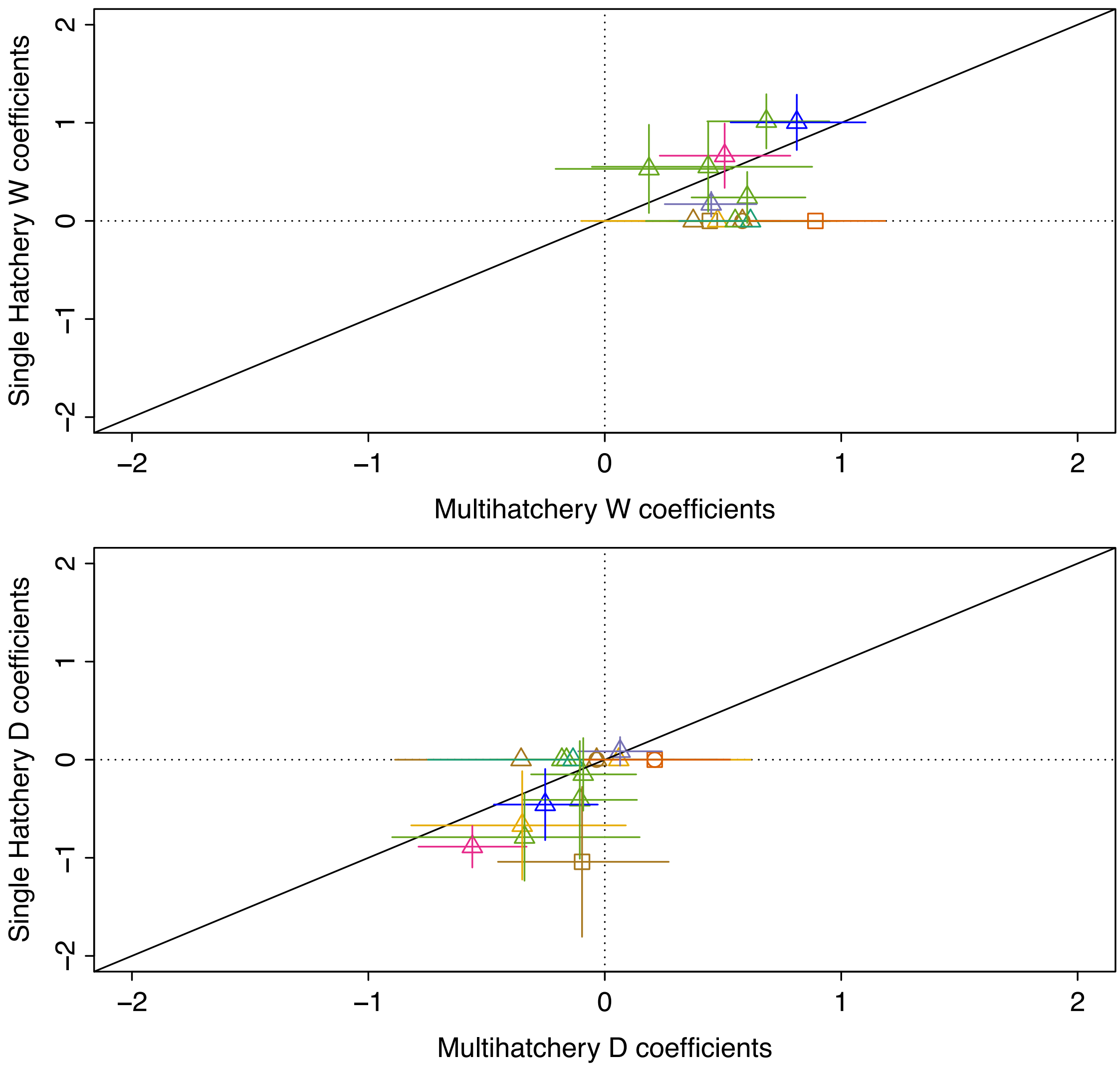


Figure CH. 30. Model coefficient estimates for single-hatchery (MLE +/- 1.96SE) and multi-hatchery models (posterior mean with 95% credible intervals) for linear terms for *Weight* (*W*) and *Day* (*D*) at-release. Multi-hatchery Chinook models include multiple life-stages whereas single hatchery estimates are for sub-yearling smolt (△) and fry (□) life-stage specific models. The diagonal line indicates the 1:1 ratio between single-hatchery and multi-hatchery estimates. Note single hatchery model estimates of *W* for Terrace Fry (*W* = -27.4, SE= 11.8) and Chehalis Smolts (*W* = -19.8, SE= 4.4) are not shown due to scale. Estimates from hatcheries excluded from single hatchery modelling are not shown.

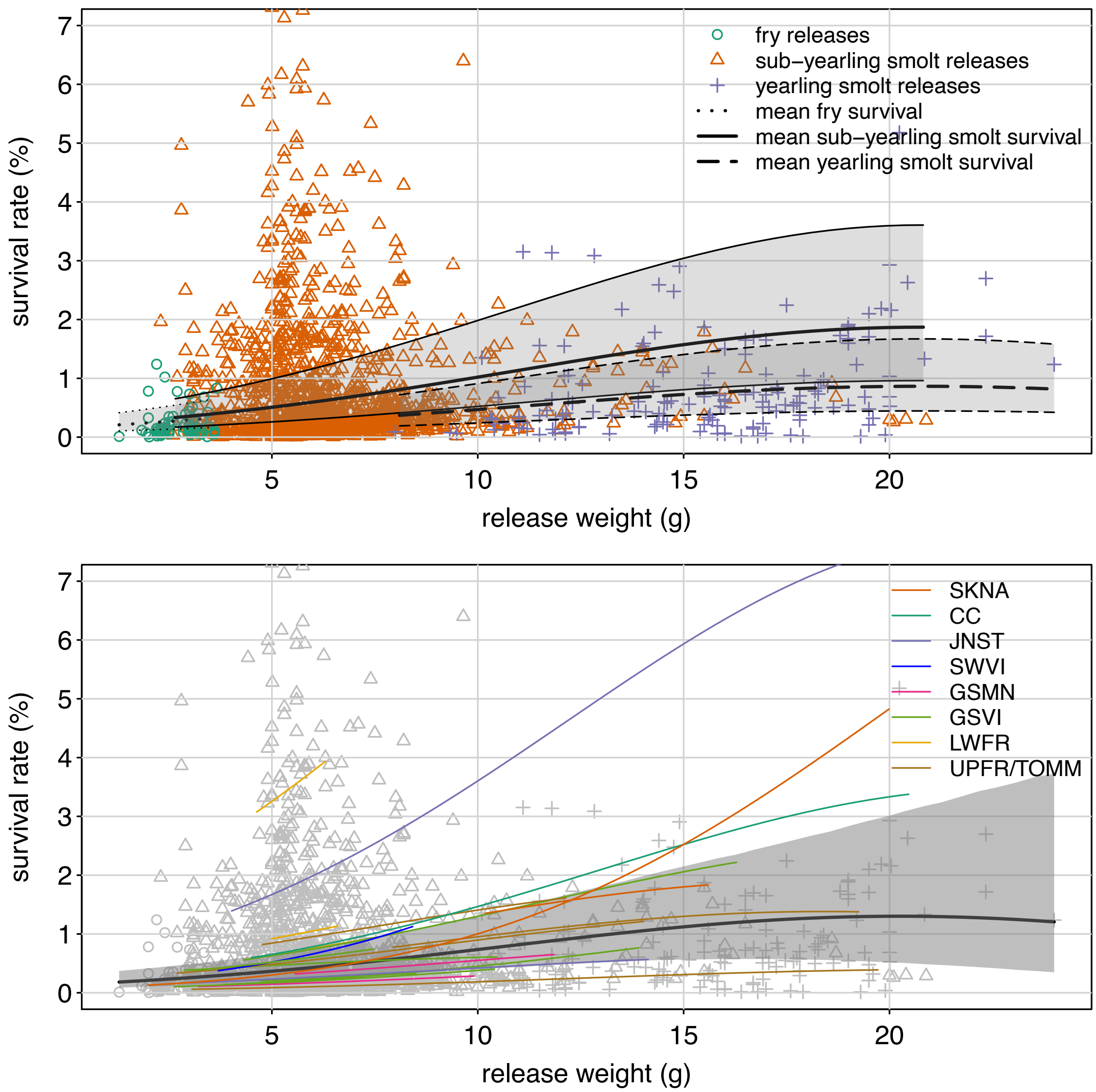


Figure CH.31. Top: Multi-hatchery model fits (MLEs) with 95% CIs for average hatchery survival for Chinook at different release weights for fry, sub-yearling smolts, and yearling smolts. Bottom: Hatchery average and hatchery-specific survival responses for the central 95% distribution of observed weights-at-release for each hatchery. The black line (mean posterior) and shaded areas (95% credible interval) indicate the average weight effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLEs). Note observations with survival rates greater than 7% are not shown.

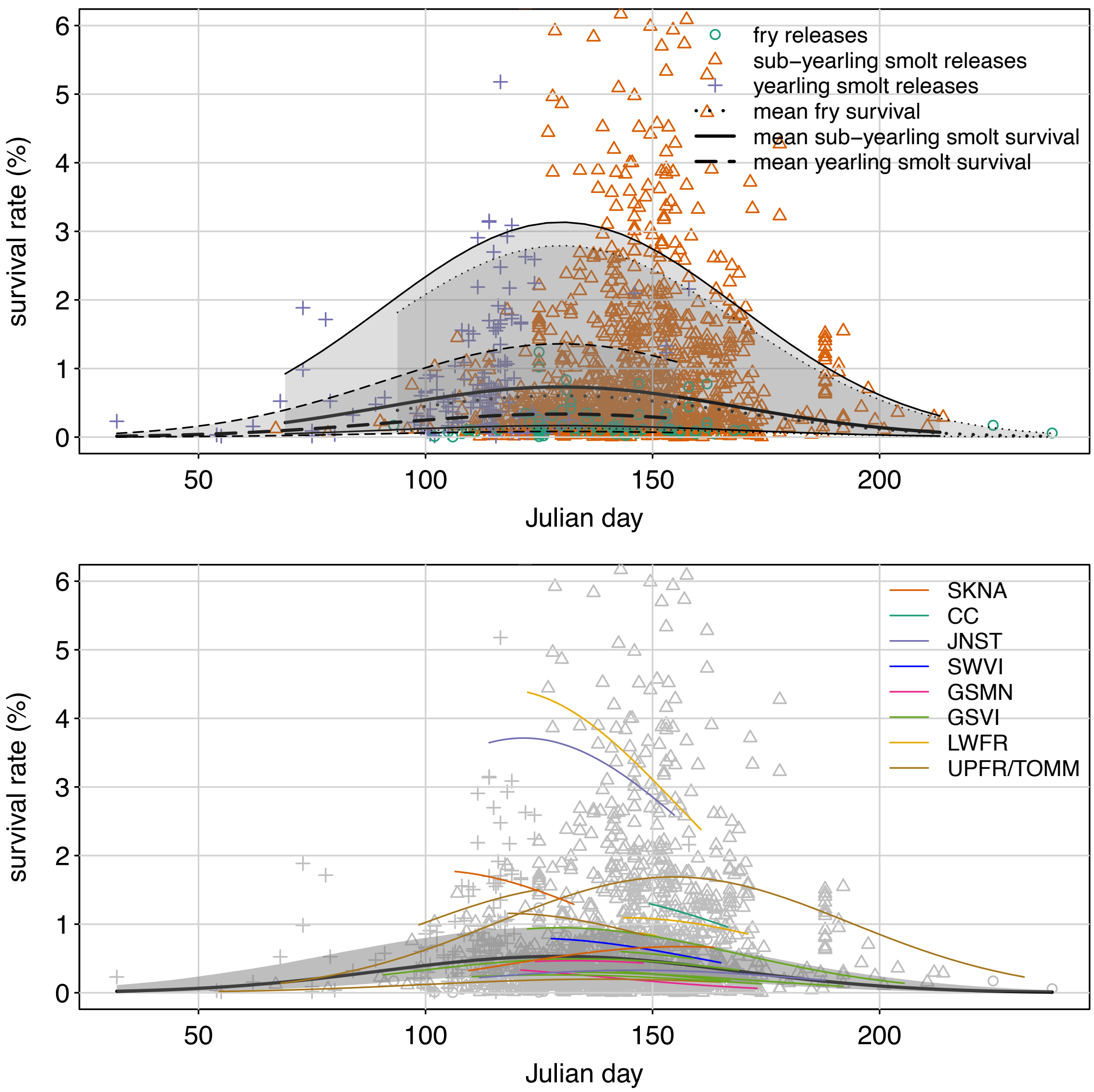


Figure CH.32. Top: Multi-hatchery model fits (MLEs) with 95% CIs for average hatchery survival for Chinook at different release days for fry, sub-yearling smolts, and yearling smolts. Bottom: Hatchery average and hatchery-specific survival responses for the central 95% distribution of observed days-at-release for each hatchery. The black line (mean posterior) and shaded areas (95% credible interval) indicate the average day effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLEs). Note observations with survival rates greater than 6% are not shown.

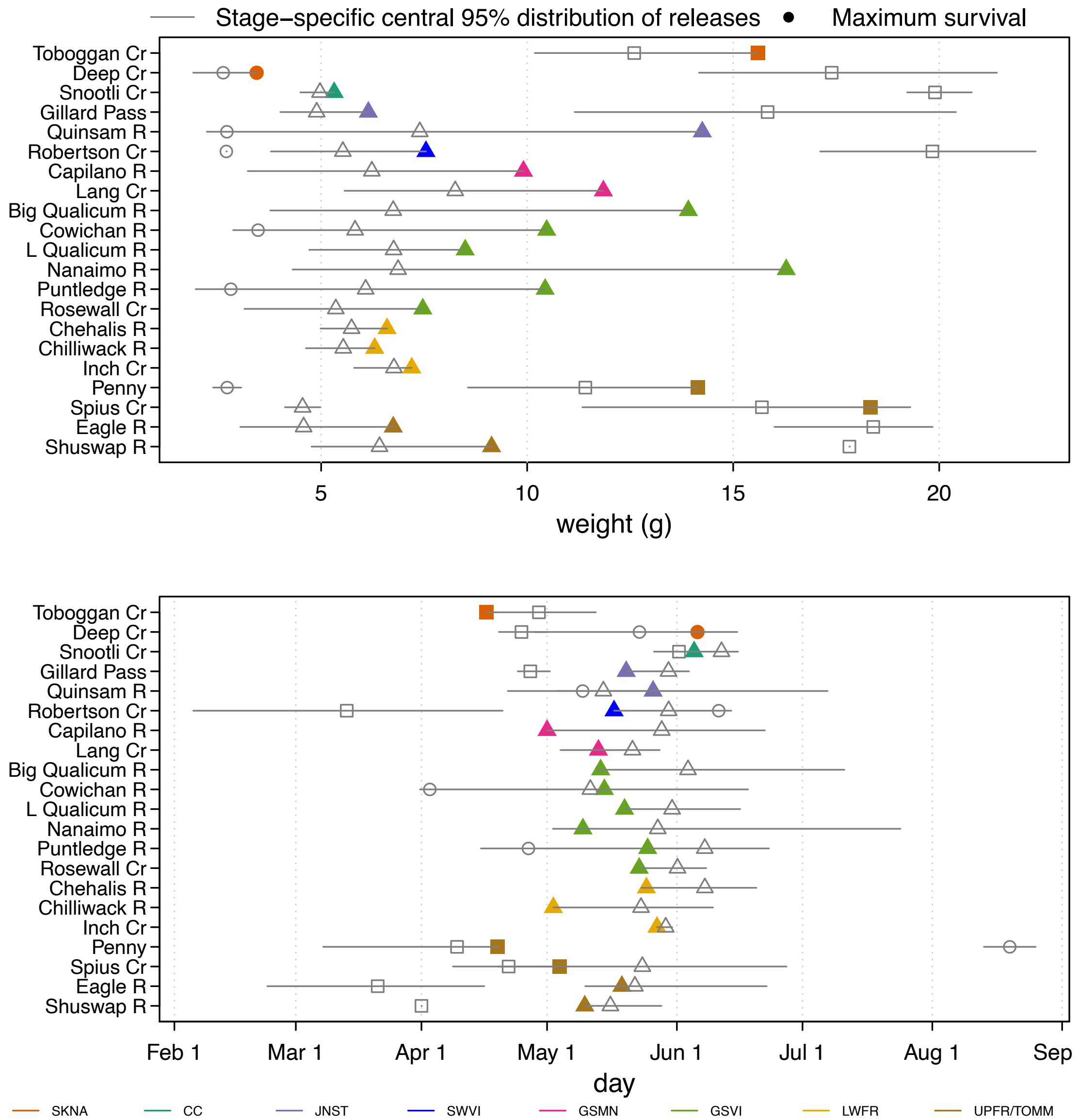


Figure CH.33. Optimal weights (top) and days-at-release (bottom) for maximum Chinook survival for multi-hatchery model posterior means. For each hatchery, the horizontal lines indicate the central 95% distribution of release weights or days for each life-stage (some of which overlap) with means for fry (○), sub-yearling (△) and yearling smolts (□). The coloured circle indicates the release weight or day within the central 95% distribution of observations (grey line) that is expected to maximize survival for the life-stage most commonly released at each hatchery.

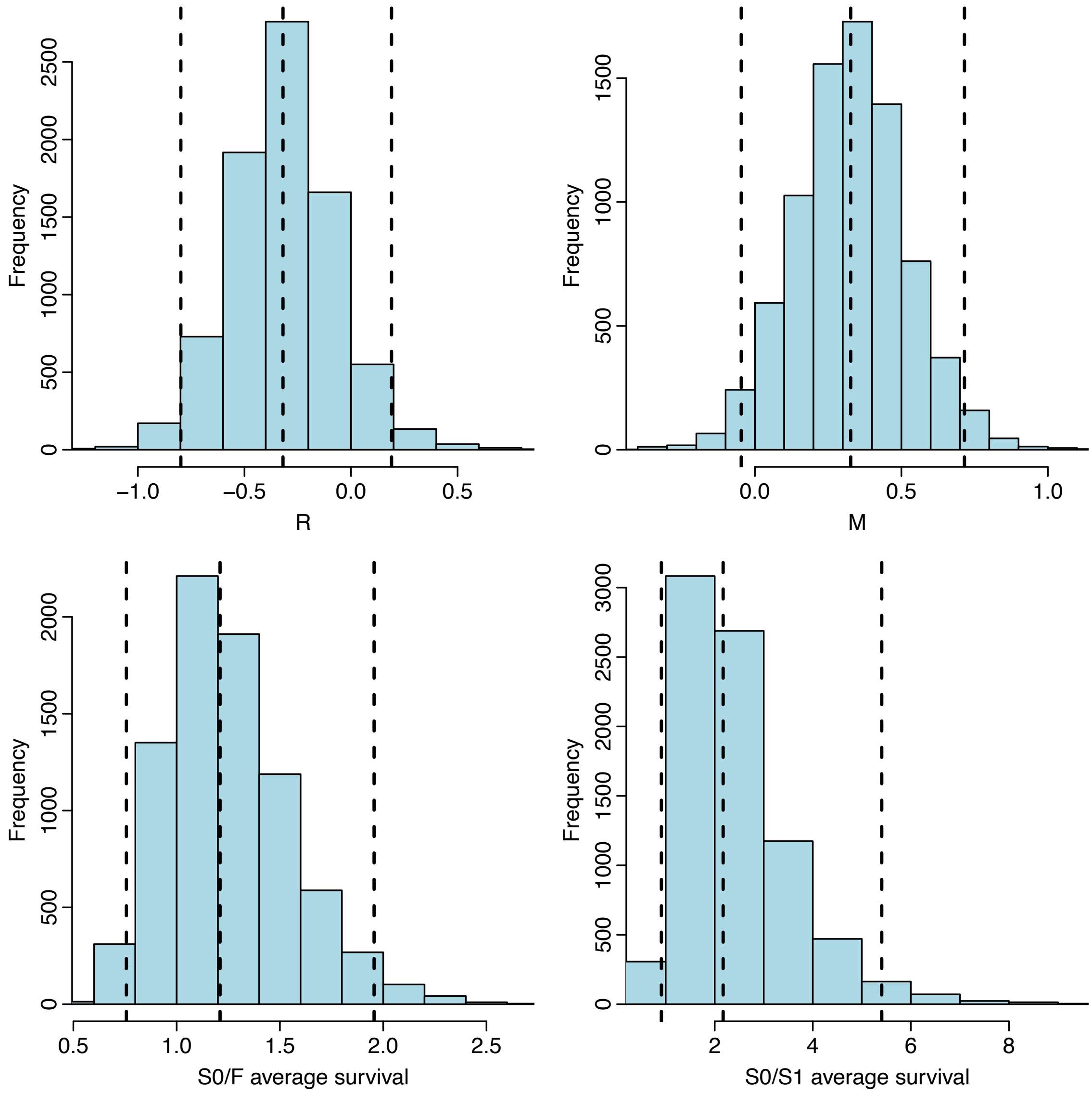
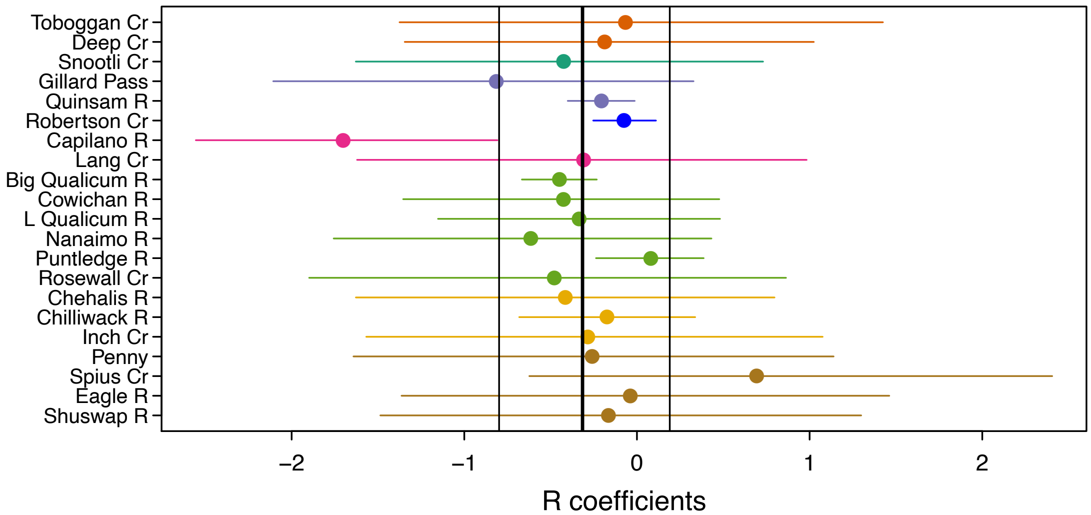


Figure CH.34. Posterior distribution of coefficient estimates for Chinook multi-hatchery survival models for hatchery release biomass (*R*), log river migration distance (*M*), the ratio of average fry to sub-yearling smolt (F/SO) survival, and the ratio of average sub-yearling to yearling smolt (S0/S1) survival. For each distribution the vertical dotted lines indicate the 2.5th, 50th, and 97.5th percentiles.



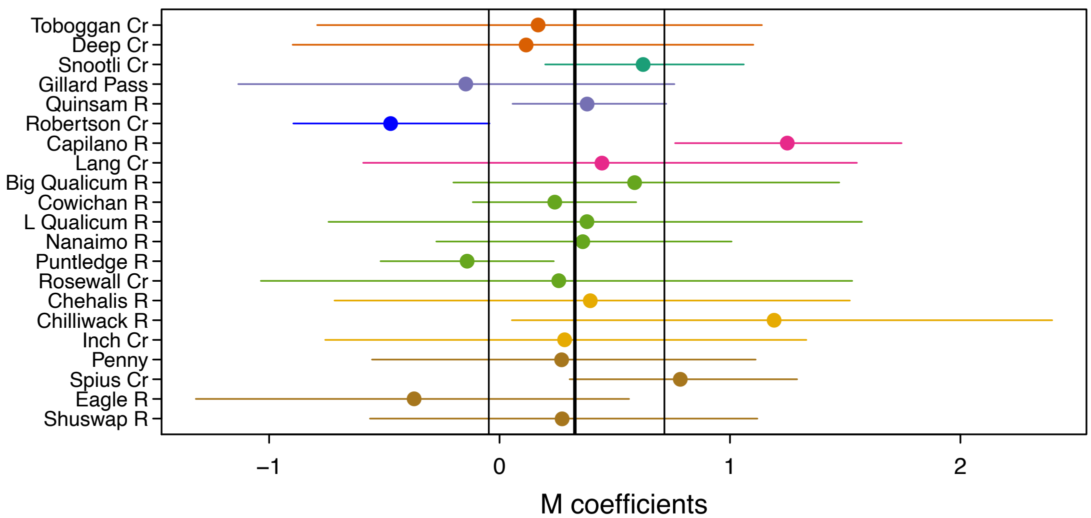


Figure CH. 35. Multi-hatchery Chinook survival model coefficient estimates for the release biomass (*R*) and the log river outmigration distance (*M*) predictors. The circles indicate hatchery specific mean posterior estimates along with 95% credible intervals, while the vertical lines indicate the mean posterior for the average effect across all hatcheries (thick black line) with 95% credible intervals for the posterior distribution (thin black lines).

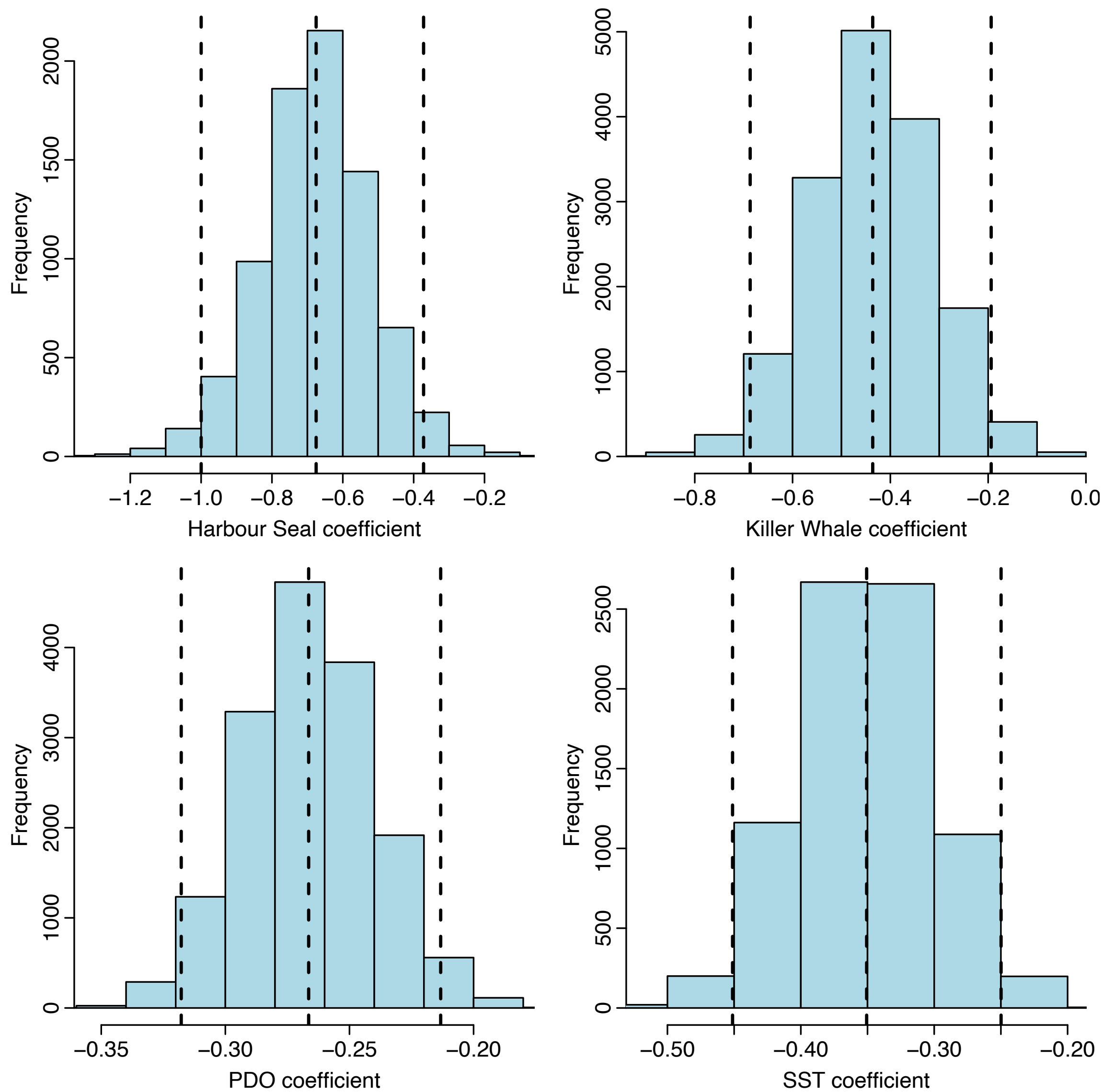


Figure CH.36. Posterior distribution of coefficient estimates for the 4 Chinook multi-hatchery survival models that were fit with environmental covariates (Harbour seals, Killer Whales, PDO, SST) instead of year effects. For each distribution the vertical dotted lines indicate the 2.5th, 50th, and 97.5th percentiles.

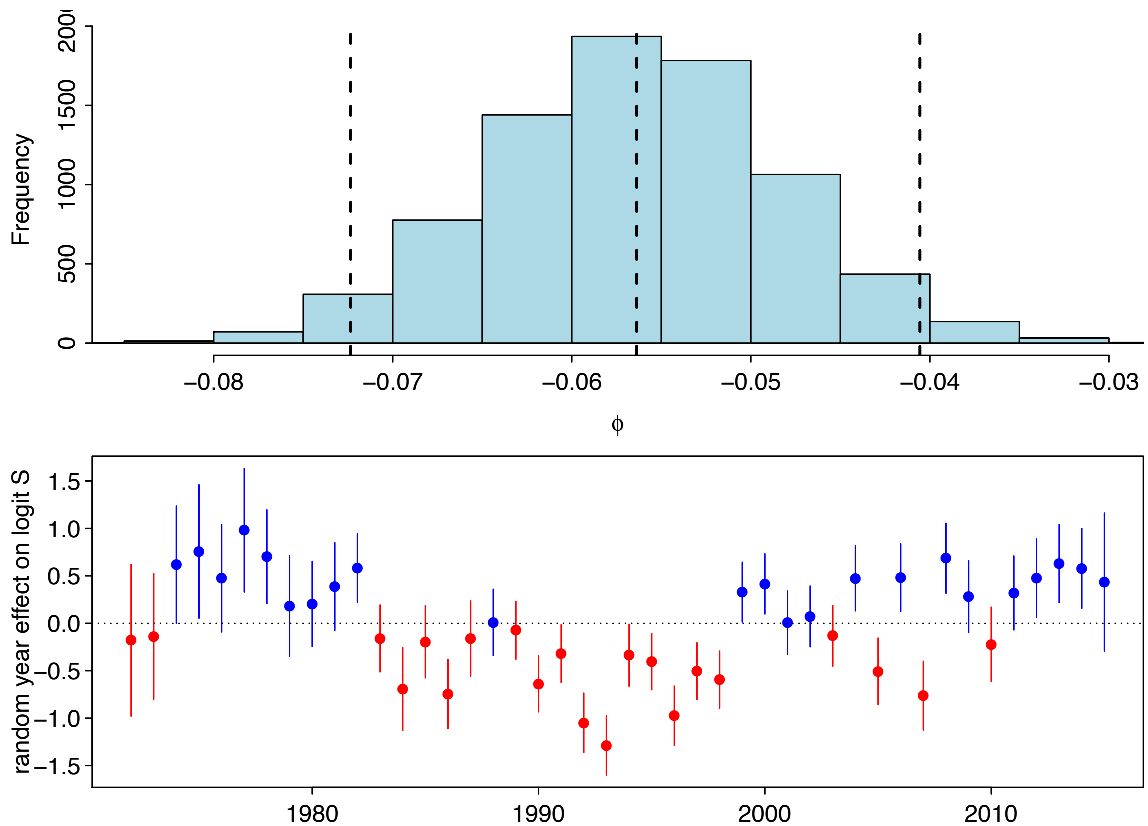


Figure CH.37. Top: Posterior distribution of estimated annual declines in average logit Survival from 1972-2015 ocean entry years with vertical dotted lines for 2.5th, 50th, and 97.5th percentiles. Bottom: The estimated deviations in average Chinook logit survival (i.e., random year effects, Δ_t) from the temporal trend for the full multi-hatchery model with multiple life stages. Negative (red) values indicate a year with a greater rate of decline that the average trend and positive (blue) values indicate a year effect with a lower rate of decline than the average trend.

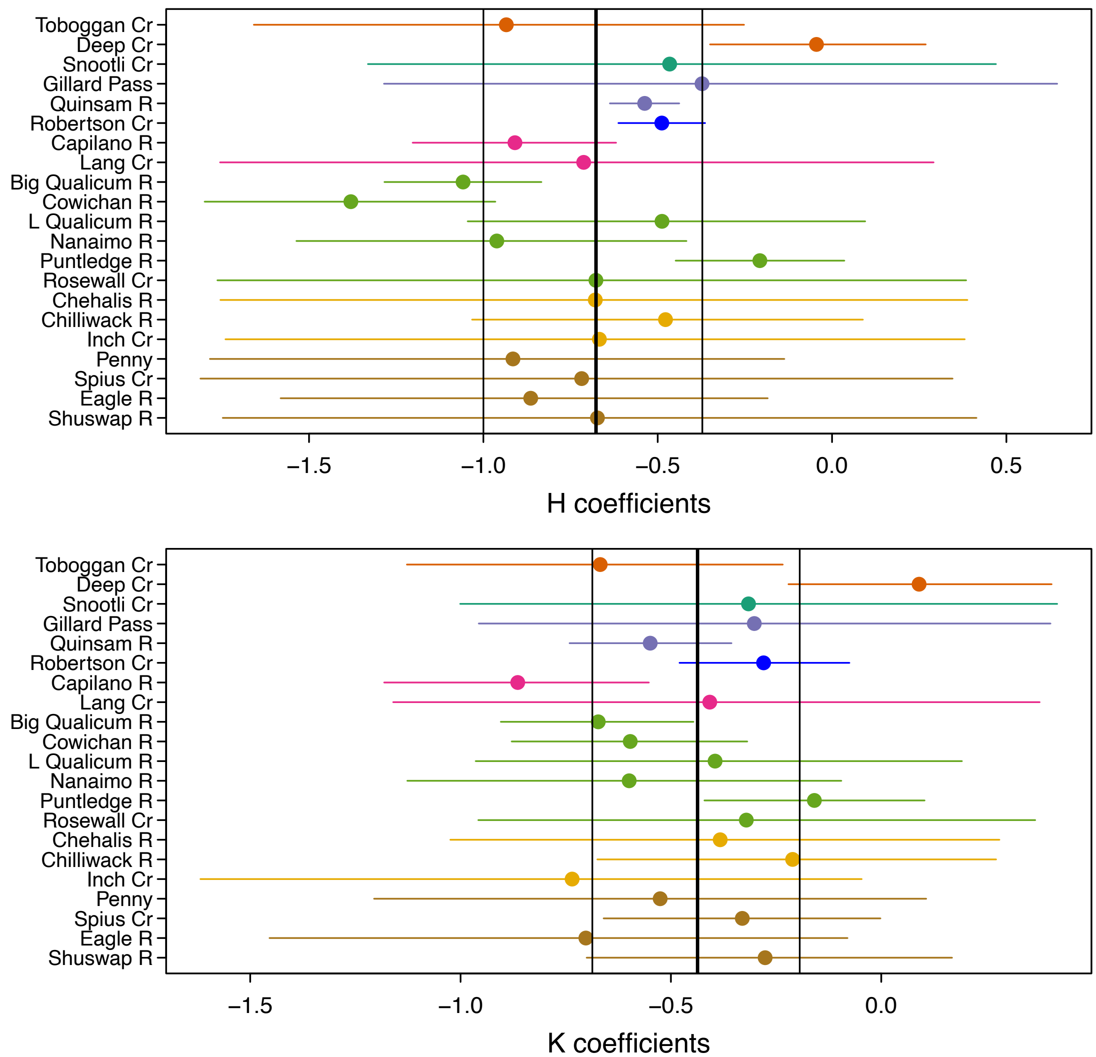


Figure CH.38. Coefficient estimates for multi-hatchery Chinook survival models fit with Harbour Seal (H) and Killer Whale (K) covariates. The circles indicate hatchery specific mean posterior estimates along with 95% credible intervals, while the vertical lines indicate the mean posterior for the average effect across all hatcheries (thick black line) with 95% credible intervals (thin black lines).

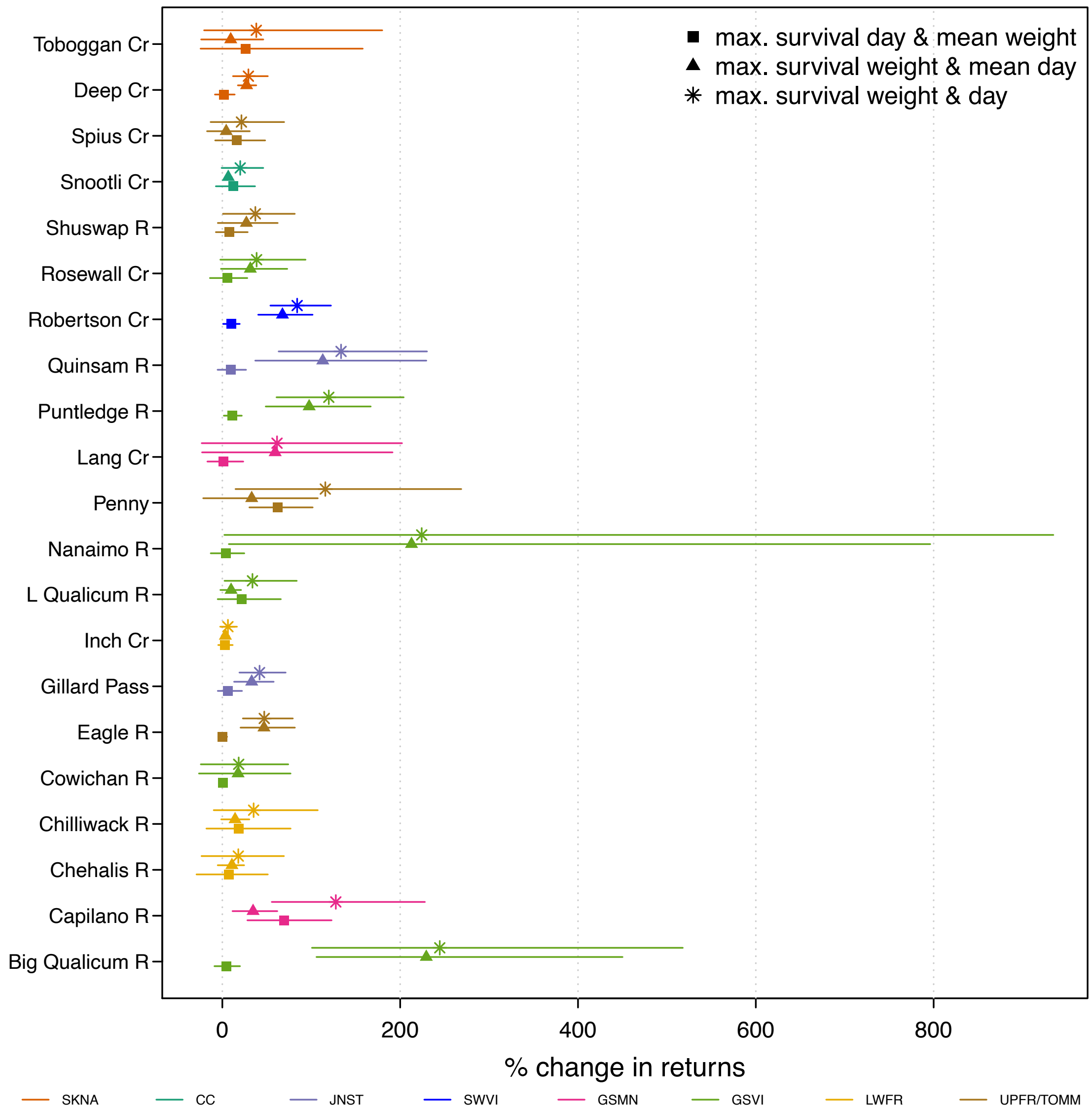


Figure CH.39. Estimated increase in average Chinook returns (%) for 2000-2015 ocean entry years for different release weights and days relative to the mean release weight and day. For each hatchery, the % change in returns is shown for release weights and/or days within the historical observations that are expected to maximize survival for the life-stage most commonly released. Points indicate median posterior estimates, while error bars show 95% credible intervals. Values shown are for fry (Deep Cr), yearling smolts (Penny Creek, Spius Cr, Toboggan Cr) and sub-yearling smolts (all others).

Coho Figures

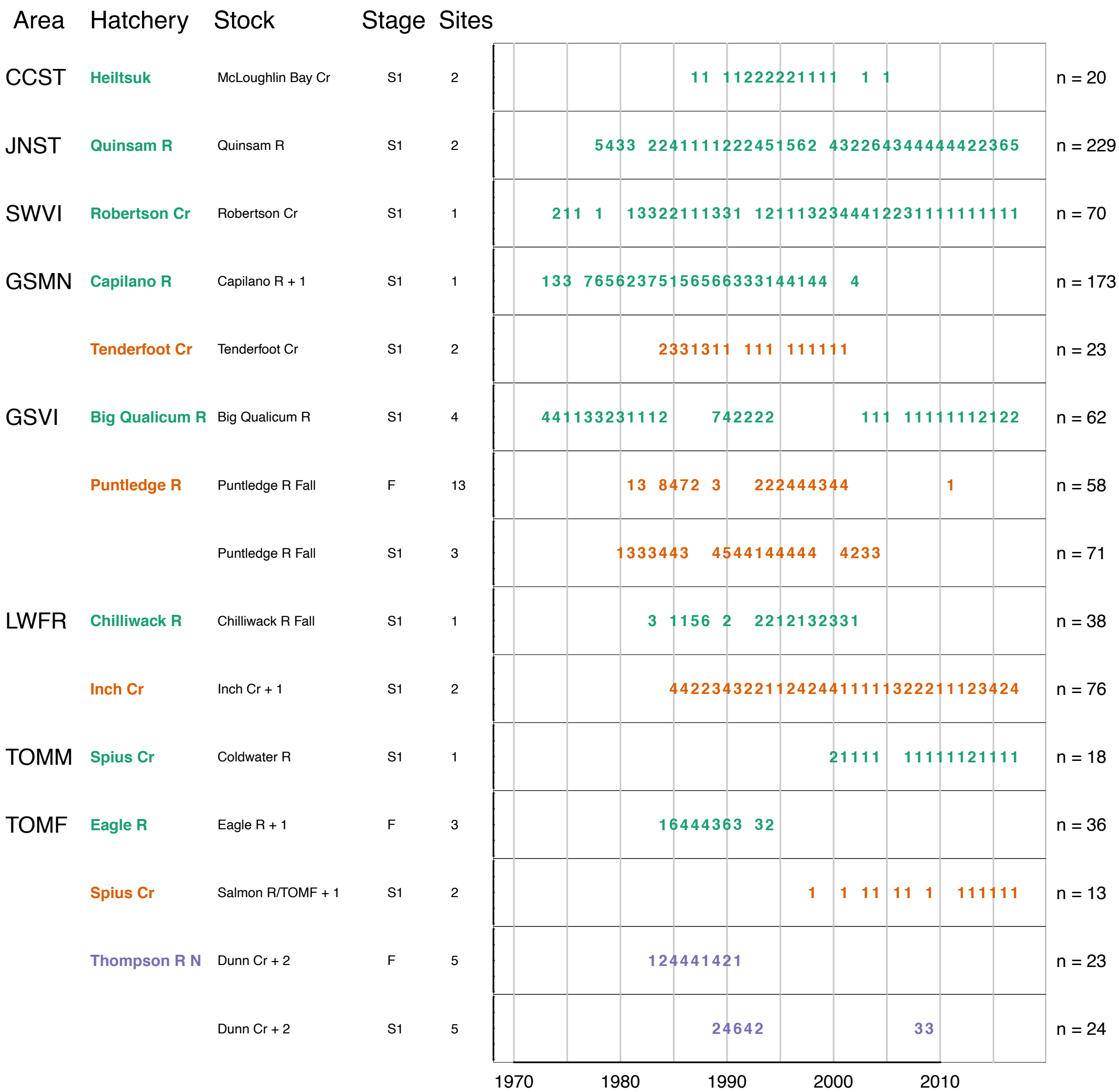


Figure CO.1: Coho CWT hatchery fry (F) and yearling (S1) releases by ocean entry year used for fitting individual hatchery **survival models**. Releases are grouped by hatchery and release site sub-areas (CCST=Central Coast, JNST= Johnstone Strait, SWVI=Southwest Vancouver Island, GSMN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, LWFR = Lower Fraser, TOMM= Lower Thompson, TOMF= Upper Thompson). Different colours are used to distinguish different hatchery releases in each sub-area.

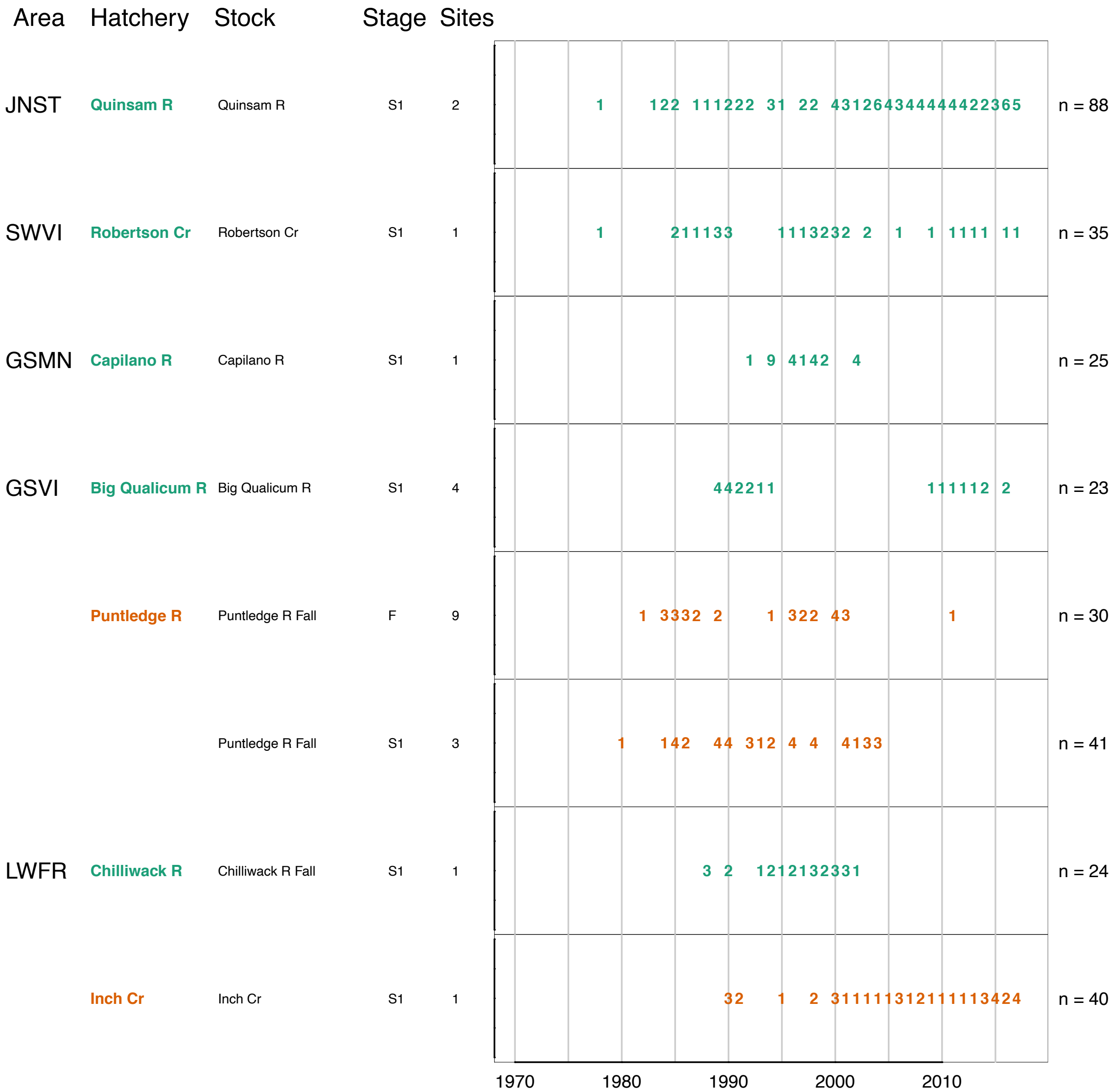


Figure CO.2: Coho CWT hatchery fry (F) and yearling (S1) releases by ocean entry year used for fitting individual hatchery **return age models**. Releases are grouped by hatchery and release site sub-areas (JNST= Johnstone Strait, GMSN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, LWFR = Lower Fraser, TOMF= Lower Thompson, TOMM= Upper Thompson, SWVI=Southwest Vancouver Island). Different colours are used to distinguish different hatchery releases in each sub-area.

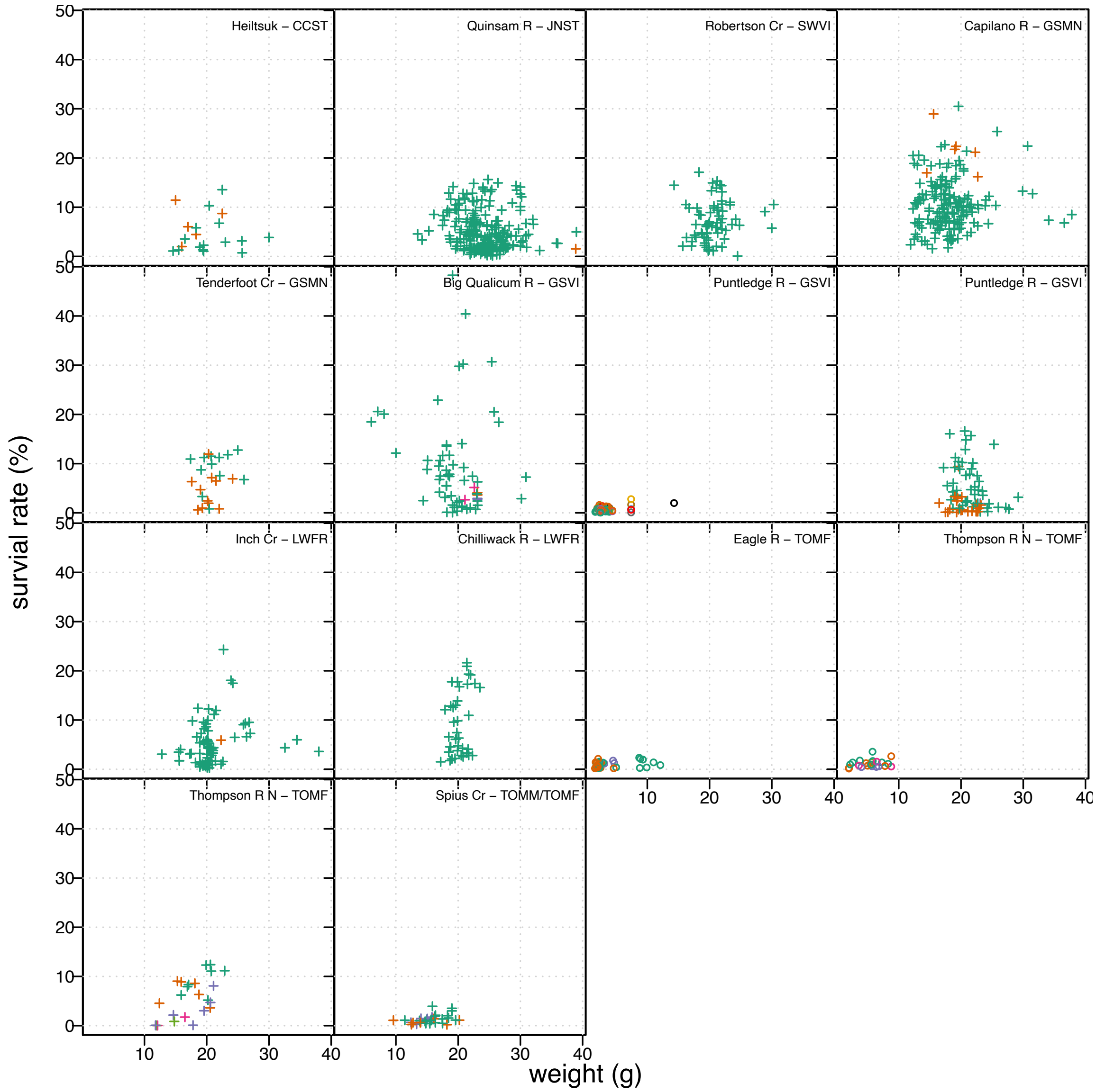


Figure CO.3. Smolt-to-adult survival rates (%) by weight-at-release for fry (O) and yearling (+) CWT Coho hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

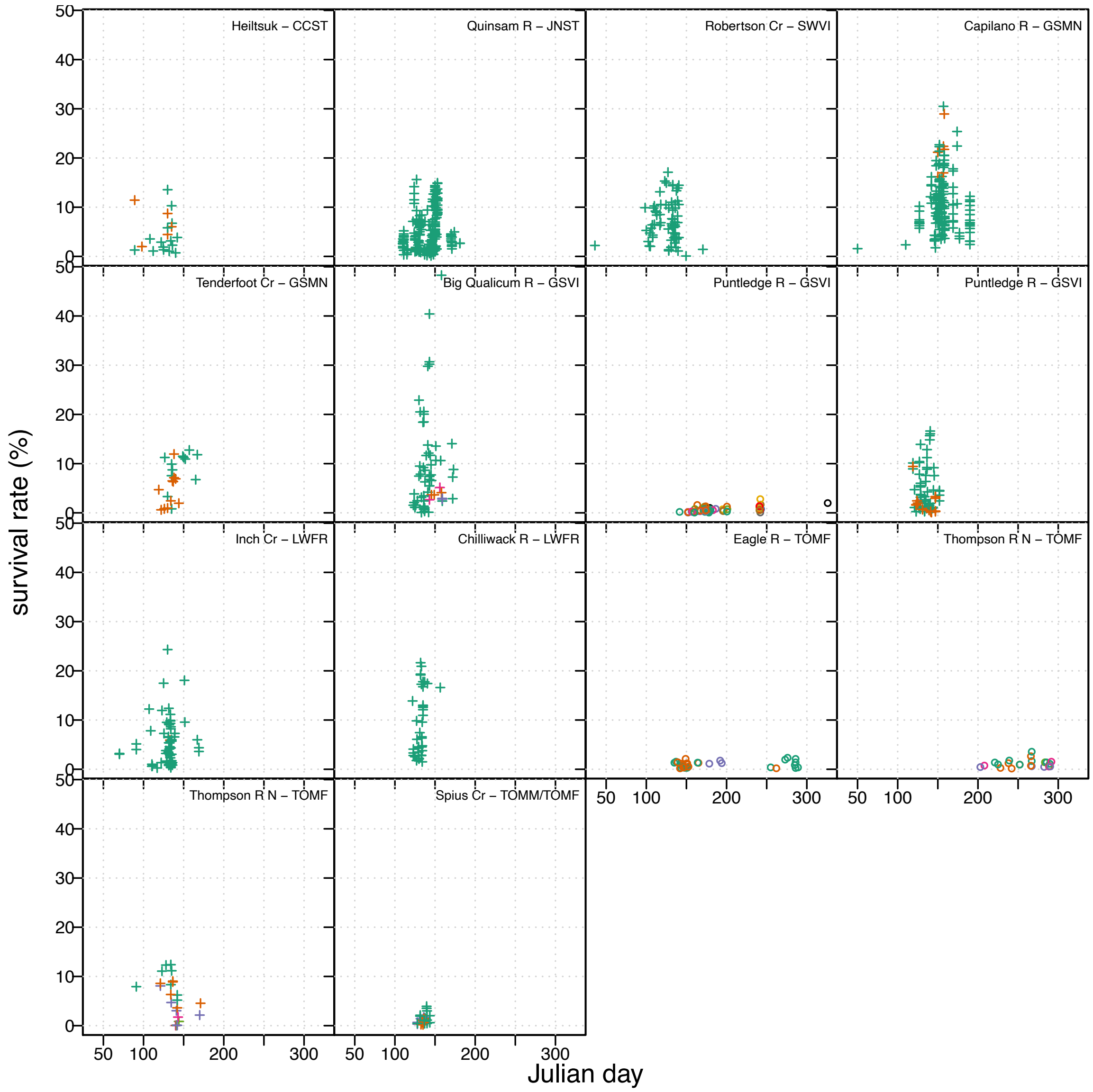


Figure CO.4. Smolt-adult survival rates (%) by Julian day for fry (○) and yearling (+) CWT Coho hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

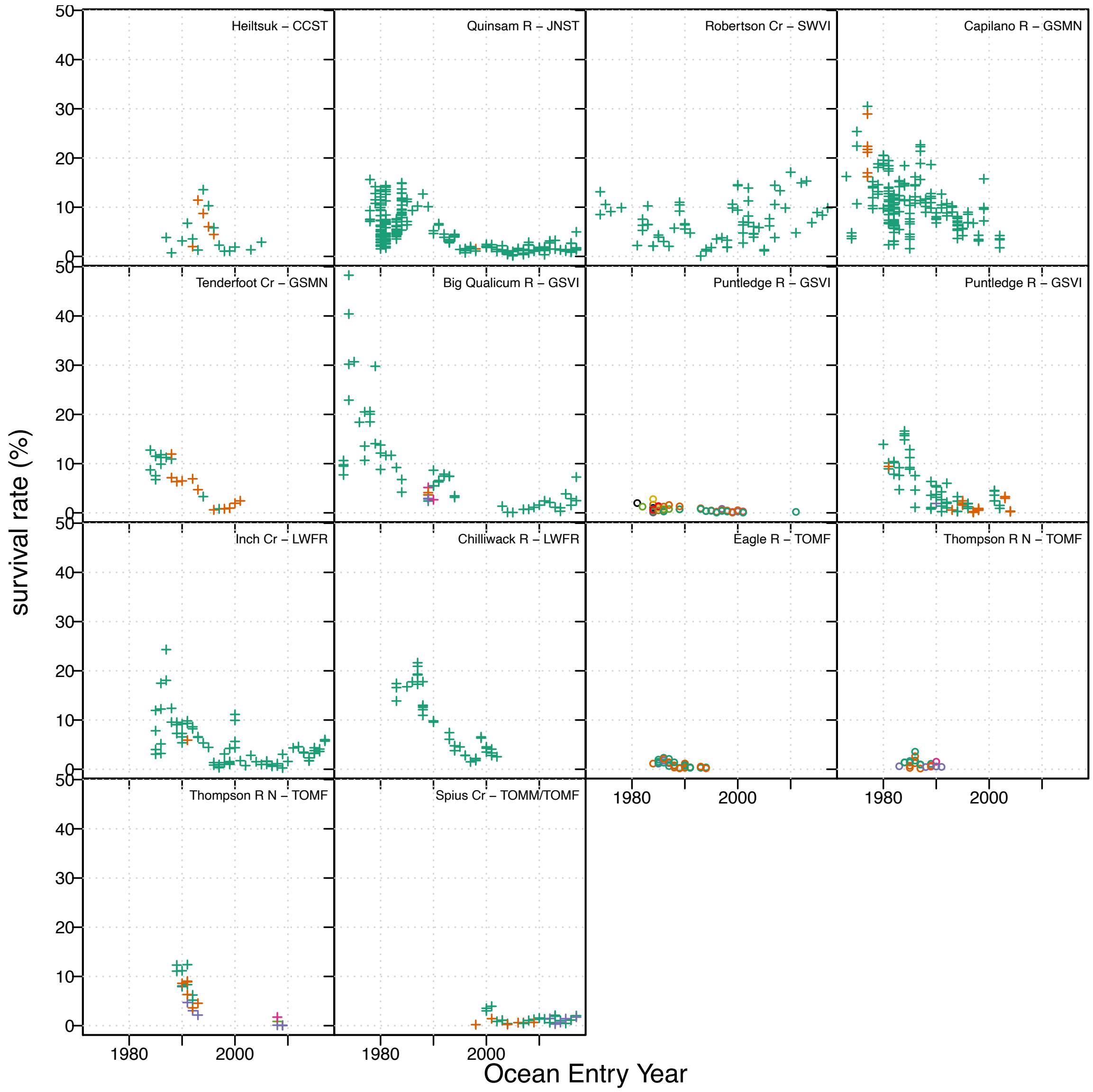


Figure CO.5. Smolt to adult survival rates (%) by ocean entry year for fry (o) and yearling (+) CWT Coho hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

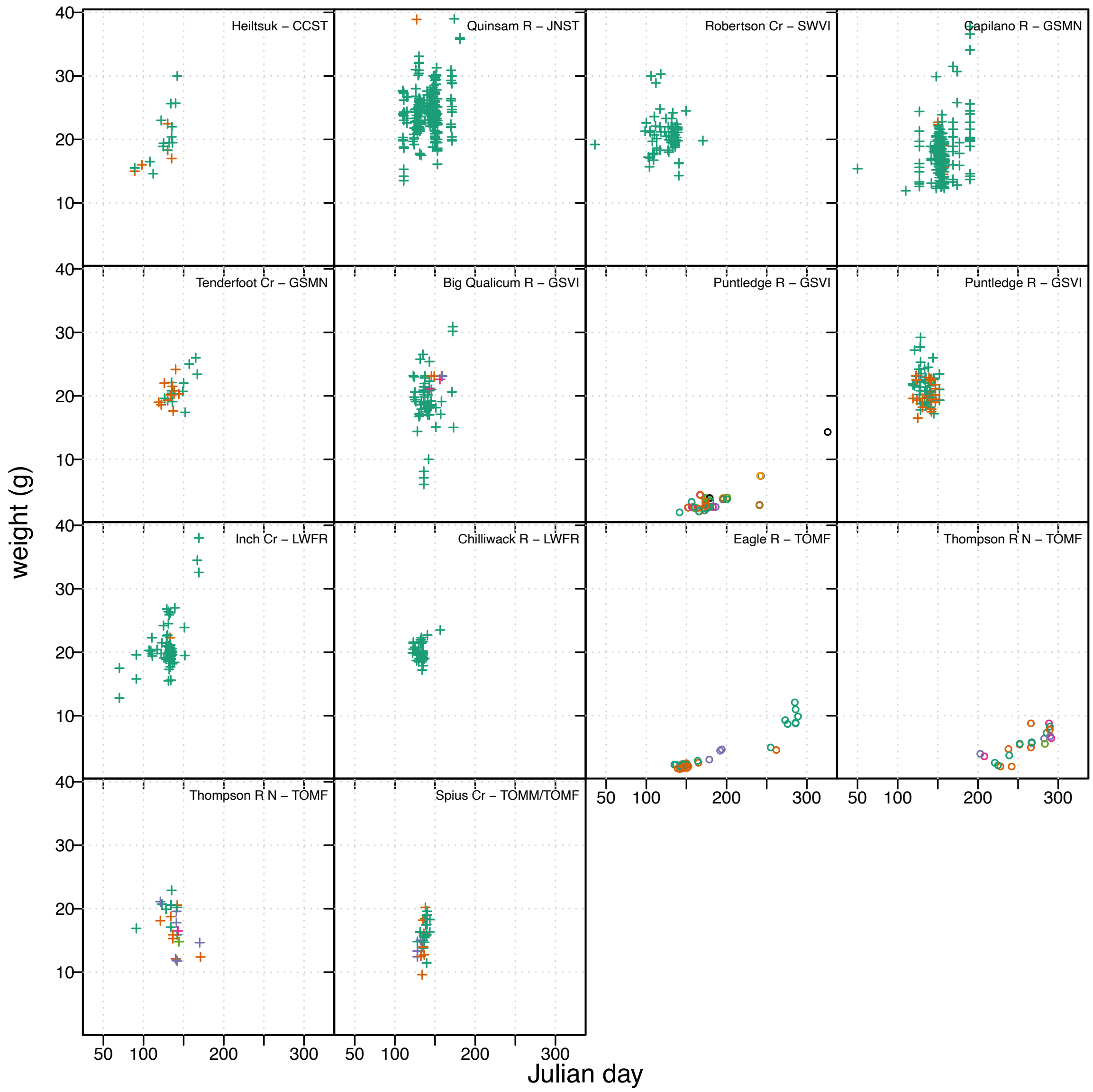


Figure CO.6. Weight-at-release by Julian day for fry (○) and yearling (+) CWT Coho hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

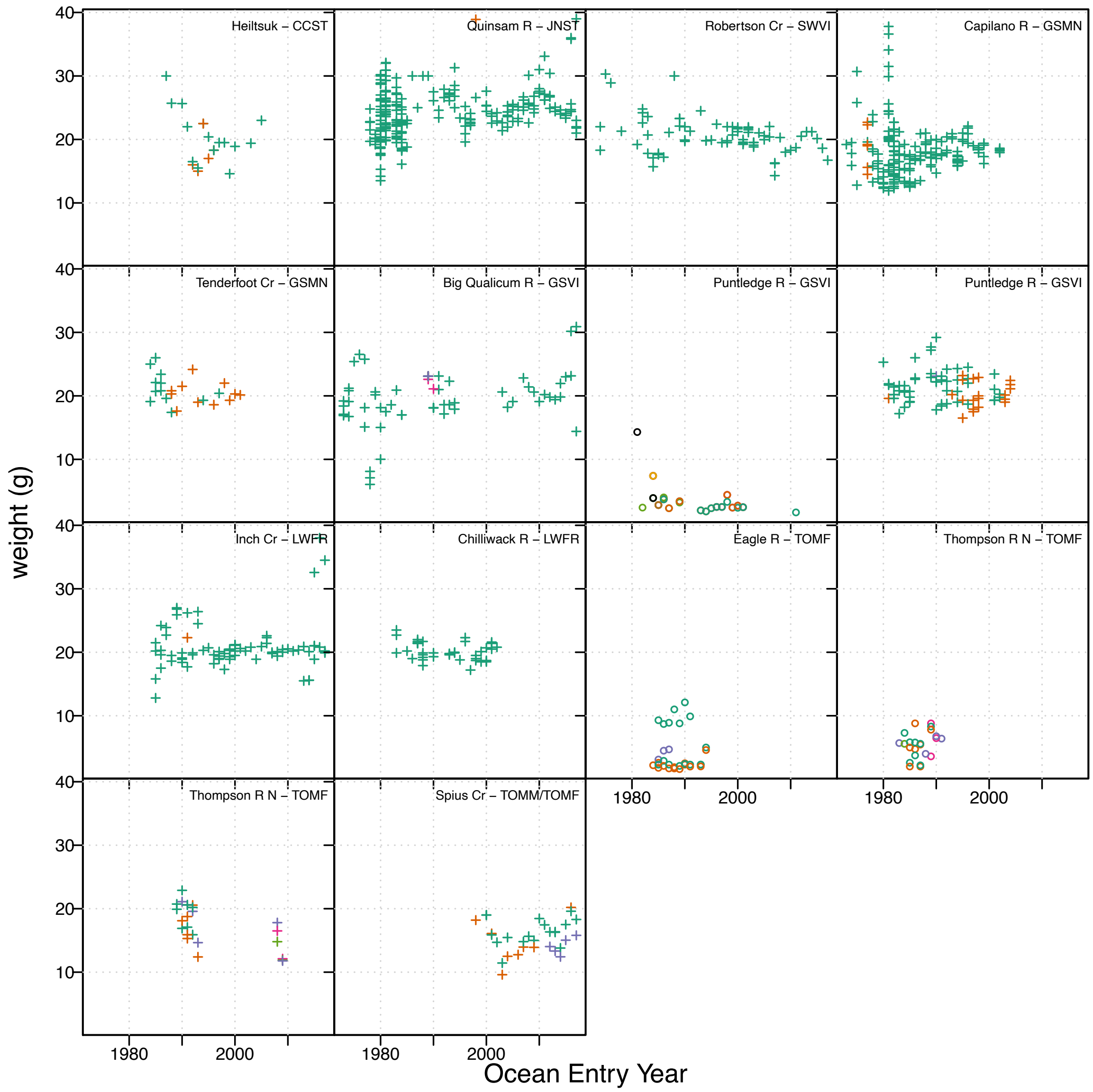


Figure CO.7. Weight-at-release by ocean entry year for fry (O) and yearling (+) CWT Coho hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

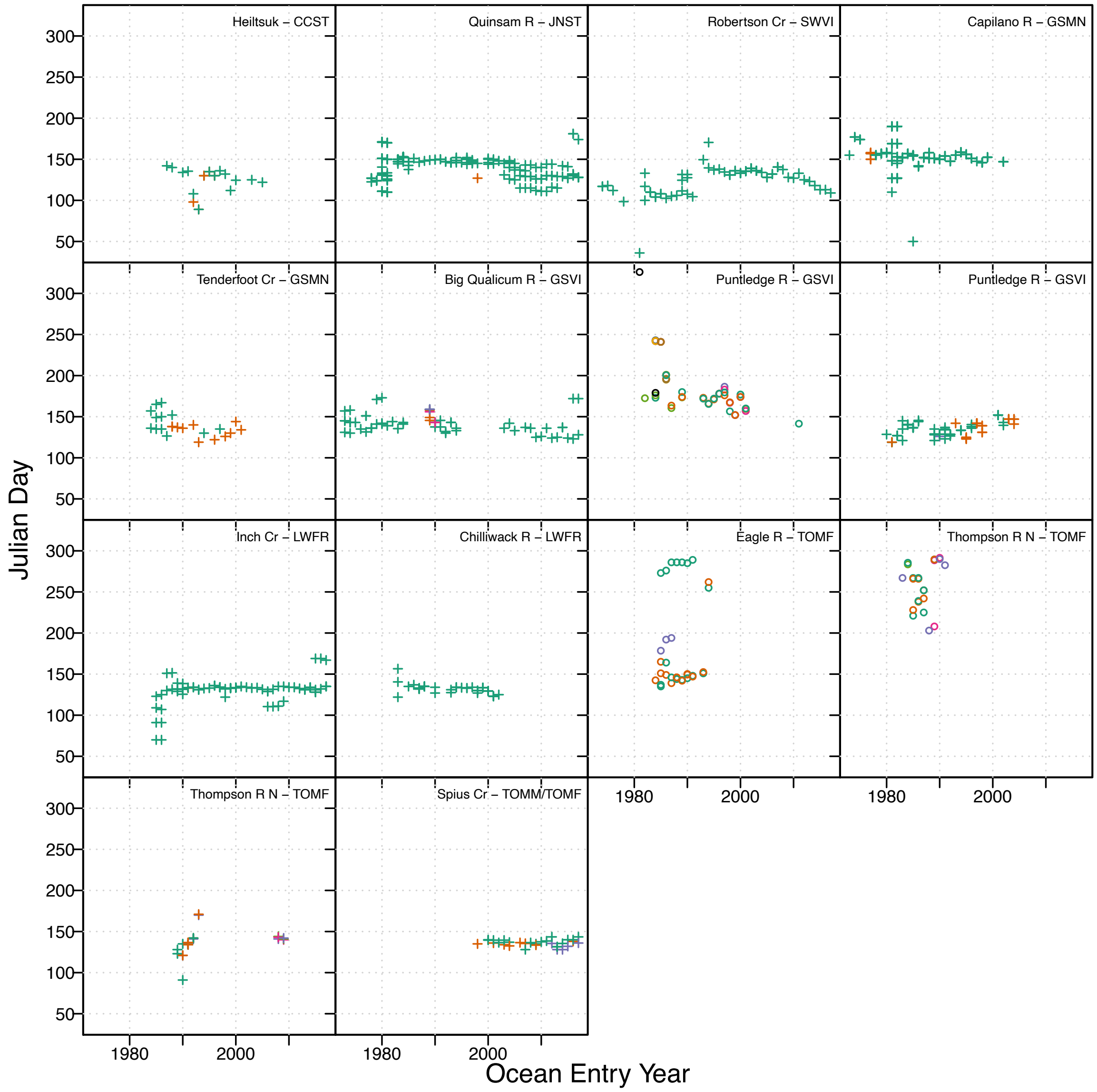


Figure CO.8. Julian day-at-release by ocean entry year for fry (○) and yearling (+) CWT Coho hatchery releases included in **survival model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

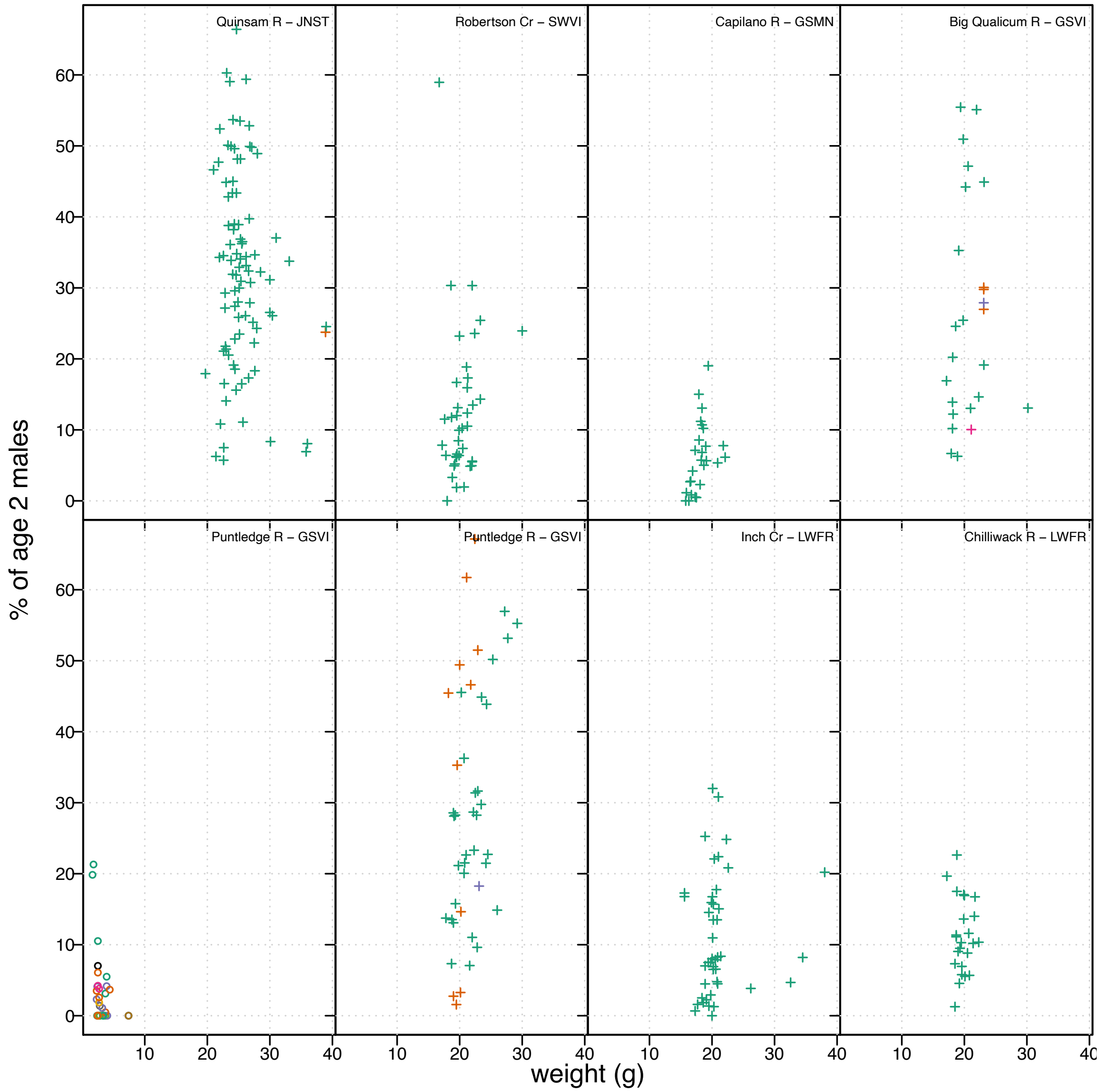


Figure CO.9. Proportion of age-2 males in male returns by weight-at-release for fry (○) and yearling (+) CWT Coho hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

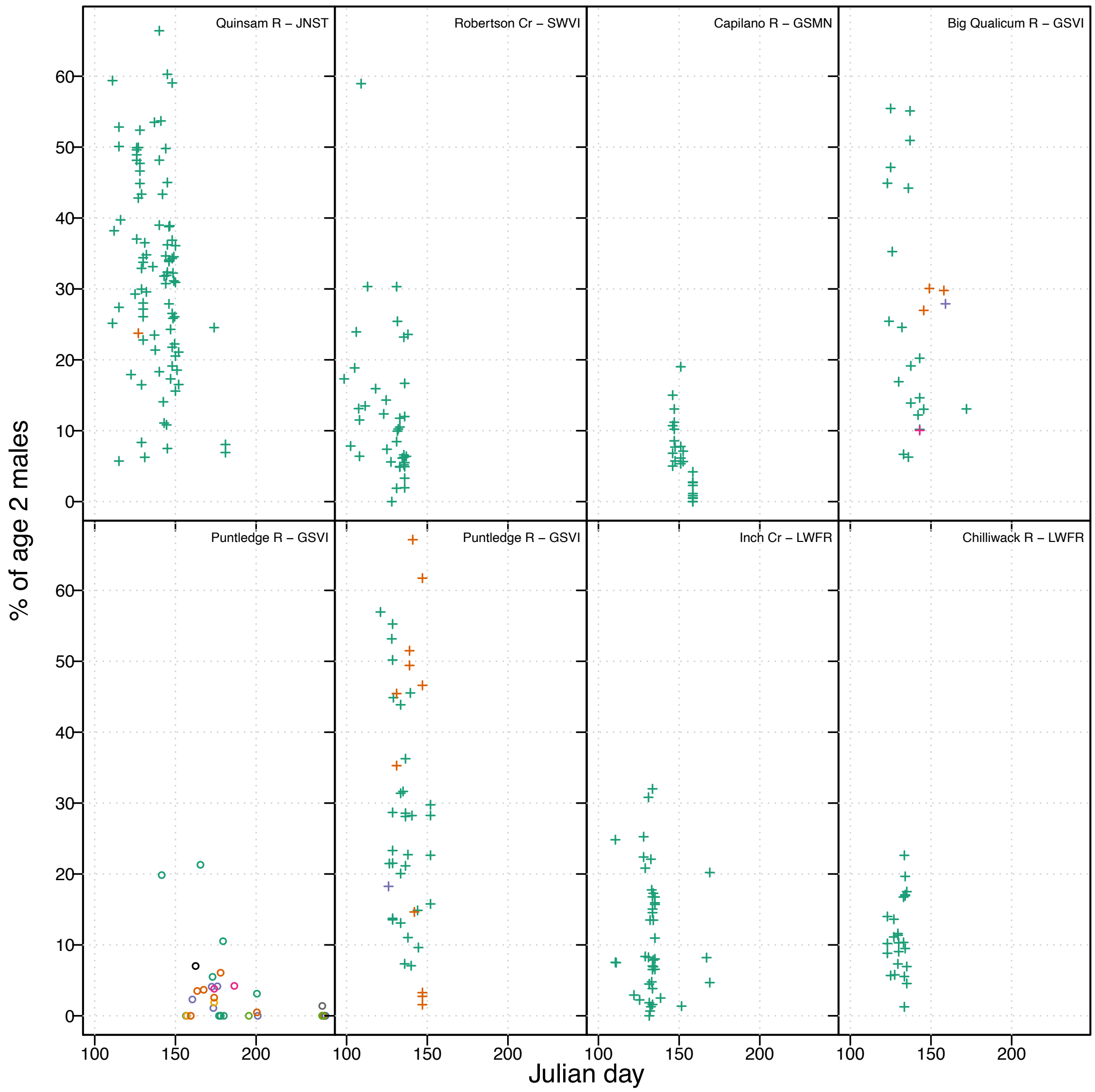


Figure CO.10. Proportion of age-2 males in male returns by Julian day-at-release for fry (O) and yearling (+) CWT Coho hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

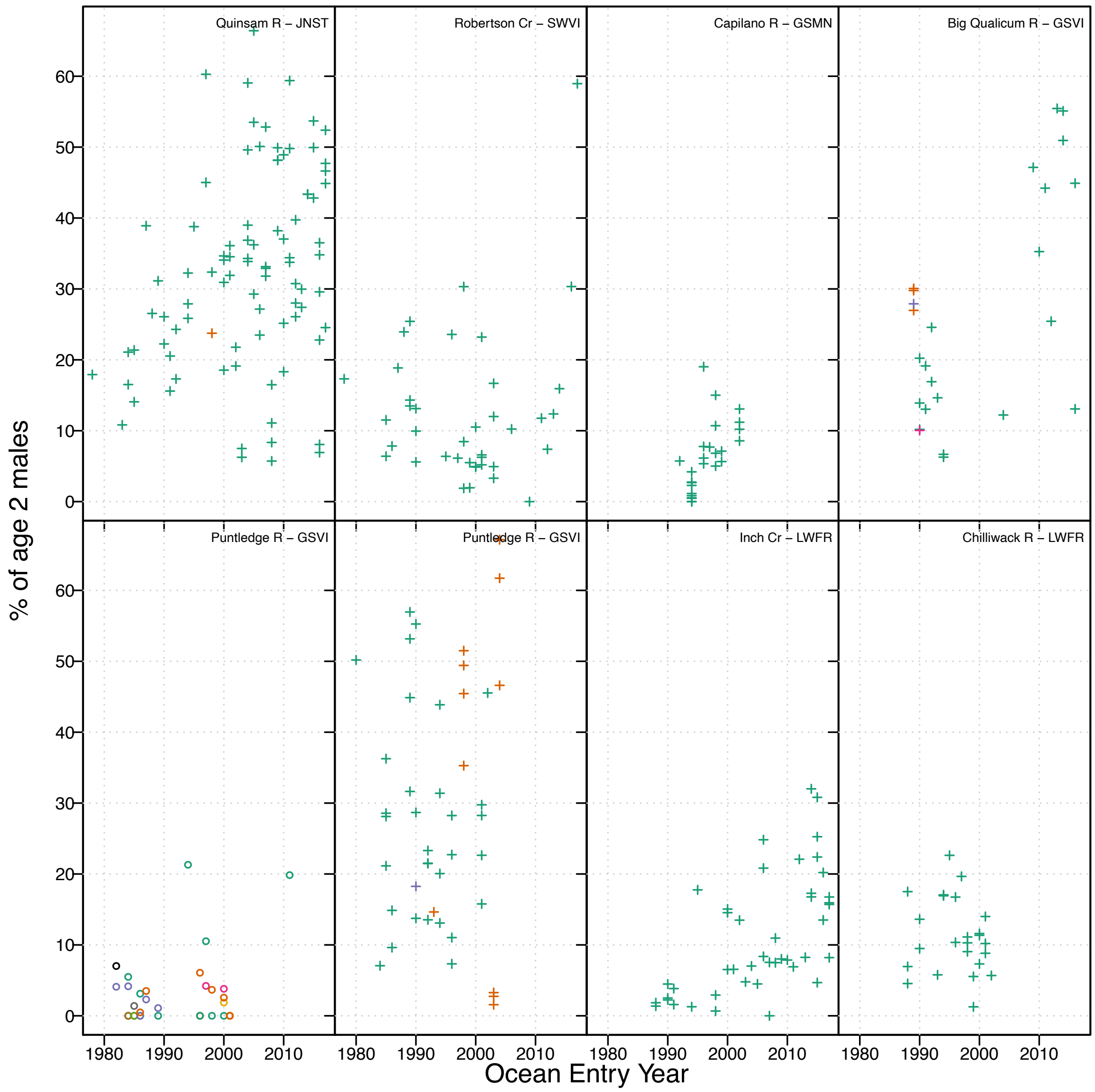


Figure CO.11. Proportion of age-2 males in male returns by ocean entry year for fry (O) and yearling (+) CWT Coho hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

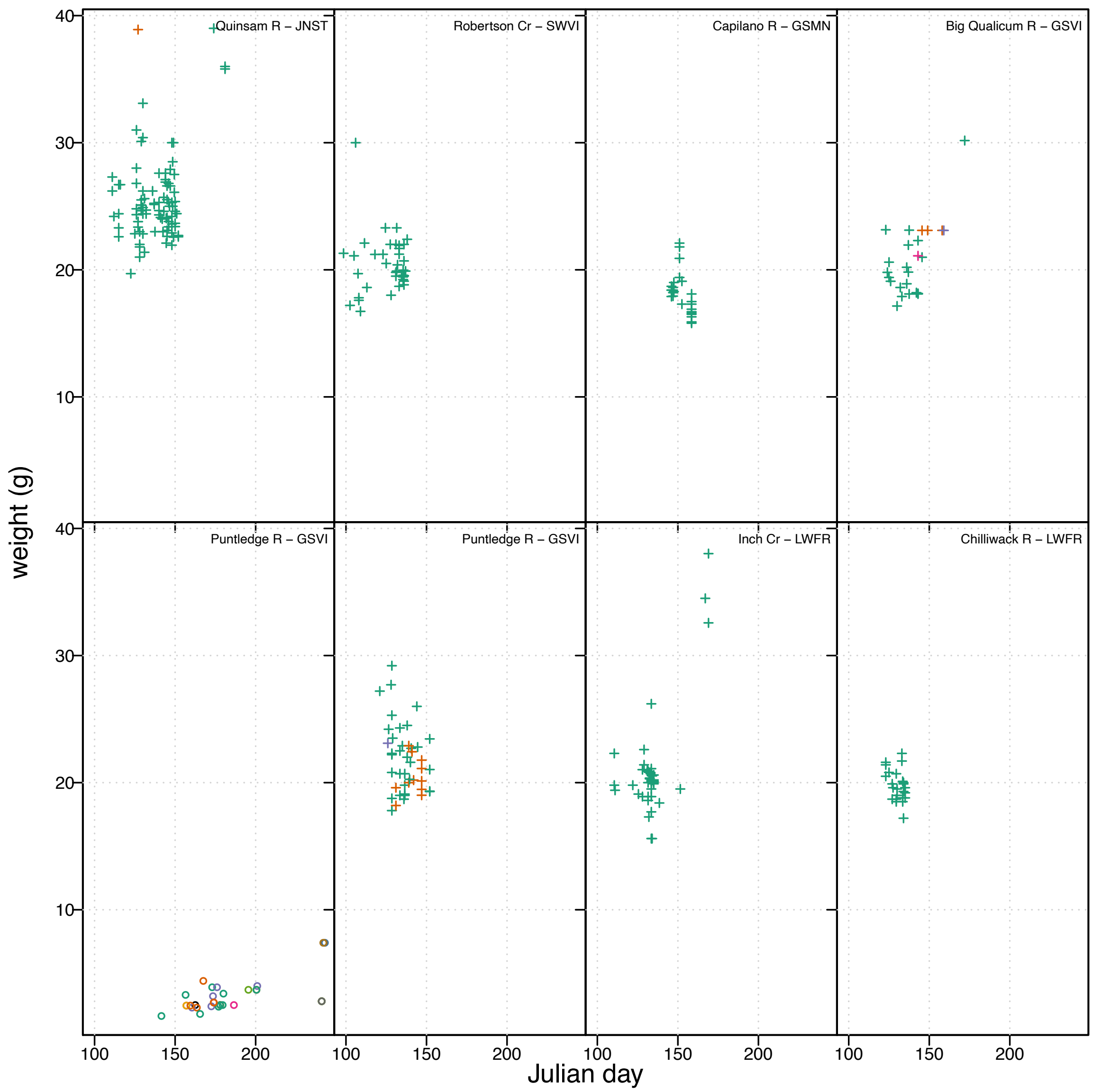


Figure CO.12. Weight-at-release by Julian day for fry (O) and yearling (+) CWT Coho hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

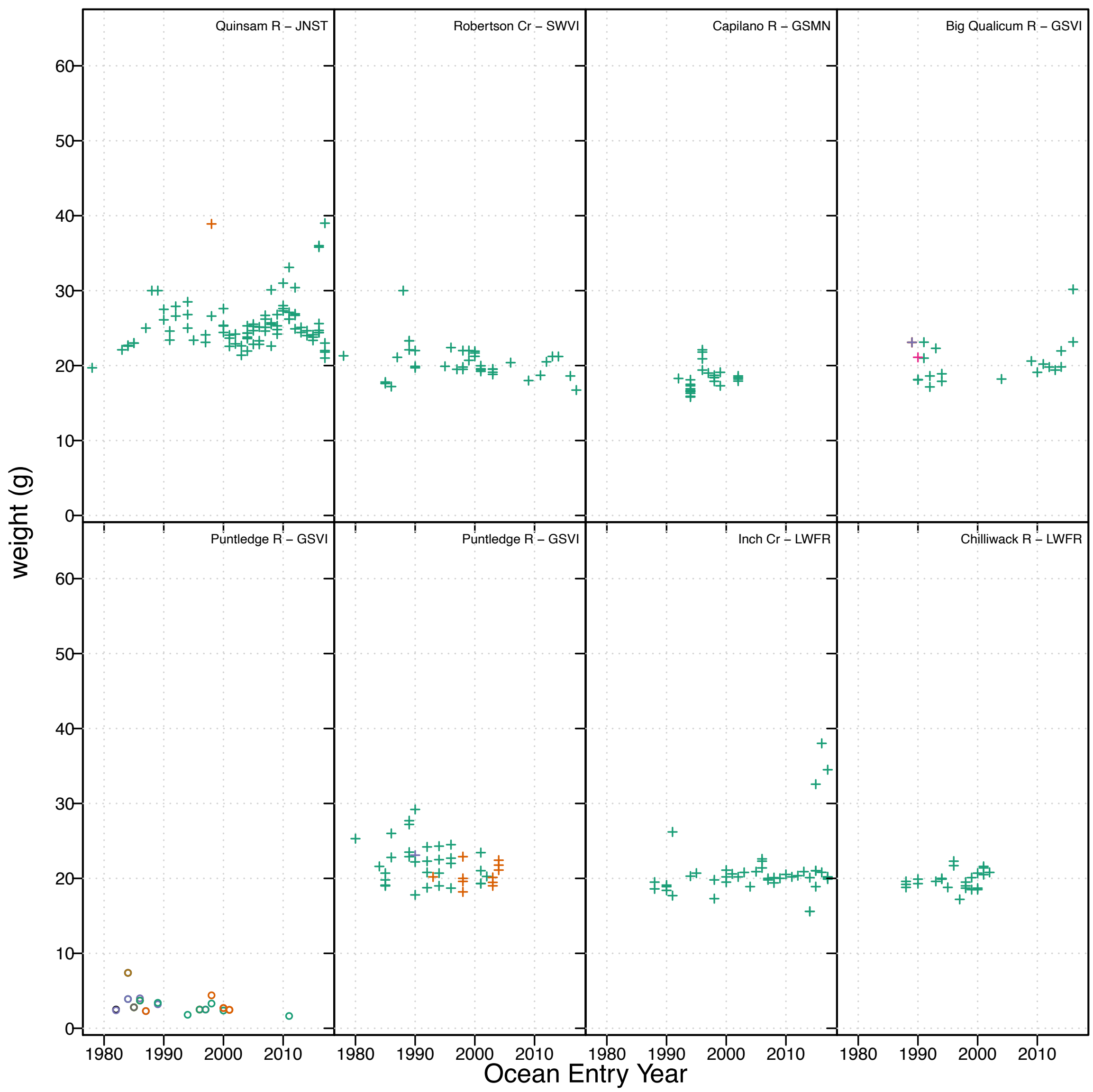


Figure CO.13. Weight-at-release by ocean entry year for fry (O) and yearling (+) CWT Coho hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

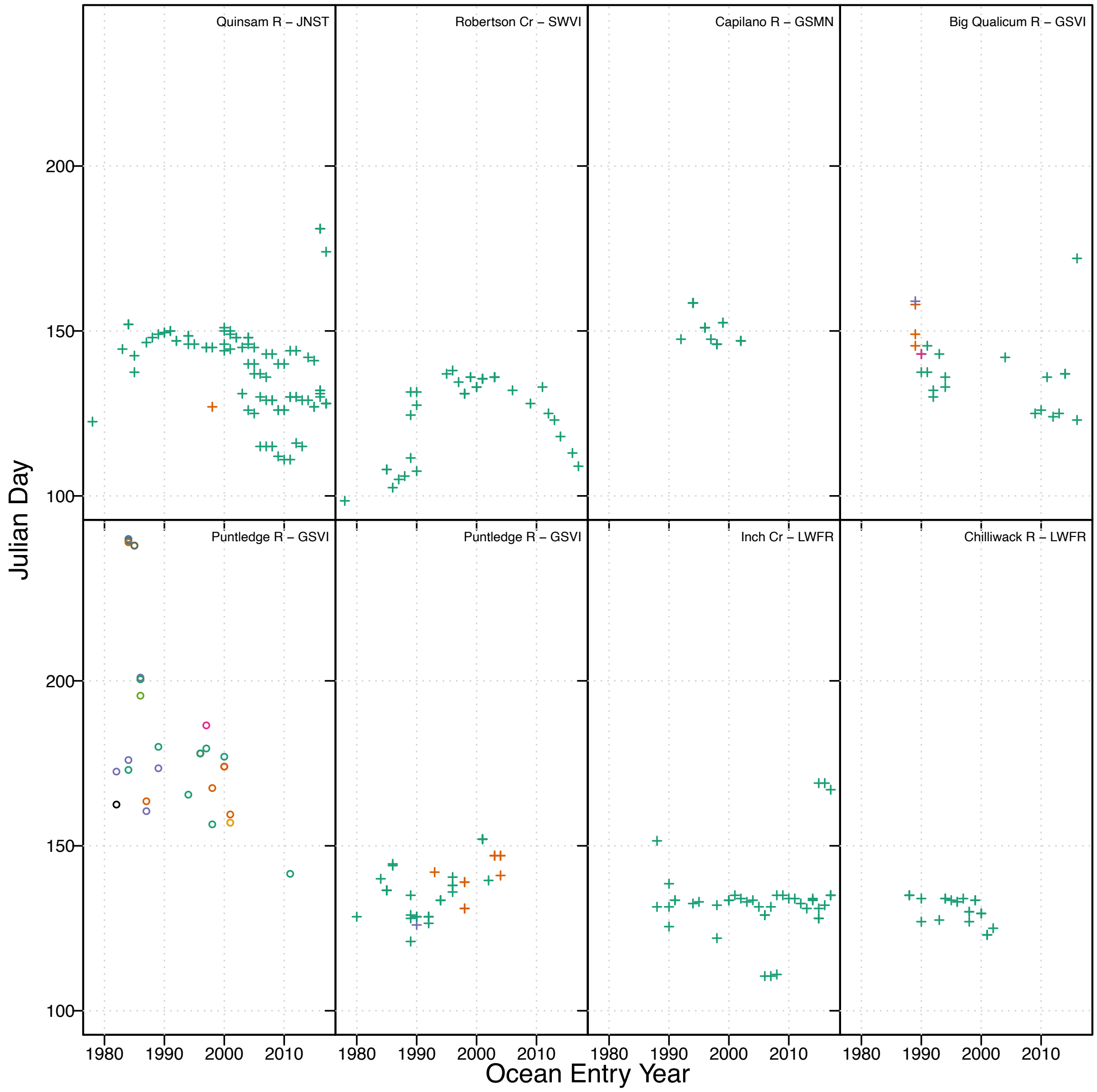


Figure CO.14. Julian day-at-release by ocean entry year for fry (○) and yearling (+) CWT Coho hatchery releases included in **return age model fitting**. Different colors indicate different combinations of stock and release sites for each hatchery with green indicating the most frequent stock released and release site.

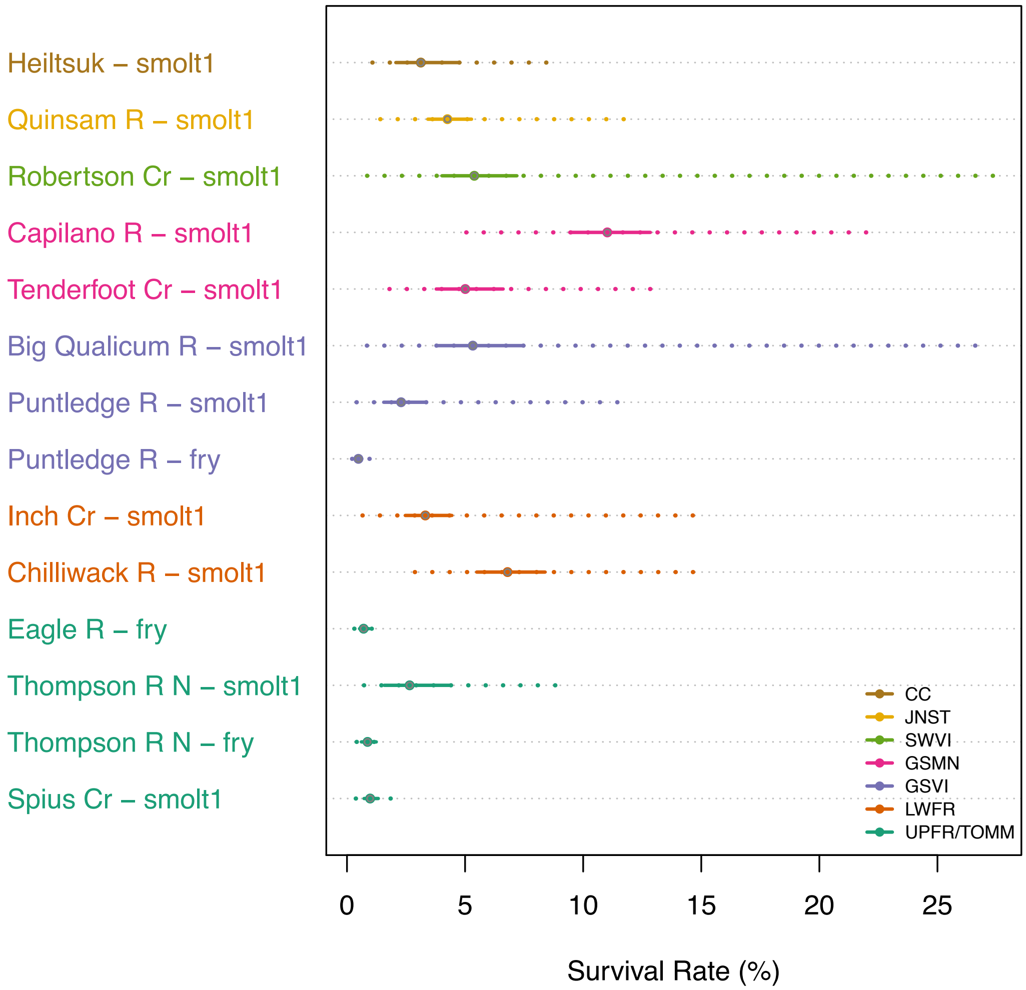


Figure CO.15. Mean Coho **survival** rates and 95% confidence intervals accounting for uncertainty in both fixed and random effects for top model fits for each hatchery. Solid lines indicate uncertainty due to fixed effects, while the dotted lines indicate uncertainty from both fixed and random year effects. The survival rates reflect estimated survival for the average values of covariates. For models with a stock effect (Quinsam River), the survival rates are shown for the most common stock and release site (Quinsam River stock released at Quinsam River).

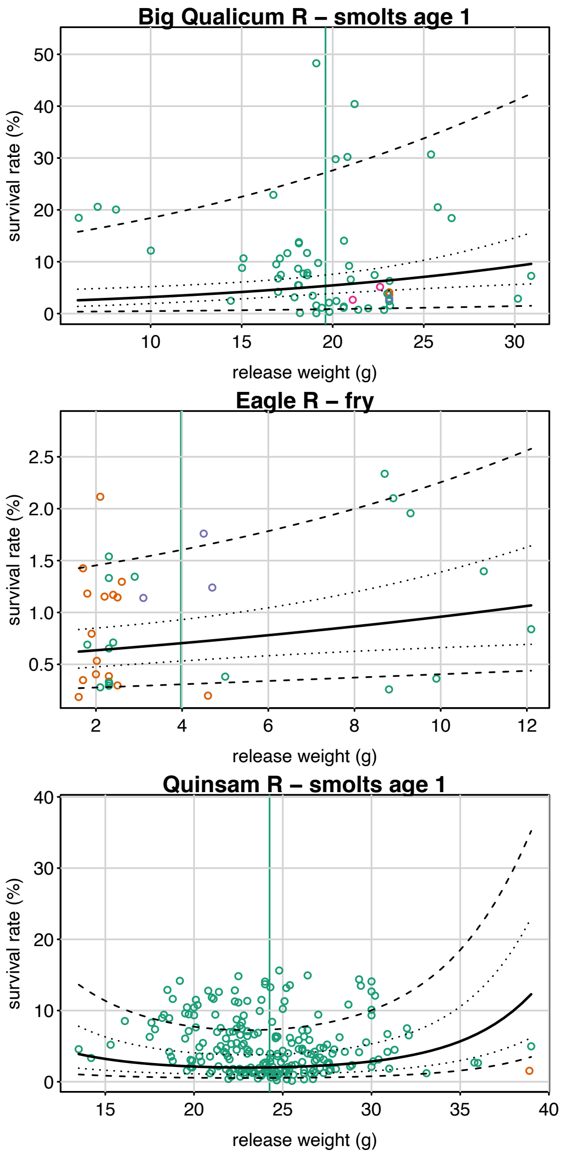


Figure CO.16. Mean **survival** (solid line) for Coho at different release weights for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). Different colours indicate different combinations of stocks and release sites for each hatchery, while the solid green vertical line indicates the mean weight-at-release. Hatcheries without *Weight* effects in top models are not shown.

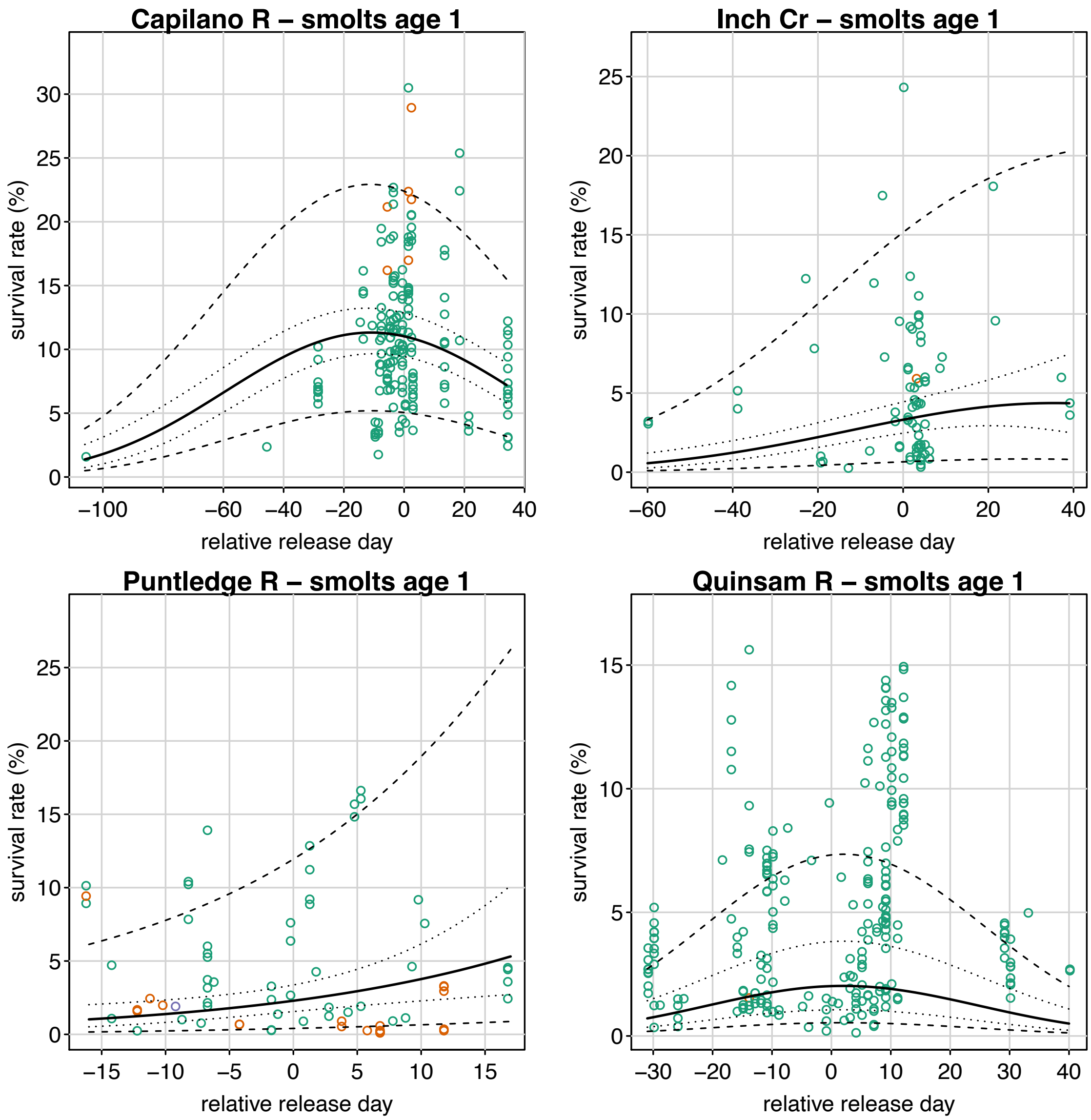


Figure CO.17. Mean **surviva**l (solid line) for Coho at release days for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). The zero day indicates the mean release date for a hatchery, while different colours indicate different combinations of stocks and release sites. Hatcheries without *Day* effects in top models are not shown. Hatcheries without *Day* effects in top models are not shown.

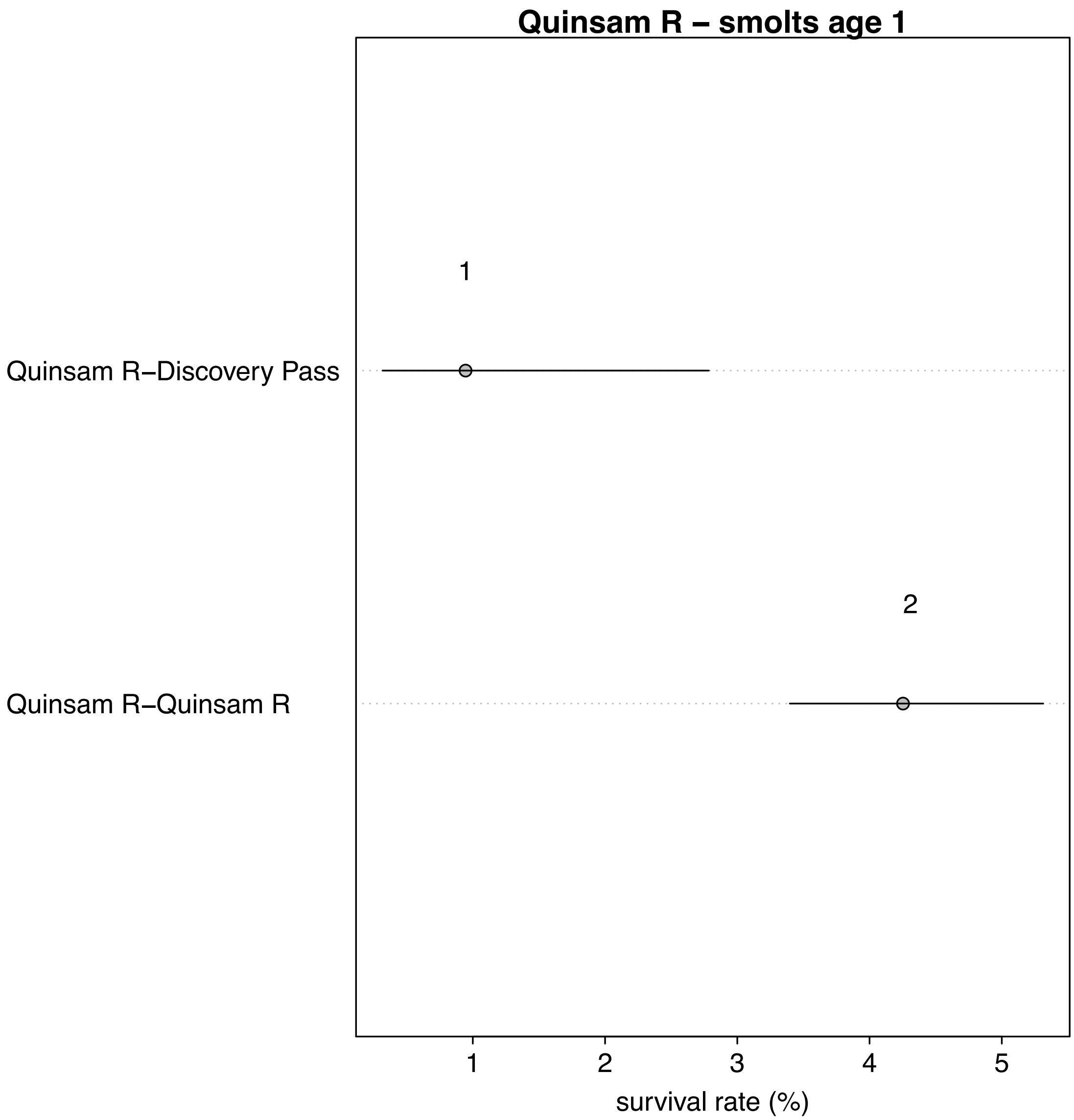


Figure CO.18. Estimated marginal mean Coho **survival** rates for Quinsam River Hatchery yearling releases at Quinsam River and Discovery Pass seapen. Quinsam River hatchery was the only the Coho survival model that included a release site effect in the top model. The numbers indicate groups whose survival rates are significantly different from one another (i.e., group 1 is different from group 2, but there is no difference between group 12 and 1 or group 12 and 2). Error bars are shown for 95% confidence intervals. The y-axis shows the stock released (Quinsam River) followed by a dash and the release site. Release site locations are shown in Appendix B.

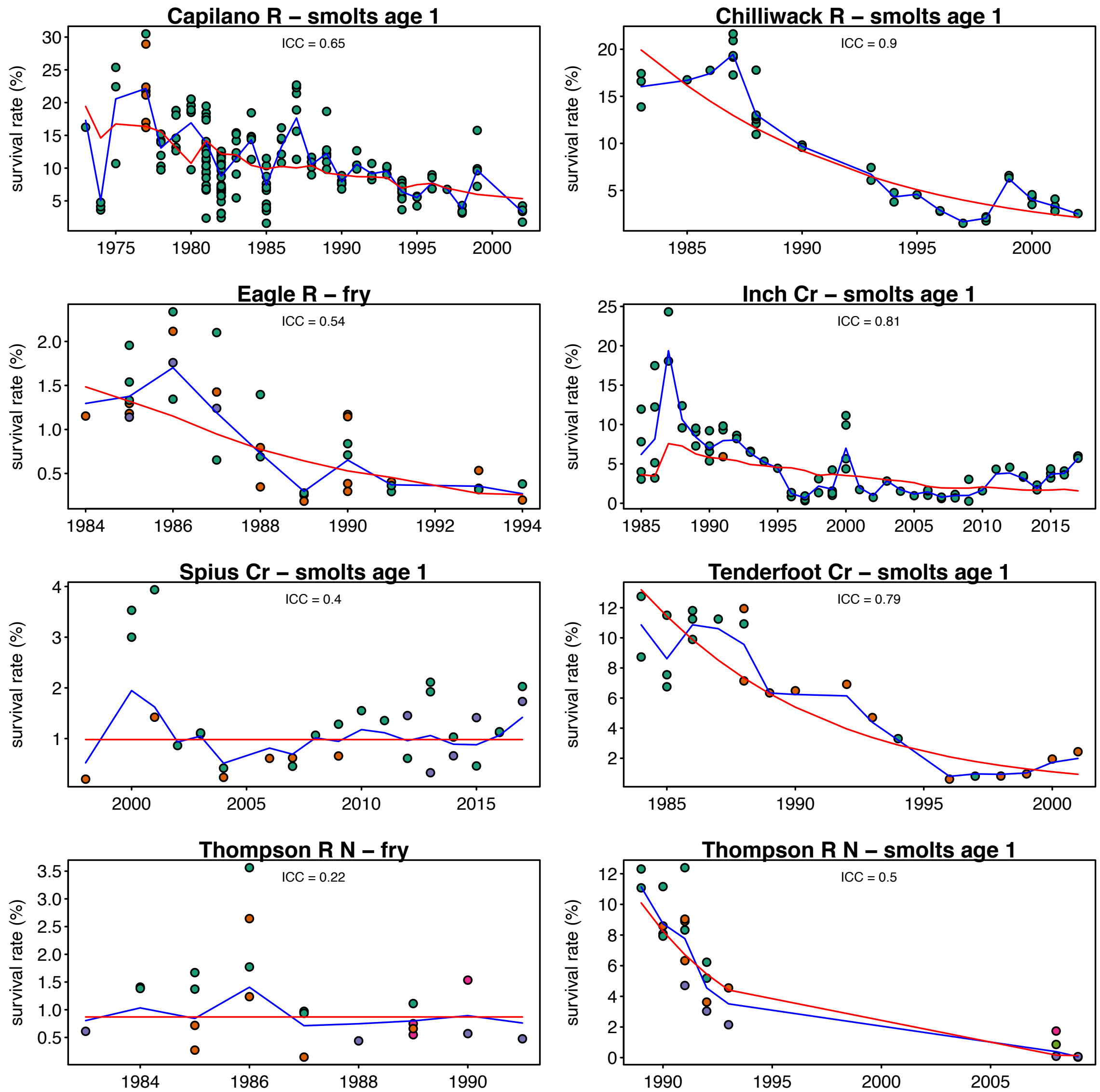


Figure CO.19. Top model fits for Mainland BC hatcheries' average Coho **survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects. Different colors indicate different combinations of stocks and release sites for each hatchery with green indicating the most frequent stock released and release site.

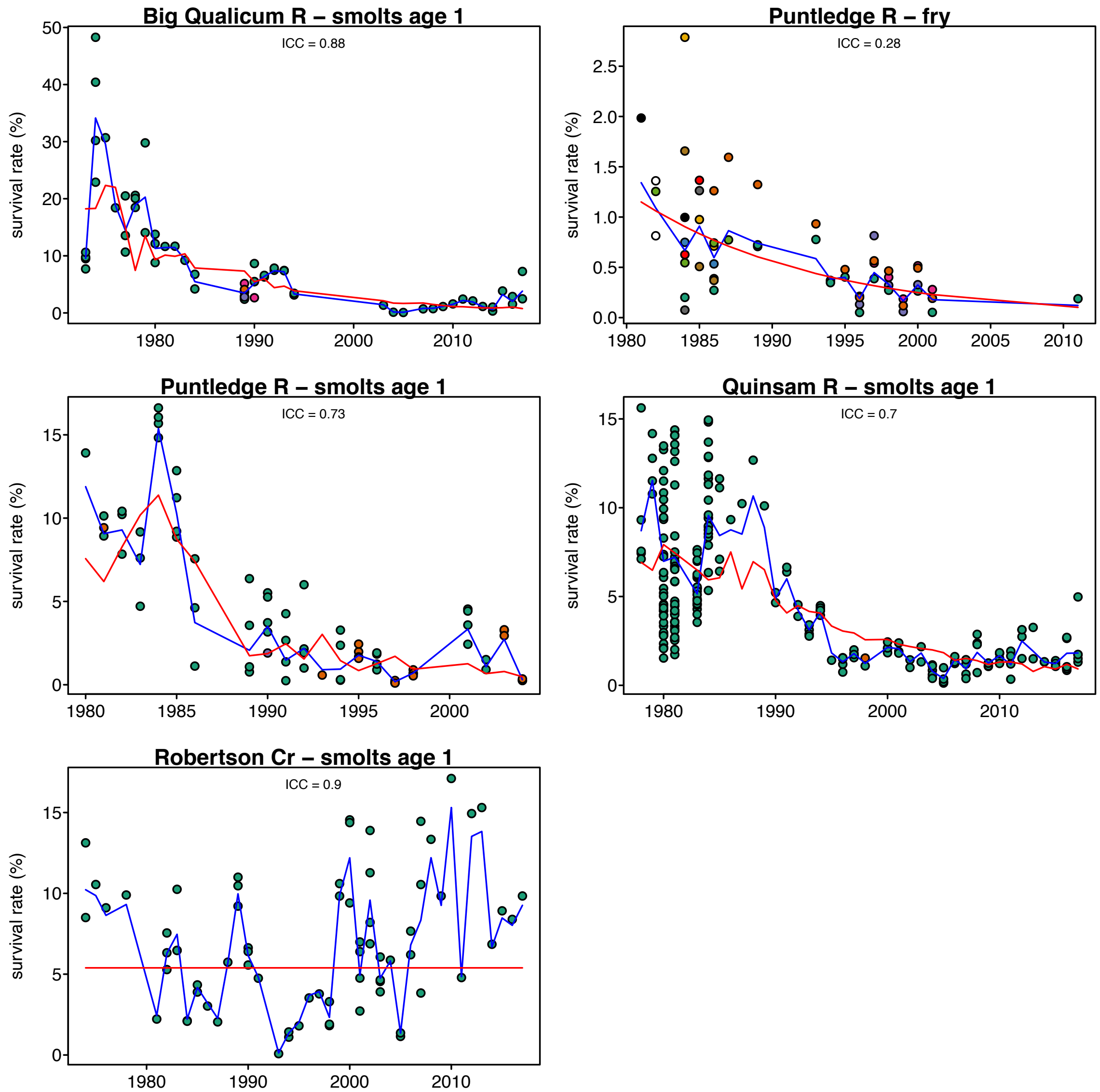


Figure CO.20. Top model fits for Vancouver Island hatcheries' average Coho **survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects. Different colors indicate different combinations of stocks and release sites for each hatchery with green indicating the most frequent stock released and release site.

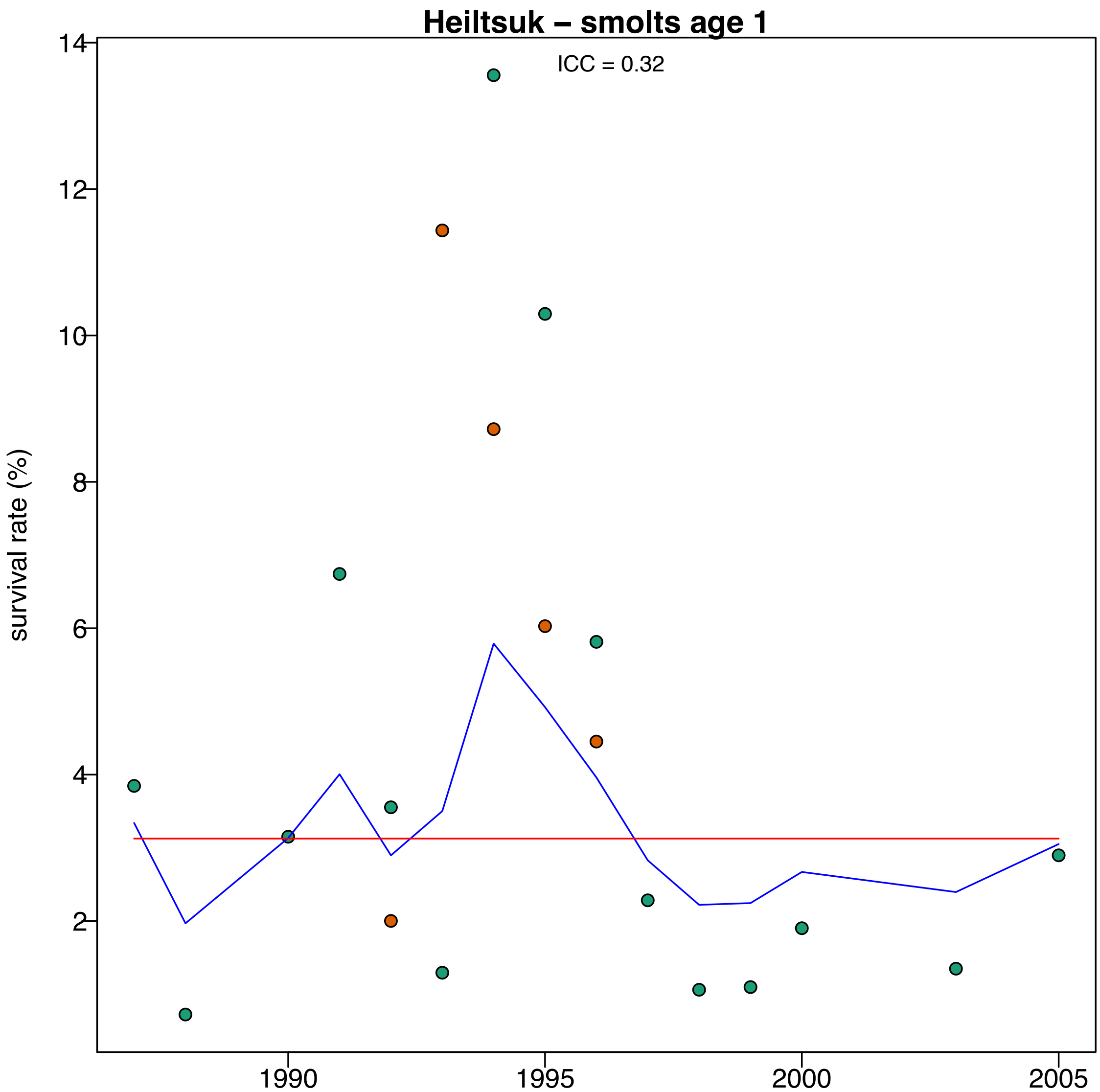


Figure CO.21. Top model fits for Northern BC hatcheries' average Coho **survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects. Different colors indicate different combinations of stocks and release sites for each hatchery with green indicating the most frequent stock released and release site.

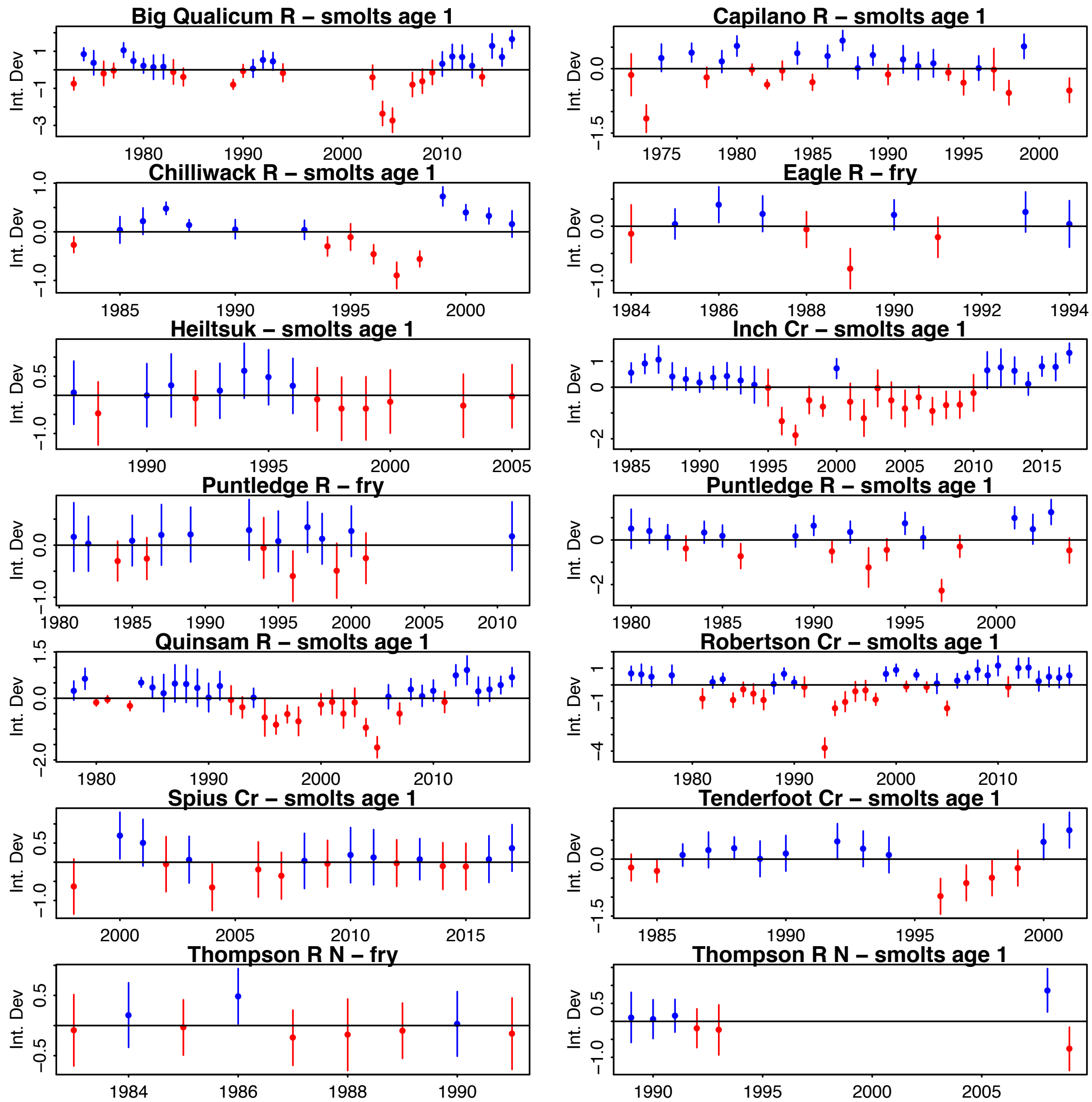


Figure CO.22. The ocean entry year-effect deviation in average Coho logit **survival** (i.e., Δ_t) for each hatchery and life-stage model. Negative (red) values indicate a year effect below the average and positive (blue) values indicate a year effect above the average.

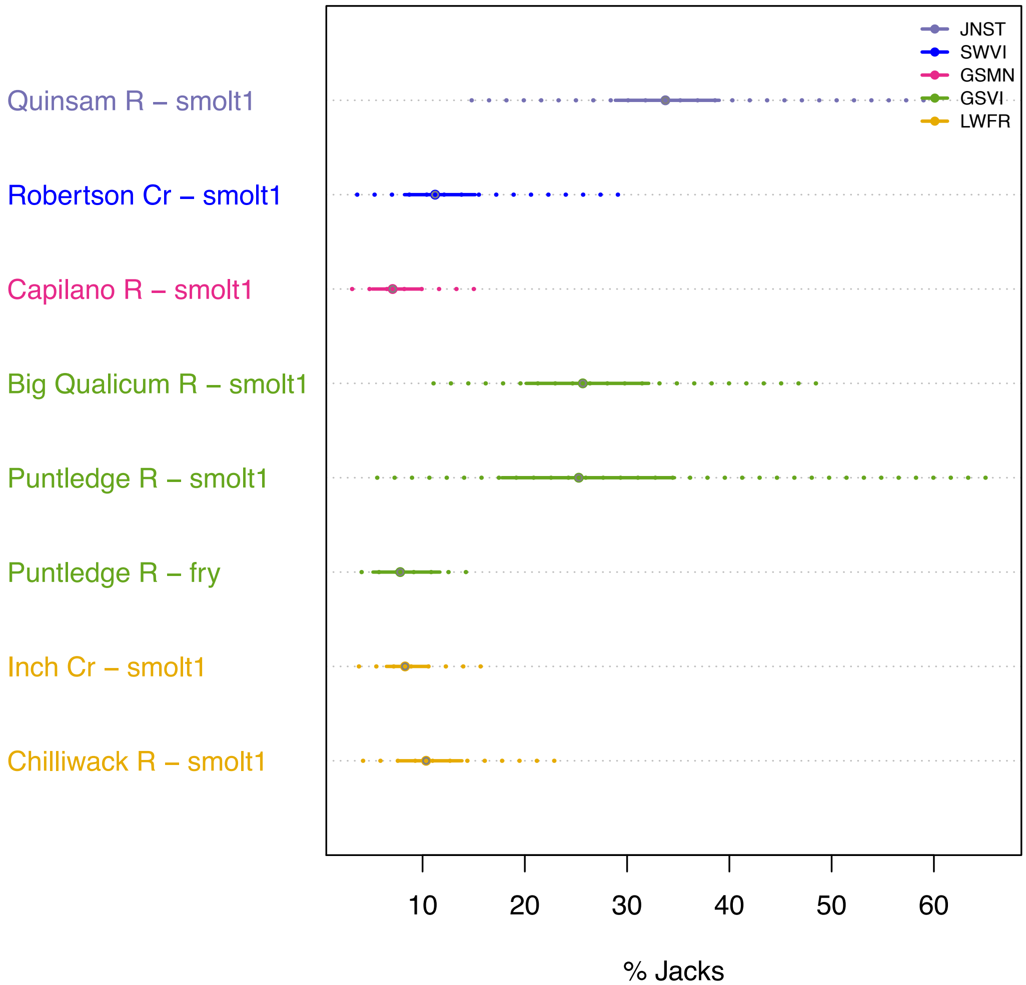


Figure CO.23. Mean **% of age-2 males** in Coho returns and 95% confidence intervals accounting for uncertainty in both fixed and random effects for top model fits for each hatchery. Solid lines indicate uncertainty due to fixed effects, while the dotted lines indicate uncertainty from both fixed and random year effects.

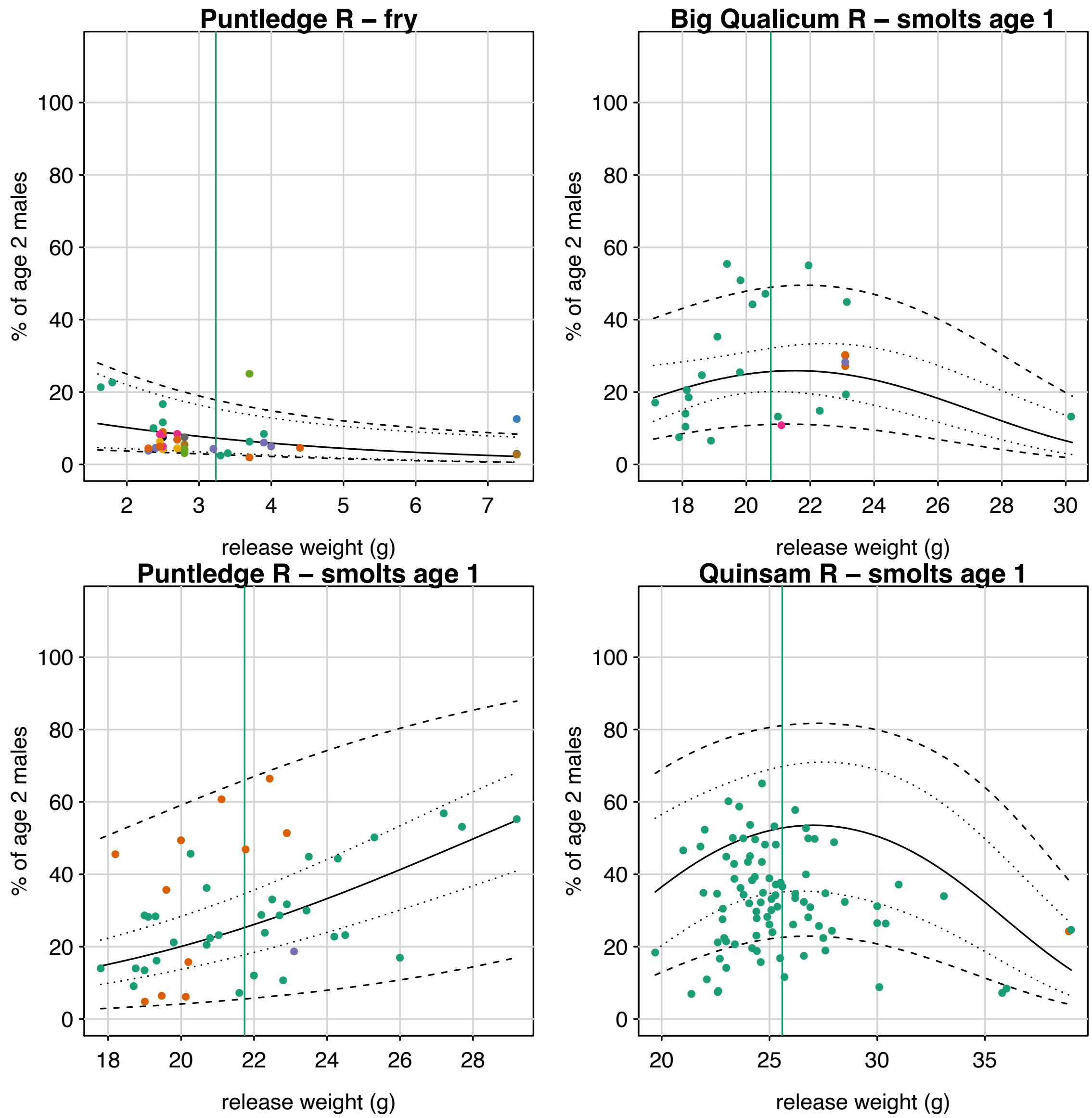


Figure CO.24. Mean **% of age-2 male returns** (solid line) for Coho at different release weights for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). Different colours indicate different combinations of stocks and release sites for each hatchery, while the solid green vertical line indicates the mean weight-at-release. Hatcheries without *Weight* effects in top models are not shown.

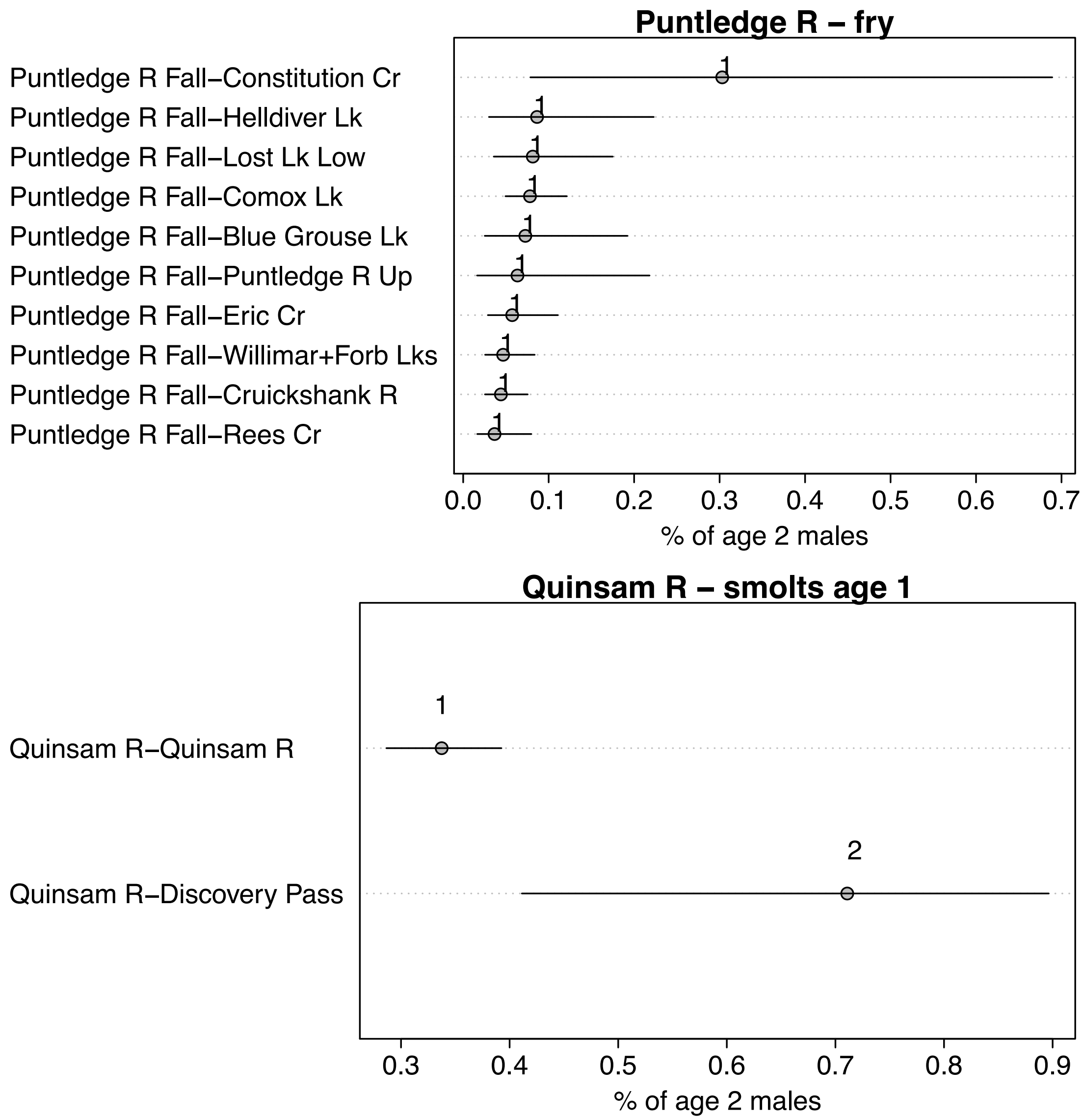


Figure CO.25. Estimated marginal mean **% of age-2 males** in Coho returns for Quinsam and Puntledge hatchery yearling releases. The numbers indicate groups where the proportion of Jacks are significantly different from one another (i.e., group 1 is different from group 2). Error bars are shown for 95% confidence intervals of fixed effects. The y-axis shows the stock released followed by a dash and the release site. Discovery pass is a seapen release site.

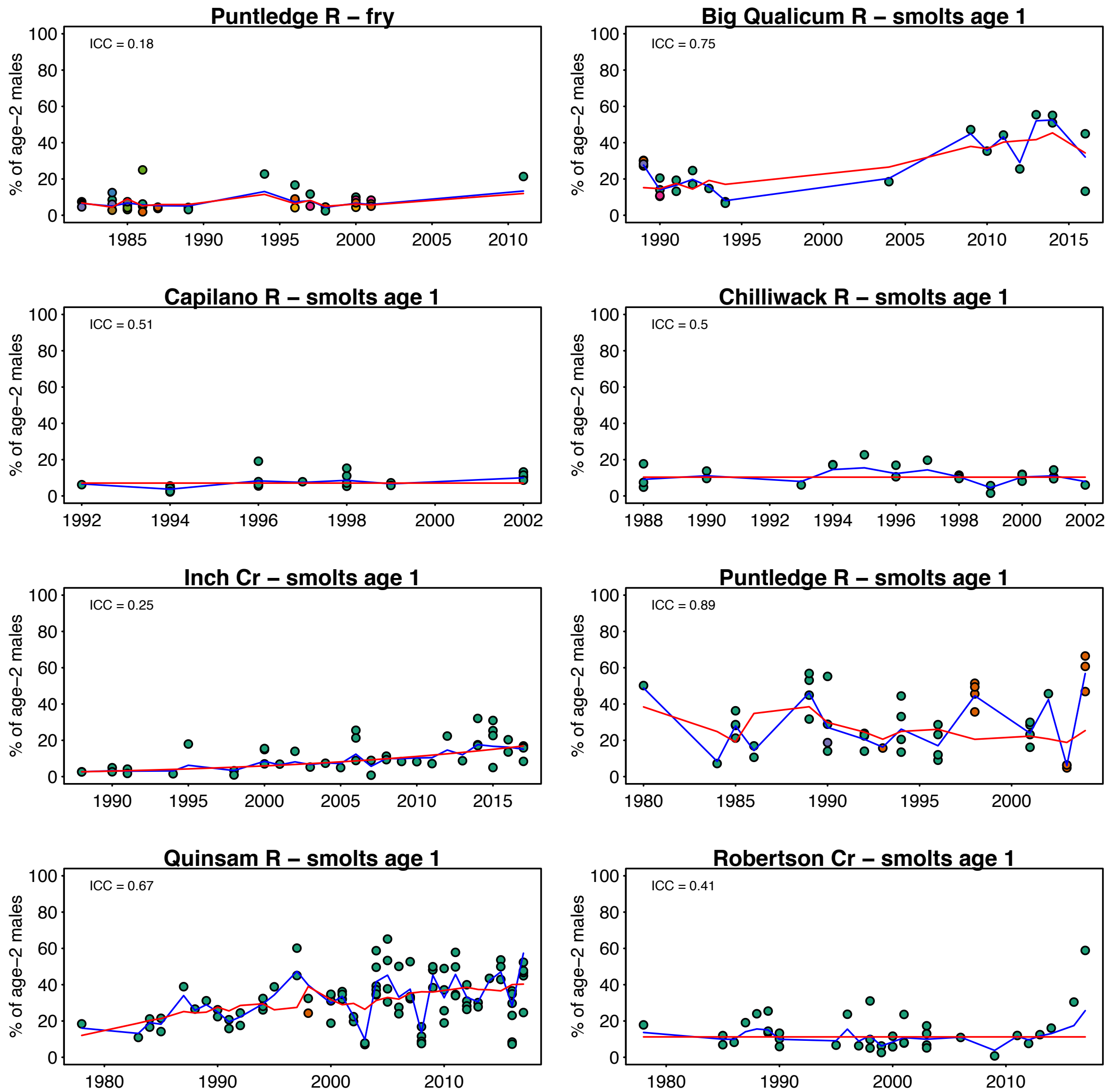


Figure CO.26. Top model fits for BC hatcheries' mean **% of age-2 males** in Coho returns over time, accounting for all predictors (e.g. weight, proportion of females, stock and release site) with (blue) and without (red) random year effects. Different colors indicate different combinations of stocks and release sites for each hatchery with green indicating the most frequent stock released and release site.

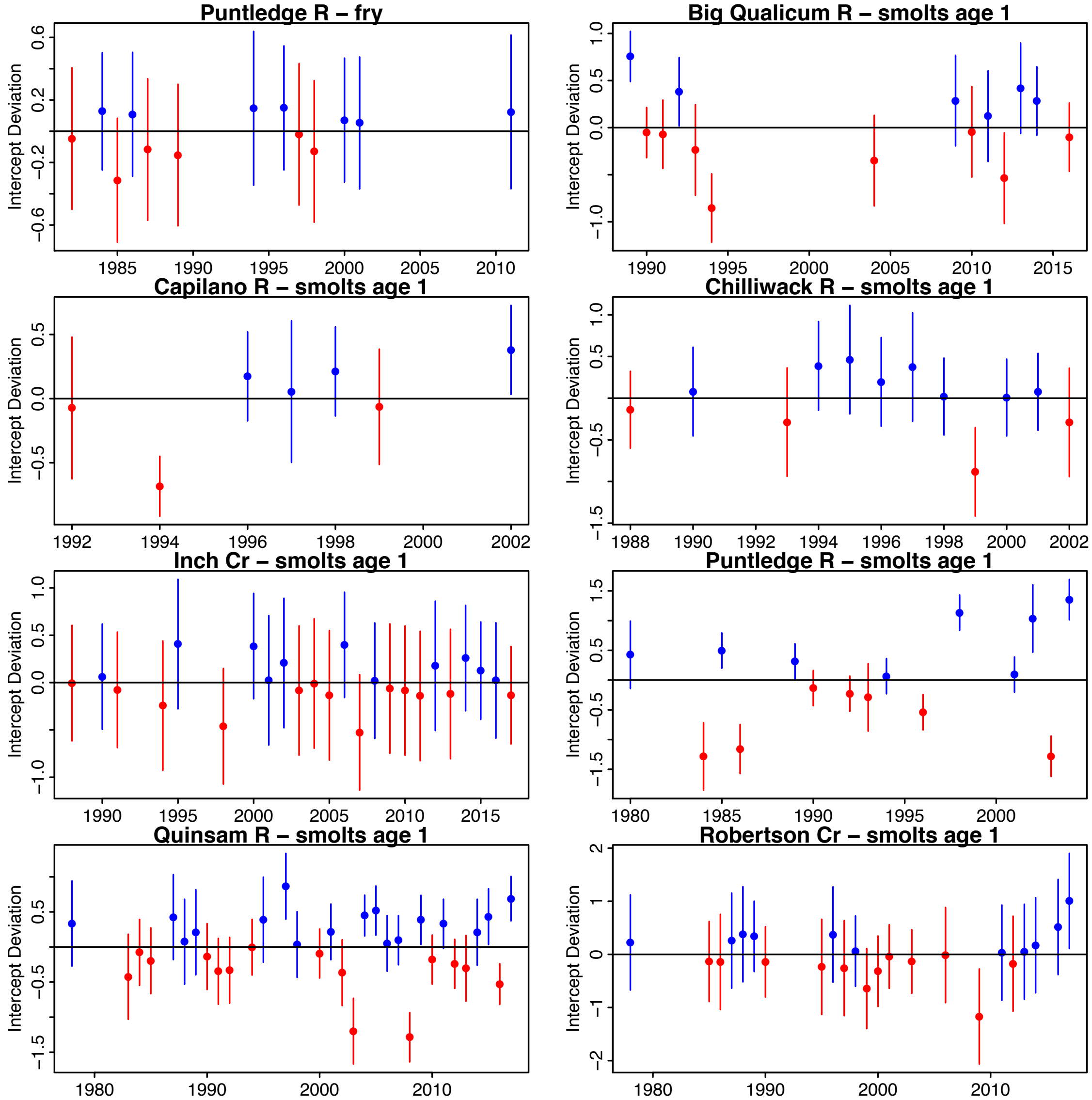


Figure CO.27. The ocean entry year-effect deviation in average **% of age-2 males** in Coho returns (i.e., Δ_t) for each hatchery and life-stage model. Negative (red) values indicate a year effect below the average and positive (blue) values indicate a year effect above the average.

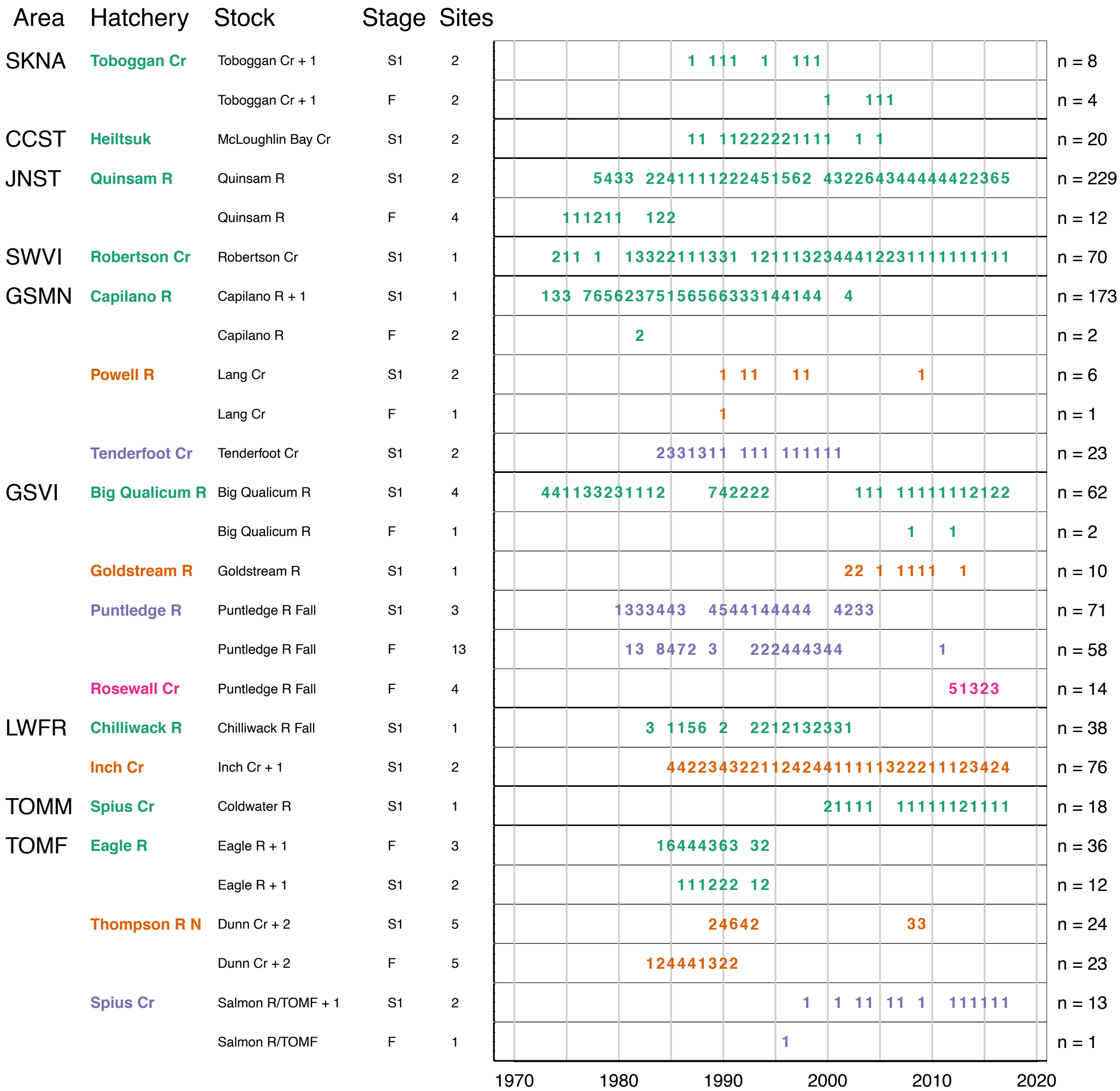


Figure CO.28: Coho CWT fry (F) and yearling smolt (S1) releases by ocean entry year used for fitting multi-hatchery survival models with multiple life-stages. Releases are grouped by hatchery and release site sub-areas (CCST=Central Coast, RIVR=Rivers inlet, SKNA = Skeena River, JNST= Johnstone Strait, SWVI=Southwest Vancouver Island, GSMN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, UPFR = Upper Fraser, LWFR = Lower Fraser, TOMM= Lower Thompson, TOMF= Upper Thompson). Different colours are used to distinguish different hatchery releases in each sub-area.

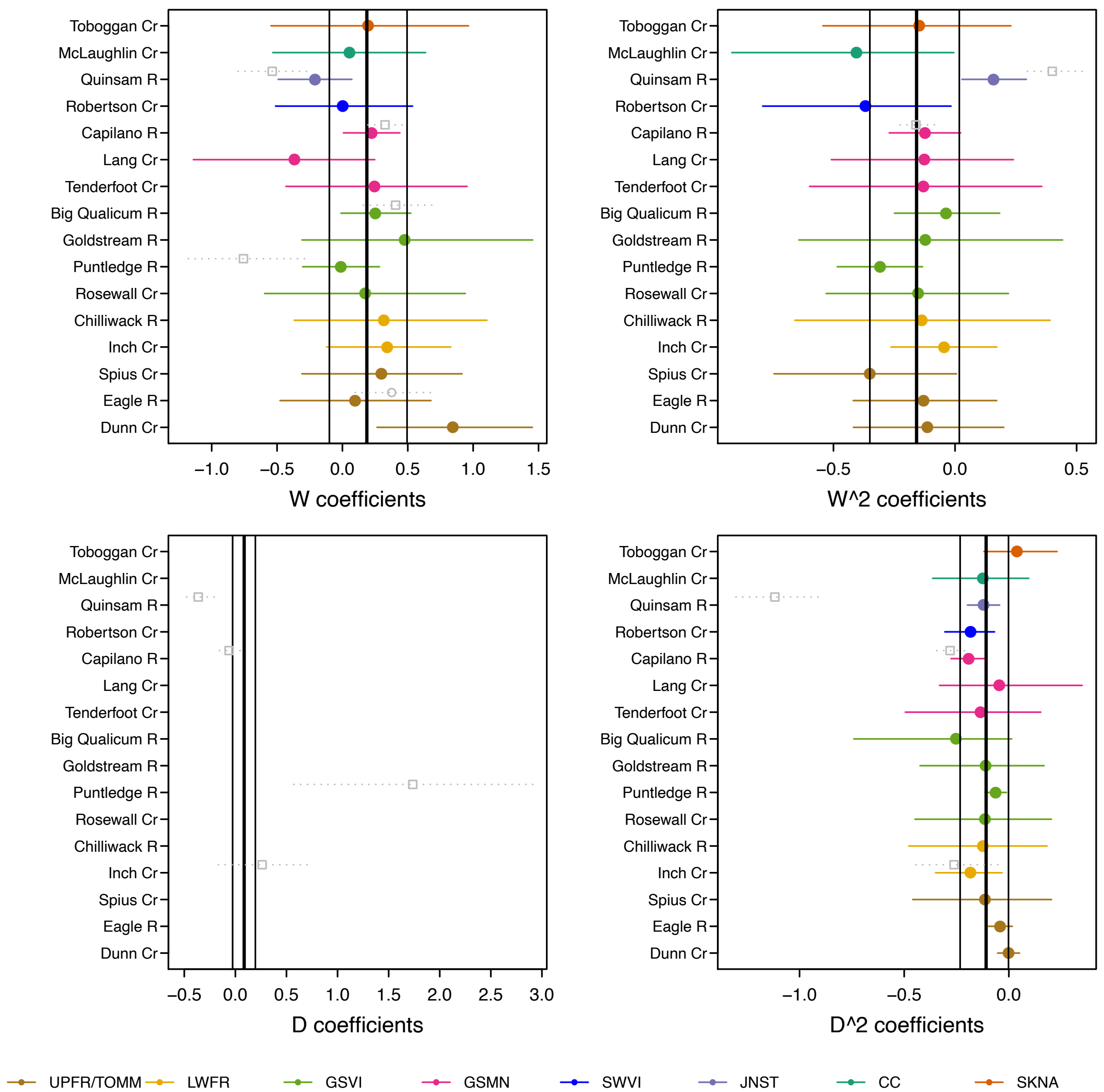


Figure CO. 29. Coho multi-hatchery survival model coefficient estimates for linear and quadratic terms for *Weight* (W, W^2) and *Day* (D, D^2) at-release. The circles indicate hatchery specific mean posterior estimates along with 95% credible intervals, while the vertical lines indicate the mean posterior for the average effect across all hatcheries (thick black line) with 95% credible intervals for the posterior distribution (thin black lines). Single-hatchery estimates and 95% CIs are shown in grey for fry (○) or yearling smolt (□) life-stage specific models.

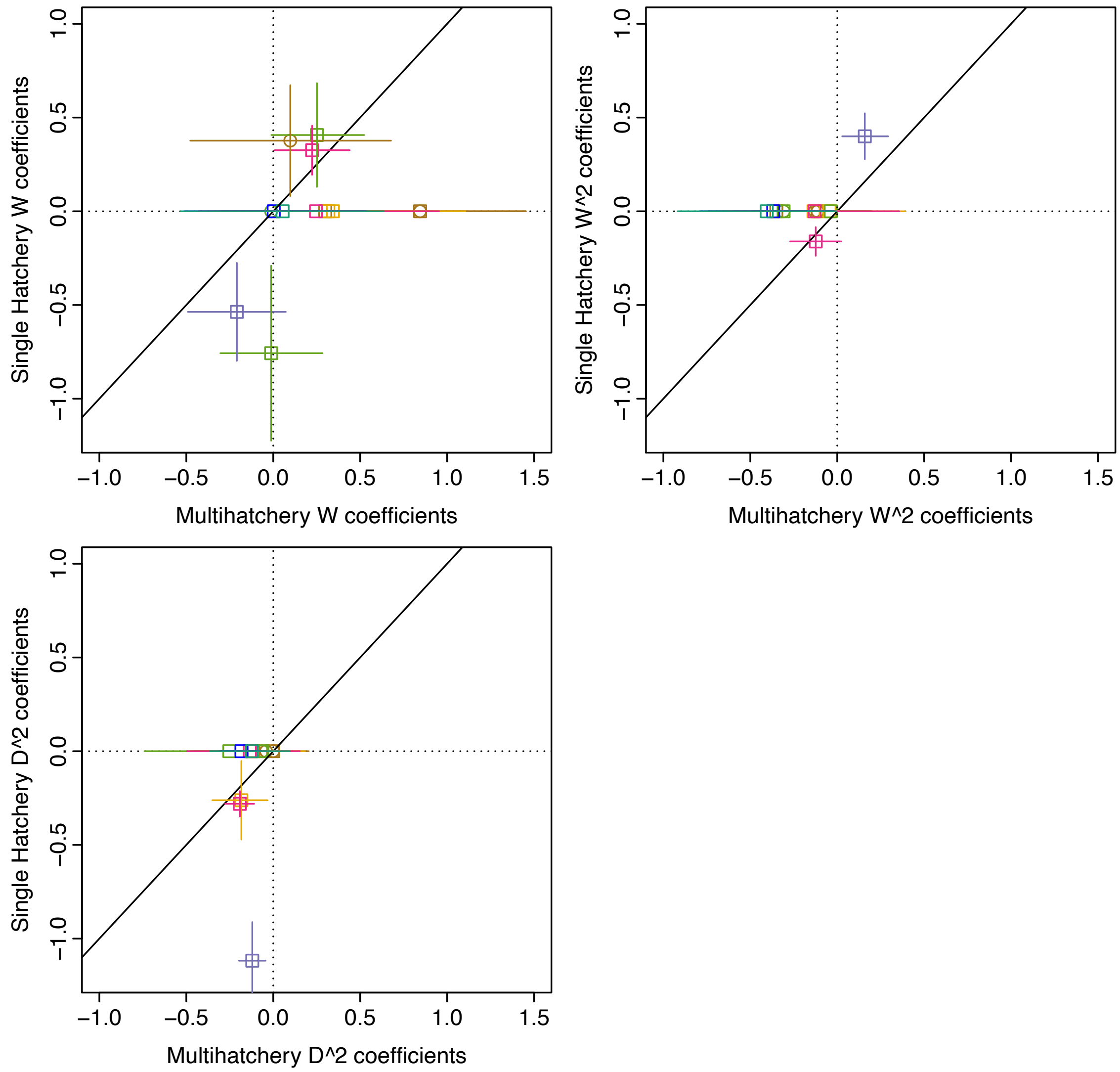


Figure CO. 30. Model coefficient estimates for single-hatchery (MLE +/- 1.96SE) and multi-hatchery models (posterior mean with 95% credible intervals) for linear and quadratic terms for *Weight* (*W, W^2*) and *Day* (*D, D^2*) at-release. Multi-hatchery Coho models include multiple life-stages whereas single hatchery estimates are for fry (○) or yearling smolt (□) life-stage specific models. The diagonal line indicates the 1:1 ratio between single-hatchery and multi-hatchery estimates. Estimates from hatcheries excluded from single hatchery modelling are not shown.

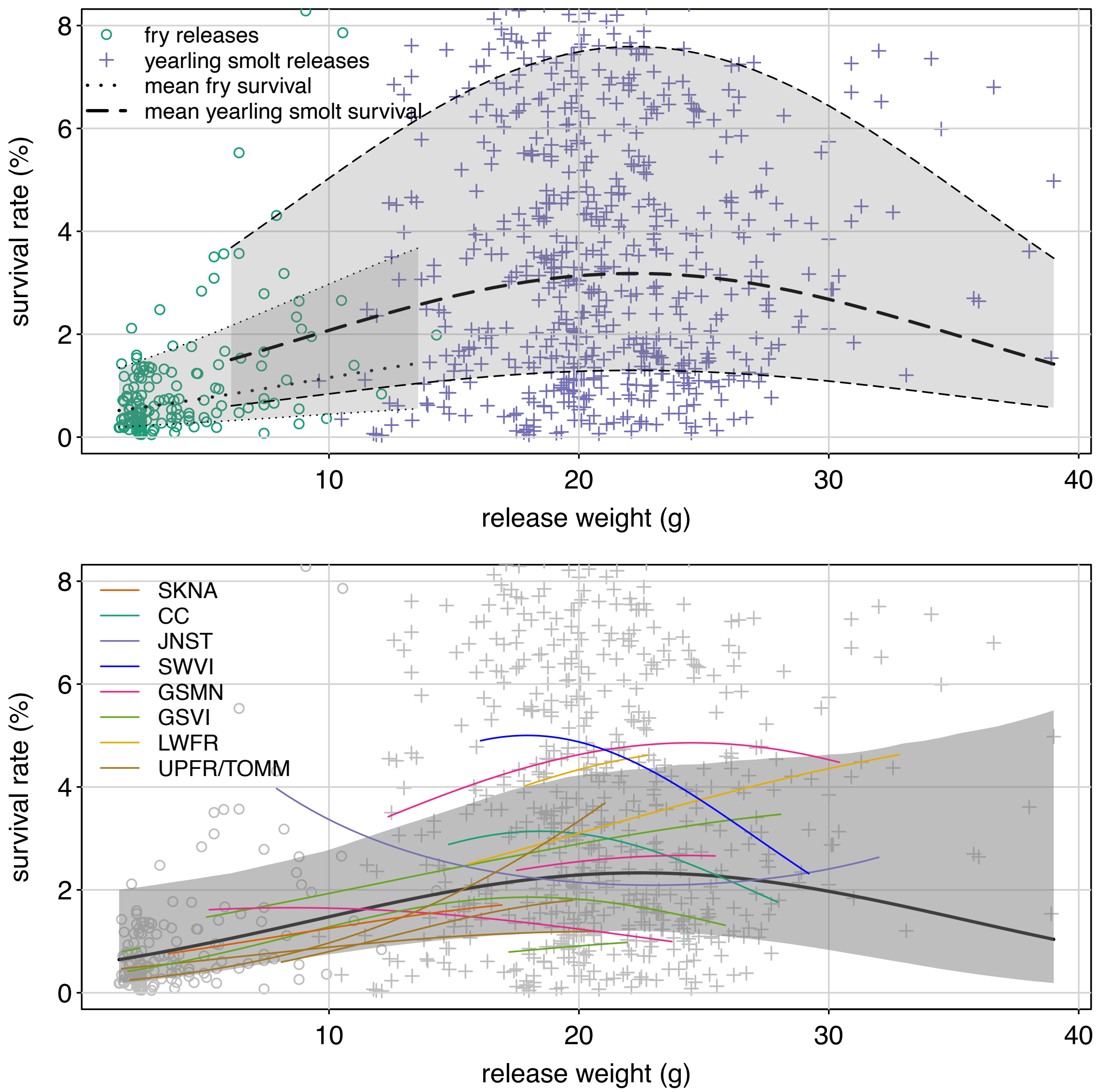
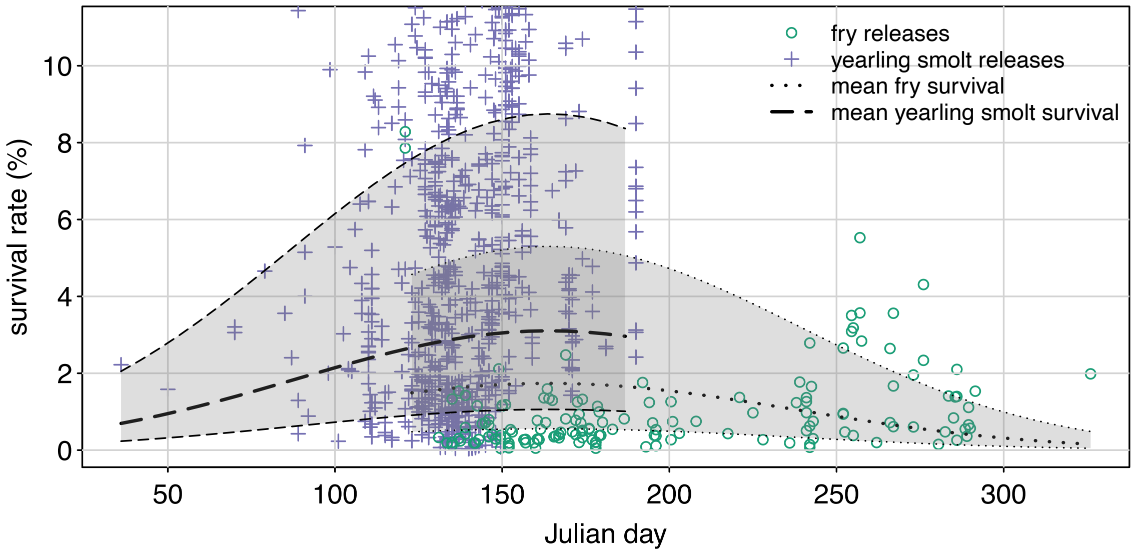


Figure CO.31. Top: Multi-hatchery model fit (MLE) with 95% CIs for average hatchery survival for Coho at different release weights for fry and yearling smolts. Bottom: Hatchery average and hatchery-specific survival responses for the central 95% distribution of observed weights-at-release for each hatchery. The black line (mean posterior) and shaded areas (95% credible interval) indicate the average weight effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLE). Note observations with survival rates greater than 8% are not shown.



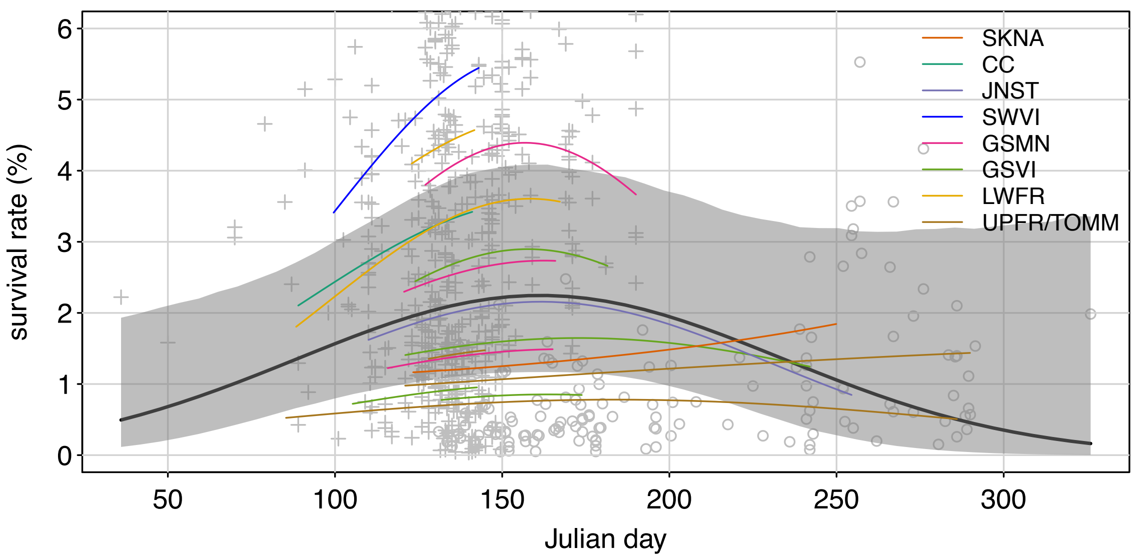


Figure CO.32. Top: Multi-hatchery model fits (MLEs) with 95% CIs for average hatchery survival for Coho at different release days for fry and yearling smolts. Bottom: Hatchery average and hatchery-specific survival responses for the central 95% distribution of observed days-at-release for each hatchery. The black line (mean posterior) and shaded areas (95% credible interval) indicate the average day effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLEs). Note observations with survival rates greater than 10% (top panel) and 6% (bottom panel) are not shown.

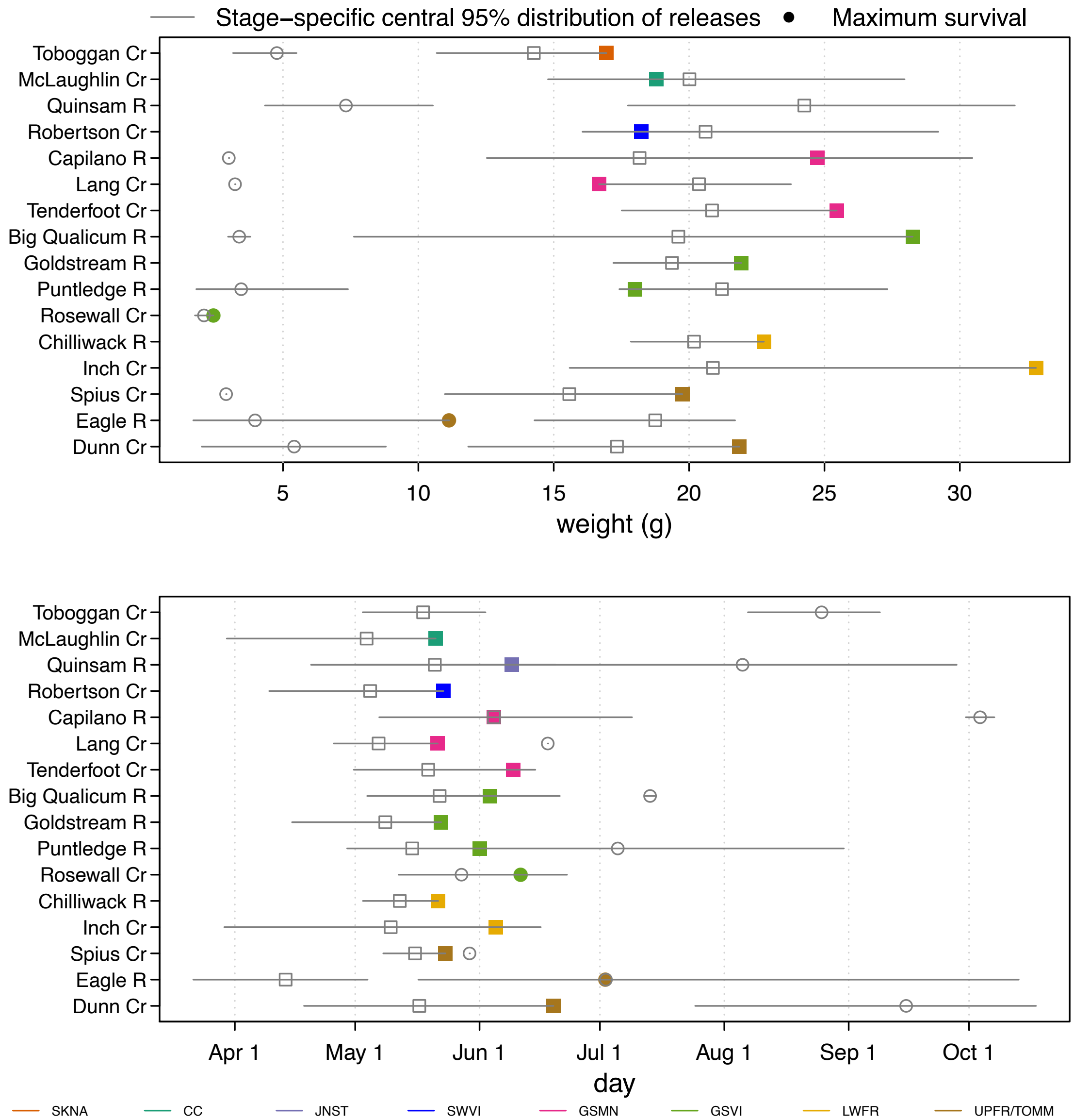


Figure CO.33. Optimal weights (top) and days-at-release (bottom) for maximum Chinook survival for multi-hatchery model posterior means. For each hatchery, the horizontal lines indicate the central 95% distribution of release weights or days for each life-stage (some of which overlap) with means for fry (○) and yearling smolts (□). The coloured circle indicates the release weight or day within the central 95% distribution of observations (grey line) that is expected to maximize survival for the life-stage most commonly released at each hatchery.

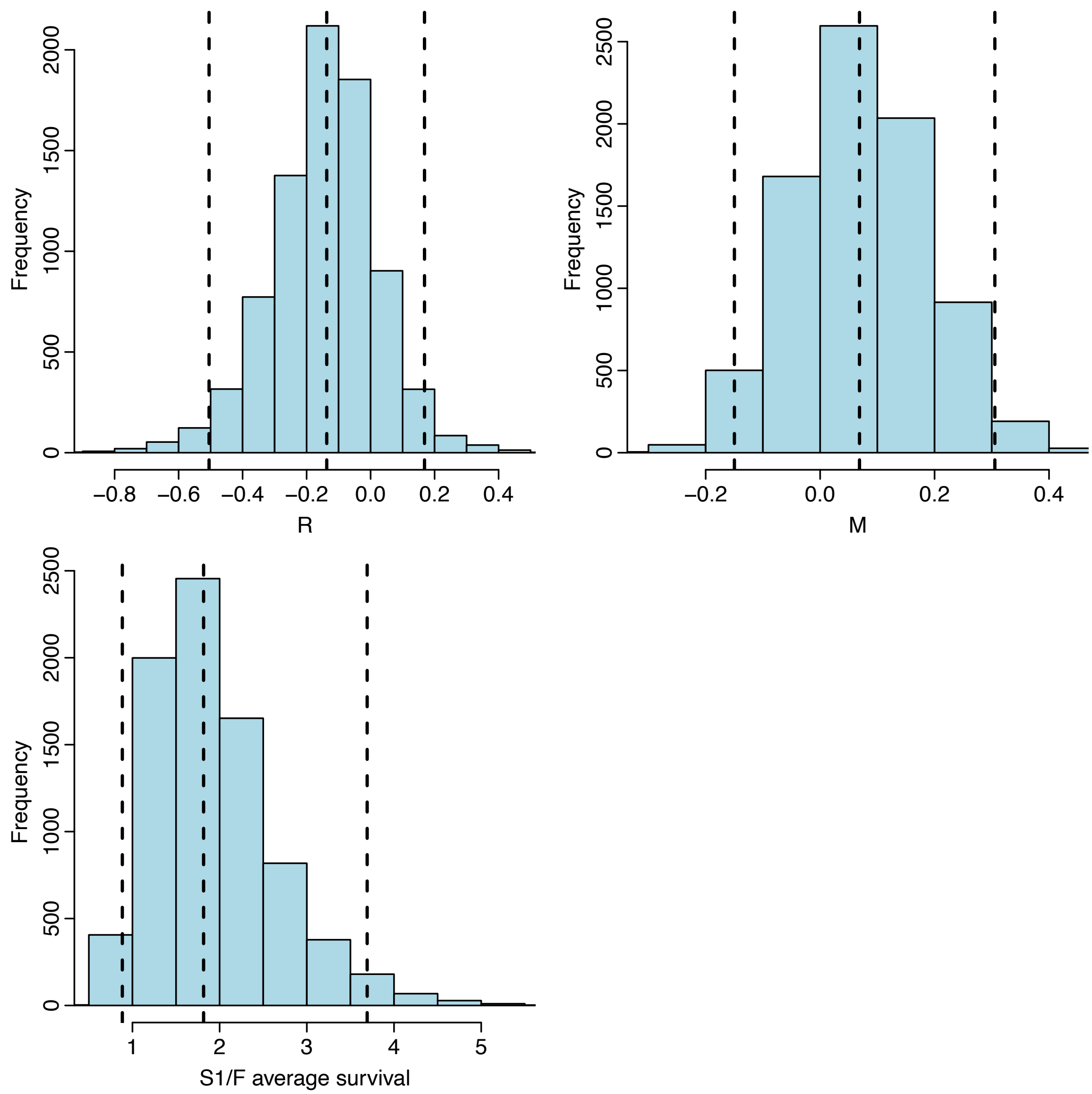


Figure CO.34. Posterior distribution of coefficient estimates for Coho multi-hatchery survival models for hatchery release biomass (*R*), log river migration distance (*M*), and the ratio of yearling smolt to fry (S1/F) survival. For each distribution the vertical dotted lines indicate the 2.5th, 50th, and 97.5th percentiles.

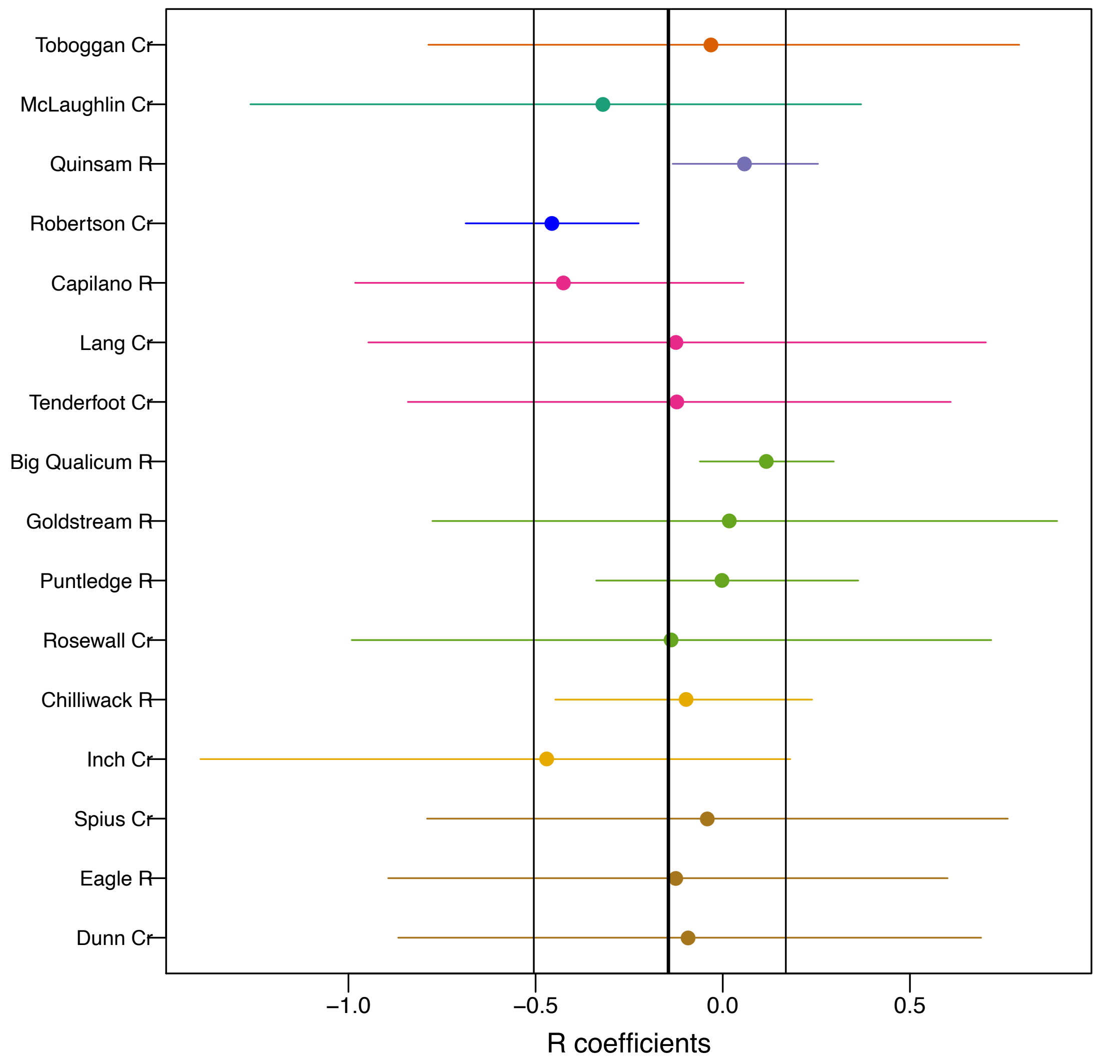


Figure CO. 35. Multi-hatchery Coho survival model coefficient estimates for the release biomass (*R*) predictors. The circles indicate hatchery specific mean posterior estimates along with 95% credible intervals, while the vertical lines indicate the mean posterior for the average effect across all hatcheries (thick black line) with 95% credible intervals for the posterior distribution (thin black lines).

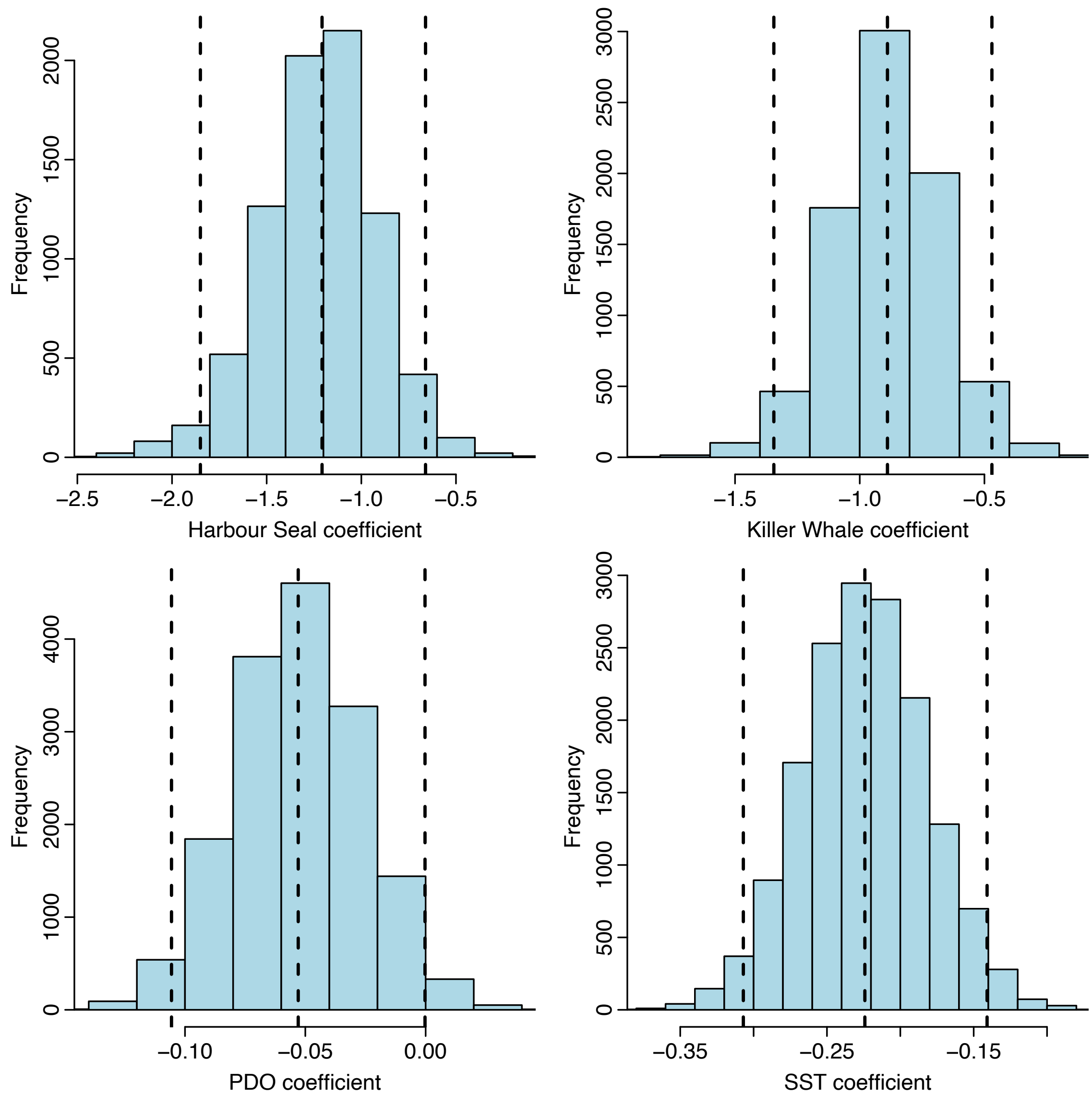


Figure CO.36. Posterior distribution of coefficient estimates for the 4 Coho multi-hatchery survival models that were fit with environmental covariates (Harbour seals, Killer Whales, PDO, SST) instead of year effects. For each distribution the vertical dotted lines indicate the 2.5th, 50th, and 97.5th percentiles.

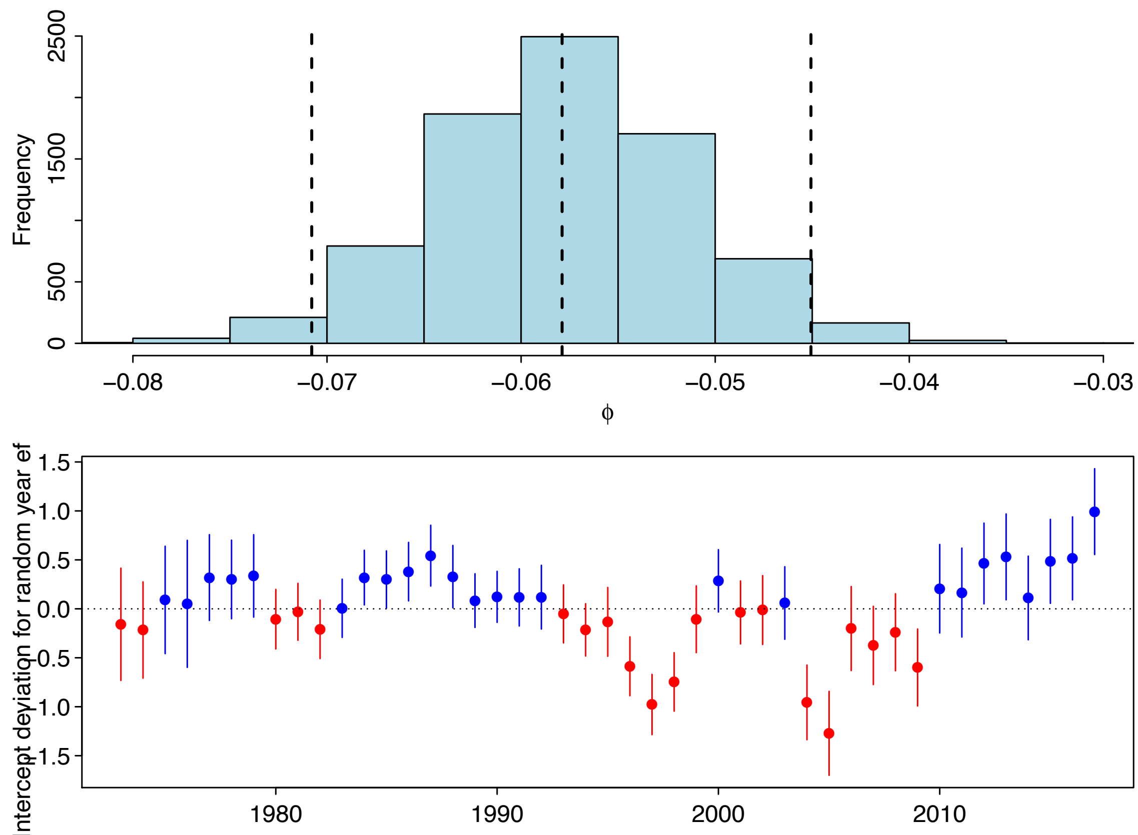


Figure CO.37. Top: Posterior distribution of estimated annual declines in average logit Survival from 1973-2017 ocean entry years with vertical dotted lines for 2.5th, 50th, and 97.5th percentiles. Bottom: The estimated deviations in average Coho logit survival (i.e., random year effects, Δ_t) from the temporal trend for the full multi-hatchery model with multiple life stages. Negative (red) values indicate a year with a greater rate of decline that the average trend and positive (blue) values indicate a year effect with a lower rate of decline than the average trend.

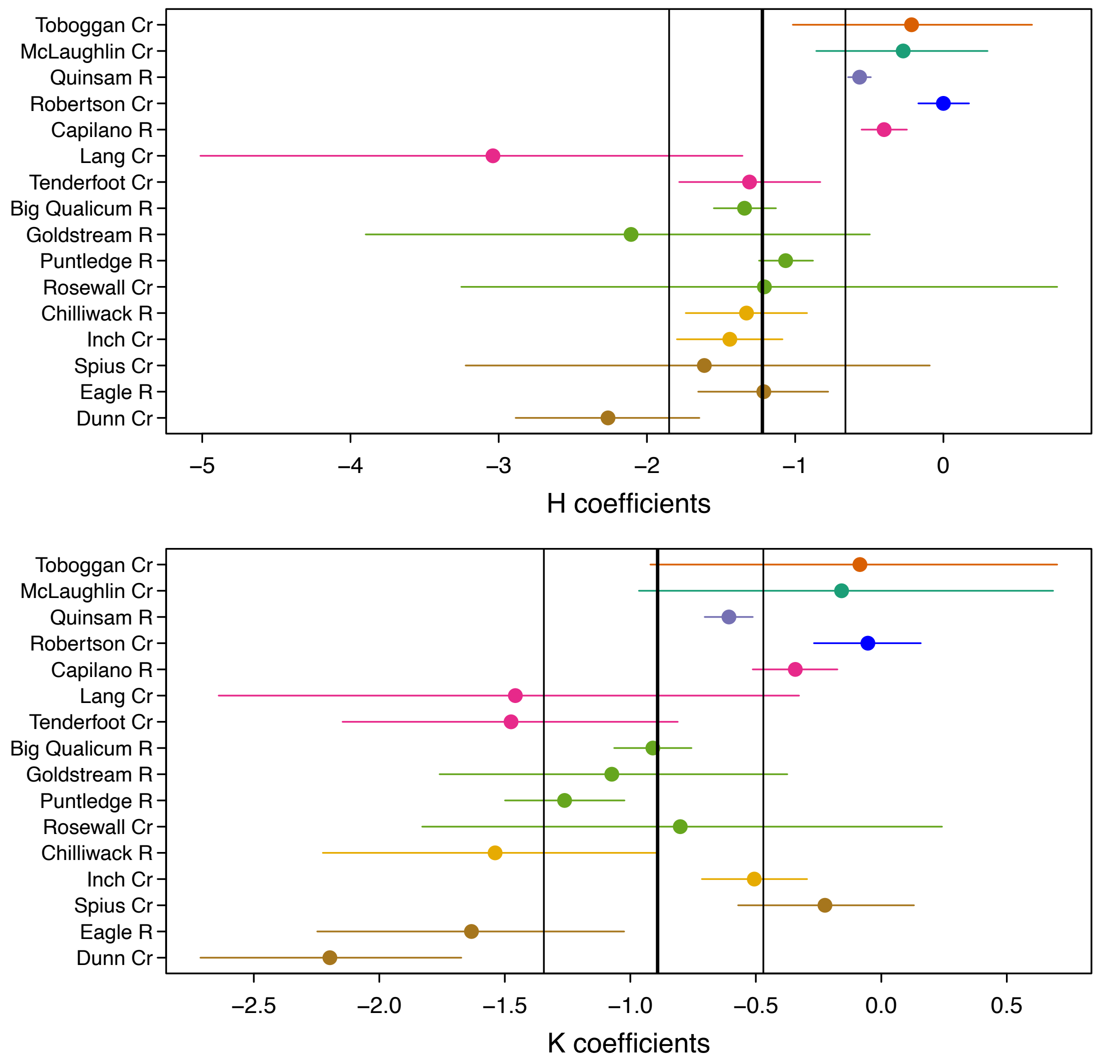


Figure CO.38. Coefficient estimates for multi-hatchery Coho survival models fit with Harbour Seal (H) and Killer Whale (K) covariates. The circles indicate hatchery specific mean posterior estimates along with 95% credible intervals, while the vertical lines indicate the mean posterior for the average effect across all hatcheries (thick black line) with 95% credible intervals (thin black lines).

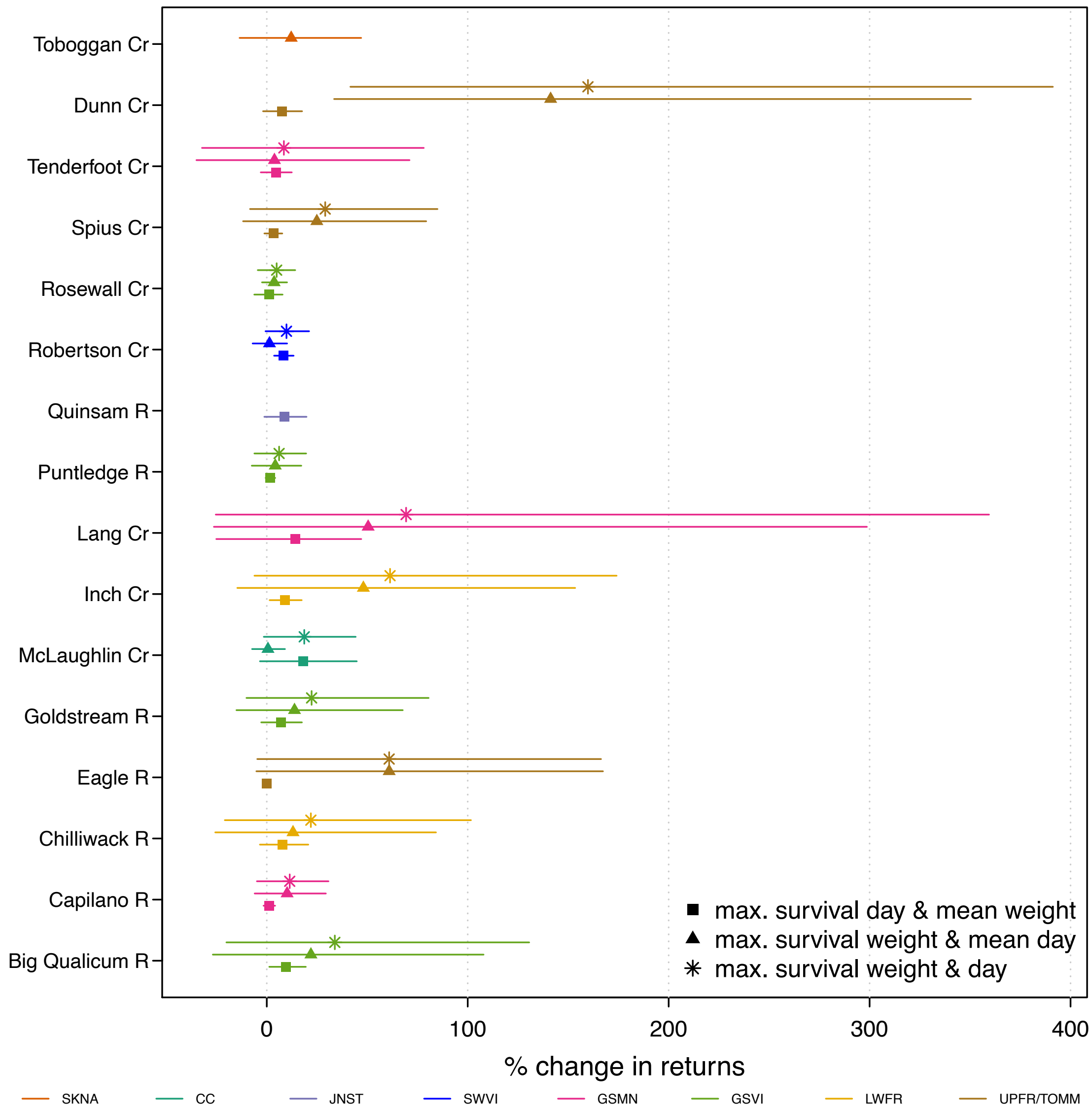


Figure CO.39. Estimated increase in average Coho returns (%) for 2000-2017 ocean entry years for different release weights and days relative to the mean release weight and day. For each hatchery, the % change in returns is shown for release weights and/or days within the historical observations that are expected to maximize survival for the life-stage most commonly released. Points indicate median posterior estimates, while error bars show 95% credible intervals. Values shown are for fry releases at Eagle River and Rosewall Creek, and yearling smolts for all other hatcheries.

Tables

Table CH.1. Hatchery-specific model results for Chinook survival from fry, smolt, and yearling releases. Predictor terms and estimated coefficients with 95% CIs (,) are shown for fixed effects included in top models selected for Chinook releases at individual hatcheries. Note the top model for Terrace yearlings and Shuswap smolts are intercept-only models with the random year effects. Hatcheries are grouped by release site areas (SK = Skeena, CCST = Central Coast, JNST = Johnstone Strait, SWVI= Southwest Vancouver Island, GSMN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, LWFR = Lower Fraser, UPFR = Upper Fraser, TOMM= Lower Thompson, TOMF= Upper Thompson). Values in grey indicate estimated coefficients with 95% CIs that include zero, indicating effects are not statistically significant.

Area	Hatchery	Life Stage	Intercept	Covariates and Categorical Fixed Effects						ICC	n	ΔAICc
				Weight	$Weight^2$	Day	Day^2	Year	Stock/ Site			
SKNA	Terrace	fry	-13.65 (-18.8, -8.51)	5.1 (1.19, 8.99)	-0.905 (-1.628, -0.172)					0.67	54	0.05
SKNA	Terrace	yearling	-4.63 (-4.91, -4.34)							0.48	26	0
CCST	Snootli Cr	sub-yearling	-4.89 (-5.58, -4.21)						+	0.84	16	0
JNST	Quinsam R	sub-yearling	-4.46 (-5.11, -3.81)	0.05 (0.01, 0.08)		0.011 (0.004, 0.018)	-0.00049 (-0.00062, -0.00036)	-0.055 (-0.076, -0.035)	+	0.73	386	1.50
SWVI	Robertson Cr	sub-yearling	-5.29 (-6.32, -4.26)	0.28 (0.2, 0.36)		-0.033 (-0.045, -0.02)	-0.00086 (-0.00138, -0.00033)	-0.055 (-0.095, -0.015)		0.94	229	0
GSMN	Capilano R	sub-yearling	-6.93 (-8.94, -4.93)	0.64 (0.31, 0.97)	-0.032 (-0.058, -0.007)	-0.038 (-0.046, -0.029)		-0.139 (-0.191, -0.088)	+	0.85	124	0
GSVI	Big Qualicum R	sub-yearling	-5.58 (-6.31, -4.86)	0.28 (0.2, 0.36)		-0.034 (-0.053, -0.015)	-0.00069 (-0.00111, -0.00027)	-0.086 (-0.114, -0.058)		0.77	114	0
GSVI	Cowichan R	sub-yearling	-4.87 (-5.68, -4.06)	0.15 (0.03, 0.27)		0.001 (-0.011, 0.013)	-0.00032 (-0.00054, -1e-04)	-0.084 (-0.109, -0.059)	+	0.31	107	0
GSVI	L Qualicum R	sub-yearling	-13.18 (-17.61, -8.73)	1.95 (0.65, 3.24)	-0.128 (-0.221, -0.034)	-0.033 (-0.052, -0.015)				0.35	46	0.37
GSVI	Nanaimo R	sub-yearling	-3.92 (-4.75, -3.08)					-0.081 (-0.136, -0.026)		0.81	32	1.70
GSVI	Puntledge R	sub-yearling	-7.89	0.35	-0.02				+	0.64	156	0

Area	Hatchery	Life Stage	Intercept	Covariates and Categorical Fixed Effects						ICC	n	ΔAICc
				Weight	Weight^2	Day	Day^2	Year	Stock/ Site			
			(-9.09, -6.68)	(0.1, 0.61)	(-0.037, -0.004)							
LWFR	Chehalis R	sub-yearling	-67.84 (-99.54, -33.17)	22.44 (10.58, 33.31)	-1.988 (-2.92, -0.975)					0.76	22	0
LWFR	Chilliwack R	sub-yearling	-3.34 (-3.62, -3.06)			-0.028 (-0.052, -0.004)				0.81	44	1.90
UPFR	Quesnel R	sub-yearling	-7.49 (-8.2, -6.76)			-0.028 (-0.046, -0.01)				0.23	24	0.52
TOMM/ TOMF	Spius Cr	yearling	-4.95 (-5.44, -4.44)			-0.044 (-0.076, -0.012)			+	0.91	61	0
TOMF	Eagle R	fry	-5.85 (-6.62, -5.07)					-0.137 (-0.273, -0.005)		0.47	28	0.97
TOMF	Shuswap R	sub-yearling	-4.93 (-5.24, -4.62)							0.81	28	1.78

Table CH.2. Hatchery-specific model results for Chinook mean return ages from smolt and yearling releases. Predictor terms and estimated coefficients with 95% CIs (,) are shown for fixed effects included in top models selected for Chinook releases at individual hatcheries. None of the 95% CIs for model coefficients include zero, indicating statistically significant effects. Hatcheries are grouped by release site areas (JNST = Johnstone Strait, GSVI = Strait of Georgia Vancouver Island).

Area	Hatchery	Life Stage	Intercept	Covariates and Categorical Fixed Effects					ICC	n	ΔAICc
				Weight	Weight^2	Year	% Females	Stock/ Site			
JNST	Quinsam R	sub-yearling	3.47 (3.35, 3.6)				0.73 (0.44, 1.02)	+	0.24	126	0.72
SWVI	Robertson Cr	sub-yearling	3.51 (3.35, 3.66)				0.61 (0.14, 1.11)		0.66	36	0
GSVI	Big Qualicum R	sub-yearling	3.33 (3.21, 3.46)						0.04	20	0
GSVI	Puntledge R	sub-yearling	3.56 (2.94, 4.14)	-0.25 (-0.43, -0.07)	0.018 (0.003, 0.033)		1.11 (0.53, 1.71)		0.49	38	0

Table CH.3. Comparison of different Chinook multi-hatchery survival models with all life stages (fry, sub-yearling smolts, yearling smolts, n=1668) using different predictor variables, including linear and quadratic terms for weight and day (W,W^2,D,D^2), life-stage (ω_S), log river migration distance (*M*), and biomass of hatchery releases at release sites (*R*). The mean posterior coefficient estimates and 95% credible intervals () are shown for the different models and the full model with all predictor variables is in bold.

Release Strategy Predictors	Intercept	Release strategy effects						ΔLOOIC
		Weight	Weight^2	Day	Day^2	Releases	Migration	
$W, W^2, D, D^2, R, M, \omega_s$	-4.01 (-4.71,-3.32)	0.52 (0.31,0.72)	-0.07 (-0.12,-0.02)	-0.16 (-0.38,0.03)	-0.14 (-0.17,-0.10)	-0.32 (-0.80,0.19)	0.33 (-0.05,0.72)	0
W, W^2, D, D^2, R, M	-3.77 (-4.42,-3.13)	0.46 (0.27,0.63)	-0.08 (-0.12,-0.03)	-0.11 (-0.32,0.08)	-0.14 (-0.18,-0.10)	-0.28 (-0.79,0.24)	0.30 (-0.08,0.68)	0.3
W, W^2, D, D^2, M	-3.58 (-4.20,-2.97)	0.42 (0.24,0.57)	-0.06 (-0.10,-0.01)	-0.08 (-0.25,0.09)	-0.14 (-0.17,-0.10)		0.14 (-0.15,0.43)	40.7
W, W^2, D, D^2, R	-3.55 (-4.15,-2.95)	0.44 (0.26,0.6)	-0.06 (-0.11,-0.02)	-0.07 (-0.25,0.09)	-0.15 (-0.18,-0.11)	-0.13 (-0.33,0.06)		70.2
W, W^2, D, D^2	-3.47 (-4.06,-2.88)	0.42 (0.24,0.58)	-0.05 (-0.10,-0.01)	-0.08 (-0.25,0.08)	-0.14 (-0.18,-0.11)			76.8

Table CH.4. Comparison of the full Chinook multi-hatchery survival model with all life stages (fry, sub-yearling smolts, yearling smolts, n=1597) with and without environmental covariates and year effects. The mean posterior coefficient estimates and 95% credible intervals () are shown for weight, day, and environmental covariates. The last row shows a model (*M_0*) with only weight (*W, W^2*), day (*D, D^2*), life-stage (ω_s), release biomass (*R*), and river migration (*M*) predictors, without any year or environmental effects. Other rows show models with the inclusion of one of the environmental covariates (*H*= Harbour Seals, *K* = Killer Whales, *S* = Sea Surface Temperature, *P* = PDO), fixed year effects ($\emptyset_t$), and random year effects (Δ_t). The top row shows the full model with both fixed and random year effects ($\emptyset_t + \Delta_t$), shown in bold in Table CH.3. MLE values are shown for $R^2_{logit(c)}$ along with $\Delta R^2_{logit(c)}$, which indicates the additional proportion of variance explained by adding the environmental or year effects relative to M_0.

Model	Coefficients for release strategy effects				Coefficients for environmental covariates				ΔLOOIC	$R^2_{logit(c)}$	$\Delta R^2_{logit(c)}$
	Weight	Weight^2	Day	Day^2	Seals	Killer Whales	PDO	SST			
$M_0 + \emptyset_t + \Delta_t$	0.52 (0.31,0.72)	-0.07 (-0.12,-0.02)	-0.16 (-0.38,0.03)	-0.14 (-0.17,-0.1)					0	0.337	0.141
$M_0 + (\theta_7 + \theta_{7h})H_h$	0.54 (0.34,0.73)	-0.07 (-0.12,-0.02)	-0.15 (-0.35,0.04)	-0.14 (-0.18,-0.1)	-0.68 (-1,-0.37)				278.0	0.386	0.191
$M_0 + \gamma_2 P$	0.46 (0.25,0.65)	-0.06 (-0.11,-0.01)	-0.10 (-0.31,0.1)	-0.13 (-0.17,-0.09)			-0.27 (-0.32,-0.21)		308.9	0.339	0.144
$M_0 + (\theta_8 + \theta_{8h})K_h$	0.45 (0.25,0.64)	-0.04 (-0.09,0.02)	-0.10 (-0.29,0.07)	-0.12 (-0.16,-0.08)		-0.44 (-0.69,-0.19)			337.2	0.339	0.143
$M_0 + \emptyset_t$	0.44 (0.23,0.65)	-0.05 (-0.11,0)	-0.08 (-0.29,0.13)	-0.13 (-0.17,-0.09)					405.6	0.341	0.146
$M_0 + \gamma_1 S$	0.32 (0.1,0.54)	-0.04 (-0.1,0.01)	0.30 (0.07,0.5)	-0.11 (-0.15,-0.07)				-0.35 (-0.45,-0.25)	555.4	0.260	0.065
M_0	0.27 (0.04,0.49)	-0.03 (-0.09,0.02)	0.07 (-0.15,0.26)	-0.09 (-0.14,-0.05)					609.7	0.195	0

Table CO.1. Hatchery-specific model results for survival for Coho fry and yearling releases. Predictor terms are on log-odds scale and estimated coefficients with 95% CIs (,) are shown for fixed effects included in top models selected for Coho releases at individual hatcheries. Note the top models for Robertson Creek yearlings, Thompson River fry, and Spius Creek yearlings are intercept-only models with the random year effects. None of the 95% CIs for model coefficients include zero, indicating statistically significant effects. Hatcheries are grouped by areas (CCST = Central Coast, JNST = Johnstone Strait, SWVI= Southwest Vancouver Island, GSMN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, LWFR = Lower Fraser, TOMM= Lower Thompson, TOMF= Upper Thompson).

Area	Hatchery	Life Stage	Intercept	Covariates and Categorical Fixed Effects						ICC	n	ΔAICc
				Weight	$Weight^2$	Day	Day^2	Year	Stock/ Site			
CCST	McLaughlin Creek	yearling	-3.43 (-3.9, -2.98)							0.32	20	0
JNST	Quinsam R	yearling	0.14 (-1.41, 1.67)	-0.35 (-0.47, -0.23)	0.008 (0.005, 0.01)	0.004 (0, 0.008)	-0.00098 (-0.00115, -8e-04)	-0.06 (-0.077, -0.044)	+	0.70	229	0
SWVI	Robertson Cr	yearling	-2.87 (-3.18, -2.55)							0.90	70	0
GSMN	Capilano R	yearling	-3.29 (-4.04, -2.53)	0.16 (0.09, 0.22)	-0.003 (-0.004, -0.002)	-0.005 (-0.009, -0.002)	-0.00025 (-3e-04, -0.00019)	-0.05 (-0.071, -0.028)		0.65	173	0
GSMN	Tenderfoot Cr	yearling	-1.88 (-2.39, -1.38)					-0.163 (-0.214, -0.113)		0.79	23	0.16
GSVI	Big Qualicum R	yearling	-2.5 (-3.42, -1.58)	0.06 (0.02, 0.09)				-0.083 (-0.106, -0.059)		0.88	62	1.36
GSVI	Puntledge R	fry	-4.45 (-4.93, -3.96)					-0.081 (-0.117, -0.046)		0.28	58	0
GSVI	Puntledge R	yearling	0.48 (-1.08, 2.01)	-0.1 (-0.17, -0.04)		0.051 (0.016, 0.085)		-0.168 (-0.226, -0.111)		0.73	71	0
LWFR	Chilliwack R	yearling	-1.39 (-1.84, -0.94)					-0.128 (-0.166, -0.09)		0.90	38	0
LWFR	Inch Cr	yearling	-2.54 (-3.12, -1.96)			0.016 (0.007, 0.026)	-0.00023 (-0.00041, -4e-05)	-0.055 (-0.087, -0.024)		0.81	76	0

Area	Hatchery	Life Stage	Intercept	Covariates and Categorical Fixed Effects						ICC	n	ΔAICc
				Weight	Weight^2	Day	Day^2	Year	Stock/ Site			
TOMM/ TOMF	Spius Cr	yearling	-4.61 (-4.93, -4.3)							0.40	31	1.14
TOMF	Eagle R	fry	-4.31 (-4.84, -3.78)	0.05 (0.01, 0.09)				-0.189 (-0.279, -0.098)		0.54	36	0
TOMF	Thompson R N	fry	-4.74 (-5.13, -4.37)							0.22	23	0.41
TOMF	Thompson R N	yearling	-2.19 (-2.87, -1.5)					-0.222 (-0.287, -0.158)		0.50	24	0

Table CO.2. Hatchery-specific model results for proportion of Jacks in returns from Coho fry and yearling releases. Predictor terms are on log-odds scale and estimated coefficients with 95% CIs (,) are shown for fixed effects included in top models selected for Coho releases at individual hatcheries. Note the top models for Robertson Creek Yearling and Chilliwack R Yearling are intercept-only models with the random year effects. None of the 95% CIs for model coefficients include zero, indicating statistically significant effects. There was no stock or release site effect in any of the top models. Hatcheries are grouped by areas (JNST = Johnstone Strait, SWVI= Southwest Vancouver Island, GSMN = Strait of Georgia Mainland, GSVI = Strait of Georgia Vancouver Island, LWFR = Lower Fraser).

Area	Hatchery	Life Stage	Intercept	Covariate coefficients for fixed effects				ICC	n	ΔAICc
				Weight	Weight^2	Year	Stock/ Release Site			
JNST	Quinsam R	yearling	-9.89 (-15.17, -4.55)	0.76 (0.35, 1.16)	-0.014 (-0.021, -0.007)	0.023 (0.003, 0.042)	+	0.67	89	0
SWVI	Robertson Cr	yearling	-2.07 (-2.42, -1.7)					0.41	39	0
GSMN	Capilano R	yearling	-2.57 (-2.94, -2.2)					0.51	26	0
GSVI	Big Qualicum R	yearling	-12.05 (-19.89, -5.42)	0.97 (0.4, 1.64)	-0.022 (-0.036, -0.011)	0.059 (0.032, 0.087)		0.75	25	0
GSVI	Puntledge R	fry	-1.58 (-3.24, 1)	-0.30 (-0.72, 0.09)			+	0.18	36	0
GSVI	Puntledge R	yearling	-4.82 (-5.92, -3.71)	0.17 (0.12, 0.22)				0.89	44	0
LWFR	Chilliwack R	yearling	-2.16 (-2.5, -1.81)					0.50	24	0
LWFR	Inch Cr	yearling	-3.6 (-4.17, -3.03)			0.069 (0.039, 0.099)		0.25	44	0

Table CO.3. Comparison of different Coho multi-hatchery survival models with all life stages (fry, yearling smolts, n=1007) using different predictor variables, including linear and quadratic terms for weight and day (W, W^2, D, D^2), life-stage (ω_S), log river migration distance (M), and biomass of hatchery releases at release sites (R). The mean posterior coefficient estimates and 95% credible intervals () are shown for the different models and the full model with all predictor variables is in bold.

Release Strategy Predictors	Intercept	Coefficients for release strategy effects						ΔLOOIC
		Weight	Weight^2	Day	Day^2	Releases	Migration	
W, W^2, D, D^2, R	-2.13 (-2.69,-1.59)	0.24 (-0.01,0.52)	-0.22 (-0.39,-0.05)	0.06 (-0.05,0.17)	-0.13 (-0.24,-0.03)	-0.13 (-0.47,0.18)		0
$W, W^2, D, D^2, R, M, \omega_s$	**-2.46 (-3.17,-1.77)**	**0.19 (-0.1,0.49)**	**-0.16 (-0.35,0.02)**	**0.09 (-0.03,0.2)**	**-0.11 (-0.23,0)**	**-0.15 (-0.50,0.17)**	**0.07 (-0.15,0.31)**	**2.1**
W, W^2, D, D^2, R, M	-2.17 (-2.77,-1.58)	0.24 (-0.02,0.51)	-0.21 (-0.39,-0.05)	0.06 (-0.05,0.16)	-0.13 (-0.25,-0.03)	-0.14 (-0.49,0.17)	0.05 (-0.17,0.3)	3.8
W, W^2, D, D^2, M	-2.07 (-2.53,-1.61)	0.23 (-0.01,0.5)	-0.21 (-0.37,-0.07)	0.08 (-0.03,0.19)	-0.13 (-0.26,-0.03)		0.02 (-0.18,0.22)	27.8
W, W^2, D, D^2	-2.05 (-2.52,-1.6)	0.23 (-0.01,0.49)	-0.21 (-0.37,-0.07)	0.08 (-0.03,0.19)	-0.14 (-0.27,-0.04)			28.1

Table CO.4. Comparison of the full Coho multi-hatchery survival model with all life stages (fry, yearling smolts, n=1007) with and without environmental covariates and year effects. The mean posterior coefficient estimates and 95% credible intervals () are shown for weight, day, and environmental covariates. The last row shows a model (M_0) with only weight (W, W^2), day (D, D^2), life-stage (ω_s), release biomass (R), and river migration (M) predictors, without any year or environmental effects. Other rows show models with the inclusion of one of the environmental covariates (H= Harbour Seals, K = Killer Whales, S = Sea Surface Temperature, P = PDO), fixed year effects ($\emptyset_t$), and random year effects (Δ_t). The top row shows the full model with both fixed and random year effects ($\emptyset_t + \Delta_t$), shown in bold in Table CO.3. MLE values are shown for $R^2_{logit(c)}$ along with $\Delta R^2_{logit(c)}$, which indicates the additional proportion of variance explained by adding the environmental or year effects relative to M_0.

Model	Coefficients for release strategy effects				Coefficients for environmental covariates				ΔLOOIC	$R^2_{logit(c)}$	$\Delta R^2_{logit(c)}$
	Weight	Weight^2	Day	Day^2	Seals	Killer Whales	PDO	SST			
$M_0 + \emptyset_t + \Delta_t$	0.19 (-0.1,0.49)	-0.16 (-0.35,0.02)	0.09 (-0.03,0.2)	-0.11 (-0.23,0)					2.1	0.311	0.046
$M_0 + (\theta_7 + \theta_{7h})H_h$	0.30 (-0.02,0.64)	-0.10 (-0.28,0.07)	0.09 (-0.03,0.19)	-0.09 (-0.19,0)	-1.22 (-1.85,-0.66)				42.9	0.441	0.176
$M_0 + (\theta_8 + \theta_{8h})K_h$	0.26 (-0.07,0.6)	-0.02 (-0.21,0.15)	0.07 (-0.04,0.18)	-0.06 (-0.14,0.01)		-0.89 (-1.34,-0.47)			143.9	0.372	0.107
$M_0 + \gamma_1 S$	0.26 (-0.14,0.67)	-0.06 (-0.27,0.14)	0.36 (0.2,0.51)	-0.14 (-0.23,-0.07)				-0.22 (-0.31,-0.14)	198.7	0.295	0.030
$M_0 + \gamma_2 P$	0.26 (-0.12,0.64)	-0.07 (-0.27,0.12)	0.09 (-0.03,0.21)	-0.09 (-0.19,-0.01)			-0.05 (-0.11,0.0)		223.6	0.288	0.022
$M_0 + \emptyset_t$	0.27 (-0.1,0.65)	-0.07 (-0.27,0.12)	0.08 (-0.03,0.2)	-0.09 (-0.2,0)					224.1	0.287	0.022
M_0	0.32 (-0.19,0.85)	0.0 (-0.23,0.22)	0.17 (0.03,0.32)	-0.23 (-0.73,0.11)					578.9	0.265	0.000

Appendix A

Table A.1. Flagged release events that were removed from datasets used for fitting survival and return age models. Comments are from interviews conducted with hatchery management staff to verify data and identify any unusual events (e.g., disease outbreaks, high mortality events, predation mitigation, operational or environmental changes) for release groups in specific brood years (unpublished data, Samantha James, PSF).

Release Code	Species	Brood Year	Stock	Hatchery	Comment
20443	Chinook	1989	Eagle R	Eagle River H	TIME OF RELEASE-YEARLING.TREATED FOR BKD PRIOR TO RELEASE
20444	Chinook	1989	Eagle R	Eagle River H	TIME OF RELEASE-YEARLING.TREATED FOR BKD 1 WK PRIOR TO RELEASE
20815	Chinook	1989	Eagle R	Eagle River H	TIME OF RELEASE-YEARLING. TREATED FOR BKD 1 WK BEFORE RELEASE
183032	Chinook	1997	Quinsam R	Discovery Passage Seapens	APRIL POINT, RELEASED DUE TO VIBRIO
183033	Chinook	1997	Quinsam R	Discovery Passage Seapens	APRIL POINT, VACCINATED 1:10 BUT RELEASED DUE TO VIBRIO.
183249	Chinook	1999	Quinsam R	Discovery Passage Seapens	SEAPEN RELEASE. SUSPECT 50K MORTS CAUSED BY PROP WASH FROM YACHT.
183253	Chinook	1999	Quinsam R	Quinsam River H	FEED/DISEASE PROBLEMS DUE TO EWOS FEED.
185307	Chinook	2006	Quinsam R	Discovery Passage Seapens	PEN #1:STORM-APPROX 1000 DEAD AT RELEASE. PEN #2:LOW MORTS, REARED 6-11 DAYS.
20230	Chinook	1989	Robertson Cr	Robertson Creek H	HELD NETPEN 24 HR. SEE ALSO 020231,020232. HEAVY REARING LOSSES.
20231	Chinook	1989	Robertson Cr	Robertson Creek H	HELD NETPEN 24 HR. SEE ALSO 020230,020232. HEAVY REARING LOSSES.
20232	Chinook	1989	Robertson Cr	Robertson Creek H	HELD NETPEN 24 HR. SEE ALSO 020230,020231. HEAVY REARING LOSSES.
181164	Chinook	2011	Atnarko R Low	Snootli Creek H	Approximately 65% of the yearling smolt release group died from a pump malfunction.
181165	Chinook	2011	Atnarko R Low	Snootli Creek H	Approximately 65% of the yearling smolt release group died from a pump malfunction.
181166	Chinook	2011	Atnarko R Up	Snootli Creek H	Approximately 65% of the yearling smolt release group died from a pump malfunction.

Release Code	Species	Brood Year	Stock	Hatchery	Comment
181696	Chinook	2011	Atnarko R Up	Snootli Creek H	Approximately 65% of the yearling smolt release group died from a pump malfunction.
181227	Chinook	1992	Nicola R	Spius Creek H	YEARLINGS.BKD. 5075 MARKS & 19782 UNMARKS REL'D SPAHOMIN POND-AFS FUNDED.
181091	Chinook	2010	Nicola R	Spius Creek H	BKD was present in this release group
25235	Coho	1987	Big Qualicum R	Big Qualicum River H	FISH REARED IN THIS CHANNEL APPEAR TO HAVE A HIGHER MORTALITY
20101	Coho	1972	Capilano R	Capilano River H	EXTENDED REARED POOR SURV (.4 AS COMP TO 4%)
24820	Coho	1987	Chilliwack R	Chilliwack River H	INFECTED WITH BKD
24832	Coho	1987	Chilliwack R	Chilliwack River H	INFECTED WITH B.K.D.
25137	Coho	1987	Chilliwack R	Chilliwack River H	INFECTED WITH B.K.D.
25138	Coho	1987	Chilliwack R	Chilliwack River H	INFECTED WITH B.K.D.
20218	Coho	1989	Chilliwack R	Chilliwack River H	TIME RELEASE - EARLY. LIGHT BKD INFECTION. SEE 020219, 020220, 020221.
20219	Coho	1989	Chilliwack R	Chilliwack River H	TIME OF RELEASE - EARLY. LIGHT BKD INFECTION. SEE 020218, 020220, 020221.
20220	Coho	1989	Chilliwack R	Chilliwack River H	TIME OF RELEASE - LATE. LIGHT BKD INFECTION. SEE 020218, 020219, 020221.
20221	Coho	1989	Chilliwack R	Chilliwack River H	TIME OF RELEASE - LATE. LIGHT BKD INFECTION. SEE 020218, 020219, 020220.
21412	Coho	1990	Chilliwack R	Chilliwack River H	SLIGHT BKD INFECTION. COMBINE WITH 021413
21413	Coho	1990	Chilliwack R	Chilliwack River H	SLIGHT BKD INFECTION. COMBINE WITH 021412
180307	Coho	1990	Eagle R	Eagle River H	TIME OF RELEASE-SM. SEE 020761-62(FRY),180331(FALL),11.5% MORTS - TREAT BKD
180308	Coho	1990	Eagle R	Eagle River H	TIME OF RELEASE-SM. SEE 020762-63(FRY),180331(FALL),16.1% MORT - TREAT'D BKD
181260	Coho	1994	Goldstream R	Goldstream River H	MECHANICAL FAILURE RESULTED IN HIGH MORTALITY; ALSO SEE 181259 & 181261
184847	Coho	2000	McLoughlin Bay Cr	McLaughlin Bay Seapen	TROUGH OF TAGGED FISH DESTROYED DUE TO BKD. RELEASED FISH HEALTHY.

Release Code	Species	Brood Year	Stock	Hatchery	Comment
24149	Coho	1985	Puntledge R	Puntledge River H	ONE TAGCODE PER SECTION OF CHANNEL
24150	Coho	1985	Puntledge R	Puntledge River H	ONE TAGCODE PER SECTION OF CHANNEL
24151	Coho	1985	Puntledge R	Puntledge River H	ONE TAGCODE PER SECTION OF CHANNEL
180725	Coho	1991	Puntledge R	Puntledge River H	RELEASE DUE TO PKD AND HIGH TEMPERATURES AS FRY
180724	Coho	1991	Puntledge R	Puntledge River H	RELEASE DUE TO PKD AND HIGH TEMPERATURES AS FRY
26363	Coho	1989	Tenderfoot Cr	Tenderfoot Creek H	SEVERE CASE BKD IN 1597 MARKED FISH
22960	Coho	1983	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
23712	Coho	1984	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
82406	Coho	1984	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
82407	Coho	1984	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
24144	Coho	1985	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
24145	Coho	1985	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
24146	Coho	1985	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
82410	Coho	1985	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
82411	Coho	1985	Big Qualicum R	Big Qualicum River H	Poor quality smolts (as ref in Irvine et al. 2013)
25135	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)
25131	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)
25132	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)
25102	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)
25111	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)
25112	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)

Release Code	Species	Brood Year	Stock	Hatchery	Comment
25133	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)
25134	Coho	1986	Big Qualicum R	Big Qualicum Est Seapen	Poor quality smolts (as ref in Irvine et al. 2013)
25130	Coho	1986	Big Qualicum R	Deep Bay/GSVI Seapen	Poor quality smolts (as ref in Irvine et al. 2013)

Table A.2 Comparison of different Chinook multi-hatchery survival models using only sub-yearling smolt releases (n=1400) with different predictor variables, including linear and quadratic terms for weight and day (W, W^2, D, D^2), life-stage (ω_S), log river migration distance (M), and biomass of hatchery releases at release sites (R). The mean posterior coefficient estimates and 95% credible intervals () are shown for the different models and the full model with all predictor variables is in bold.

Release Strategy Predictors	Intercept	Release strategy effects						ΔLOOIC
		Weight	Weight^2	Day	Day^2	Releases	Migration	
W, W², D, D², R, M	-3.75 (-4.31,-3.18)	0.28 (0.12,0.43)	-0.02 (-0.05,0.01)	-0.19 (-0.35,-0.02)	-0.11 (-0.19,-0.03)	-0.31 (-0.65,-0.05)	0.15 (-0.14,0.45)	0
W, W², D, D², M	-3.54 (-4.08,-2.99)	0.26 (0.08,0.4)	-0.01 (-0.04,0.02)	-0.18 (-0.34,0)	-0.11 (-0.18,-0.03)		0.07 (-0.20,0.36)	25.5
W, W², D, D², R	-3.64 (-4.24,-2.99)	0.28 (0.09,0.43)	-0.01 (-0.04,0.02)	-0.18 (-0.33,-0.02)	-0.12 (-0.18,-0.05)	-0.13 (-0.29,0.02)		46.7
W, W², D, D²	-3.52 (-4.14,-2.91)	0.27 (0.10,0.42)	-0.01 (-0.04,0.02)	-0.19 (-0.34,-0.03)	-0.11 (-0.17,-0.04)			54.5

Table A.3 Comparison of different Coho multi-hatchery survival models using only yearling smolt releases (n=853) with different predictor variables, including linear and quadratic terms for weight and day (W, W^2, D, D^2), life-stage (ω_S), log river migration distance (M), and biomass of hatchery releases at release sites (R). The mean posterior coefficient estimates and 95% credible intervals () are shown for the different models and the full model with all predictor variables is in bold.

Release Strategy Predictors	Intercept	Release strategy effects						ΔLOOIC
		Weight	Weight^2	Day	Day^2	Releases	Migration	
W, W², D, D², R, M	-2.34 (-3.2,-1.6)	0.03 (-0.19,0.27)	-0.10 (-0.29,0.09)	0.08 (0.01,0.15)	-0.04 (-0.15,0.09)	-0.17 (-0.49,0.16)	0.5 (0.13,0.91)	0
W, W², D, D², R	-2.10 (-2.74,-1.53)	0.02 (-0.15,0.2)	-0.11 (-0.29,0.09)	0.08 (0.01,0.15)	-0.04 (-0.14,0.08)	-0.13 (-0.4,0.15)		14.7
W, W², D, D², M	-2.16 (-2.78,-1.55)	0.02 (-0.18,0.27)	-0.09 (-0.28,0.08)	0.09 (0.02,0.16)	-0.04 (-0.15,0.1)		0.33 (0.02,0.7)	28.0
W, W², D, D²	-2.01 (-2.54,-1.52)	0.02 (-0.16,0.24)	-0.10 (-0.27,0.08)	0.09 (0.02,0.16)	-0.04 (-0.14,0.08)			33.3

Table A.4. Hatchery-specific estimates for maximum Chinook survival from multi-hatchery hierarchical models. For each hatchery, the historical weight and day at release for maximum survival is shown for the 95% central distribution of release observations for the most commonly released life stage. The mean posterior and 95% credible intervals () are also shown for the model optimum release weights and days for maximizing survival. In cases where the model optimum is included in the 95% central distribution of release observations, the historical value for maximum survival will match the model optimum. Otherwise, the historical value for maximum survival is the weight or day within the range of historical values that is closest to the model optimum. Hatcheries are ordered alphabetically. The NA values for 95% credible intervals occur when there is no estimate of an optimal release day since the estimate of the D^2 coefficient is positive.

Hatchery	Life Stage	n	Historical 95% central distribution of releases		Release weight (g) for maximum survival		Release Julian day for maximum survival	
			Weight (g)	Julian Days	Historical	Model Optimum	Historical	Model Optimum
Big Qualicum R	sub-yearling	114	4 - 14	133 - 192	14	24 (17-59)	134	134 (113-151)
Capilano R	sub-yearling	133	3 - 10	121 - 173	10	20 (12-51)	121	100 (73-119)
Chehalis R	sub-yearling	22	5 - 7	144 - 171	7	18 (0-45)	145	145 (108-189)
Chilliwack R	sub-yearling	45	5 - 6	122 - 161	6	19 (5-50)	122	116 (76-148)
Cowichan R	sub-yearling	107	3 - 10	91 - 169	10	12 (2-30)	135	135 (119-152)
Eagle R	sub-yearling	16	3 - 7	130 - 173	7	22 (14-50)	139	139 (115-165)
Gillard Pass	sub-yearling	5	4 - 6	140 - 155	6	22 (13-51)	140	121 (72-160)
Inch Cr	sub-yearling	6	6 - 7	147 - 151	7	20 (4-50)	147	130 (72-180)
L Qualicum R	sub-yearling	46	5 - 8	140 - 167	8	18 (6-48)	140	117 (70-152)
Nanaimo R	sub-yearling	34	4 - 16	122 - 205	16	21 (12-51)	130	130 (102-154)
Penny	yearling	18	9 - 14	68 - 109	14	19 (7-46)	109	155 (135-173)
Lang Cr	sub-yearling	5	6 - 12	124 - 148	12	19 (4-50)	133	133 (86-180)
Puntledge R	sub-yearling	162	4 - 10	145 - 174	10	22 (15-58)	145	128 (107-146)
Quinsam R	sub-yearling	386	3 - 14	112 - 188	14	18 (13-43)	146	146 (133-160)
Robertson Cr	sub-yearling	233	4 - 8	137 - 165	8	28 (19-69)	137	123 (106-139)
Rosewall Cr	sub-yearling	10	3 - 7	143 - 159	7	20 (6-51)	143	133 (87-183)
Shuswap R	sub-yearling	28	5 - 9	130 - 148	9	17 (6-39)	130	116 (72-151)
Snootli Cr	sub-yearling	16	4 - 5	156 - 167	5	23 (15-50)	156	132 (83-178)
Spius Cr	yearling	61	11 - 19	98 - 124	18	18 (12-38)	124	135 (107-163)
Deep Cr	fry	55	2 - 3	118 - 166	3	30 (21-74)	157	157 (135-183)
Toboggan Cr	yearling	18	10 - 16	106 - 133	16	18 (5-44)	106	97 (34-138)

Table A.5. Hatchery-specific estimates for maximum Coho survival from multi-hatchery hierarchical models. For each hatchery, the historical weight and day at release for maximum survival is shown for the 95% central distribution of release observations for the most commonly released life stage. The mean posterior and 80% credible intervals () are also shown for the model optimum release weights and days for maximizing survival. In cases where the model optimum is included in the 95% central distribution of release observations, the historical value for maximum survival will match the model optimum. Otherwise, the historical value for maximum survival is the weight or day within the range of historical values that is closest to the model optimum. Hatcheries are ordered alphabetically. The NA values for posterior mean or upper 80% credible intervals occur when there is no estimate of an optimal release weight or day since the estimate of the W^2 or D^2 coefficient is positive.

Hatchery	Life Stage	n	Historical 95% central distribution of releases		Release weight (g) for maximum survival		Release Julian day for maximum survival	
			Weight (g)	Julian Days	Historical	Model Optimum	Historical	Model Optimum
Big Qualicum R	yearling	62	8 - 28	124 - 172	28	43 (21-NA)	155	155 (149-177)
Capilano R	yearling	173	13 - 30	127 - 190	25	25 (21-39)	156	156 (149-163)
Chilliwack R	yearling	38	18 - 23	123 - 142	23	28 (17-NA)	142	161 (150-NA)
Eagle R	fry	36	2 - 11	137 - 286	11	21 (14-NA)	183	183 (159-365)
Goldstream R	yearling	10	17 - 22	105 - 142	22	32 (19-NA)	142	162 (150-NA)
McLaughlin Cr	yearling	20	15 - 28	89 - 141	19	19 (13-22)	141	161 (150-NA)
Inch Cr	yearling	76	16 - 33	88 - 167	33	46 (28-NA)	156	156 (149-173)
Lang Cr	yearling	6	17 - 24	116 - 142	17	13 (0-NA)	142	172 (152-NA)
Puntledge R	yearling	71	17 - 27	119 - 152	18	18 (16-21)	152	171 (153-197)
Quinsam R	yearling	229	18 - 32	110 - 171	NA	NA	160	160 (150-172)
Robertson Cr	yearling	70	16 - 29	100 - 143	18	18 (12-21)	143	156 (149-168)
Rosewall Cr	fry	14	2	132 - 174	2	23 (14-NA)	162	162 (150-NA)
Spius Cr	yearling	31	11 - 20	128 - 144	20	21 (18-36)	144	162 (150-NA)
Tenderfoot Cr	yearling	23	18 - 25	121 - 166	25	26 (17-NA)	160	160 (150-NA)
Dunn Cr	yearling	24	12 - 22	108 - 170	22	45 (24-NA)	170	365 (187-NA)
Toboggan Cr	yearling	8	11 - 17	123 - 153	17	24 (14-NA)	NA	NA

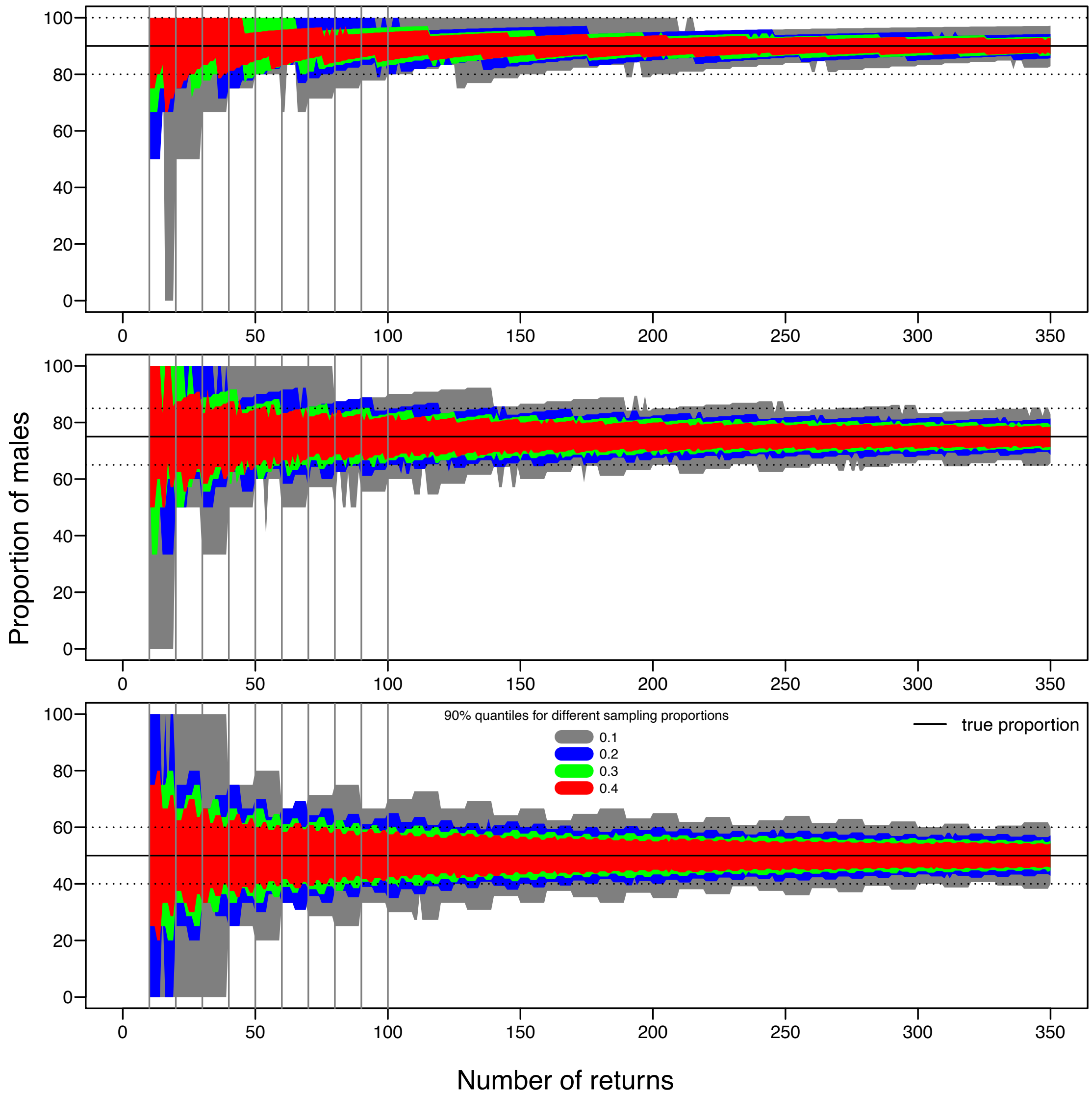


Figure A.1. Uncertainty in sex-composition estimates for simulated returns with 90% (top panel), 75% (middle panel), and 50% (lower panel) males. The 90% quantiles for the estimated proportions of males are shown for sampling rates of 10% (grey), 20% (blue), 30% (green), and 40% (red) for different return numbers. Results are based on 10,000 simulated returns for each scenario, comprised of return numbers ranging from 10 to 350 (in increments of 10) with the 3 different sex-compositions and the 4 different sampling rates.

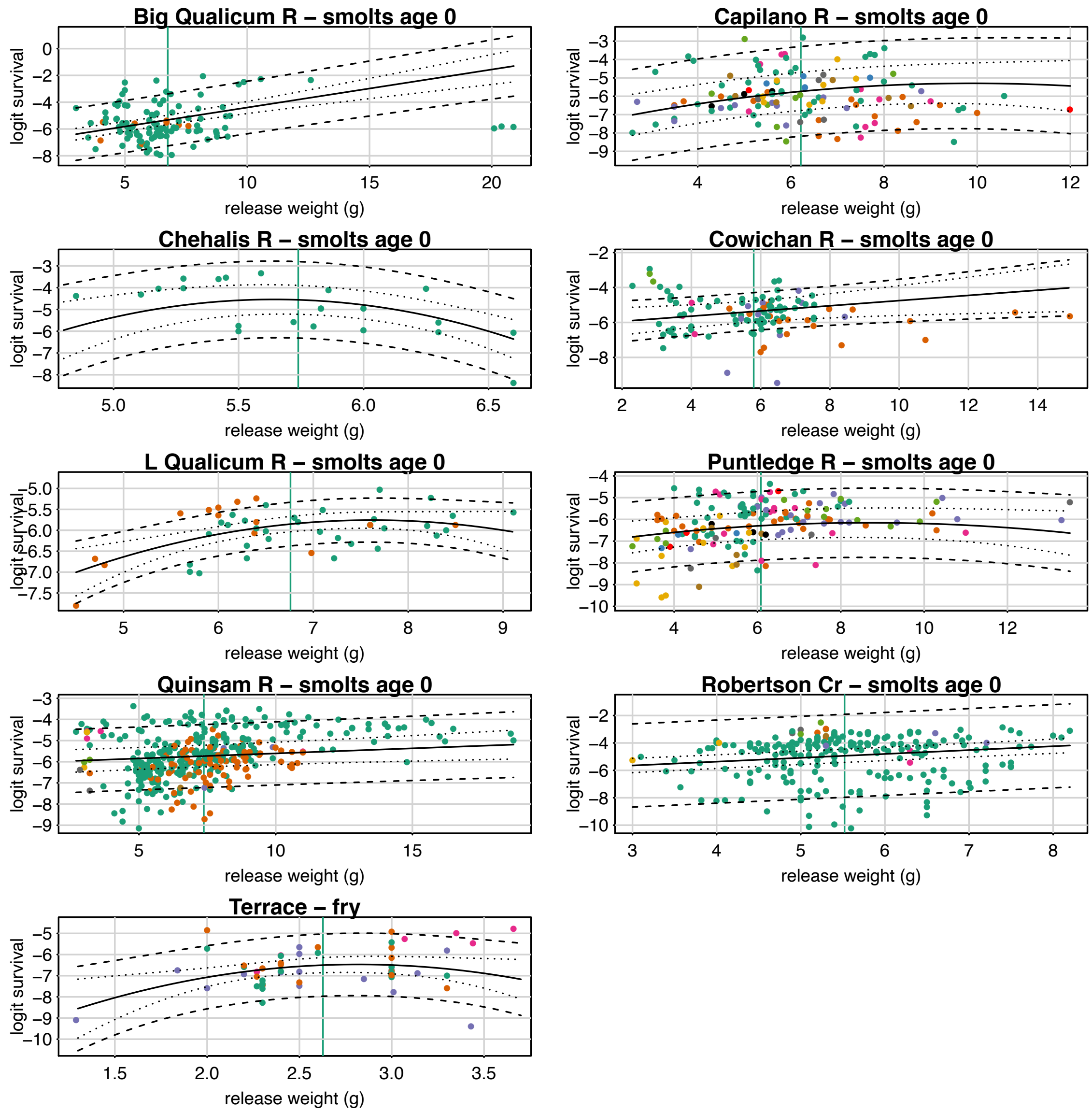


Figure A.2. Mean logit survival (solid line) for Chinook at different release weights for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). Different colours indicate different stocks released and the solid green vertical line indicates the mean weight-at-release.

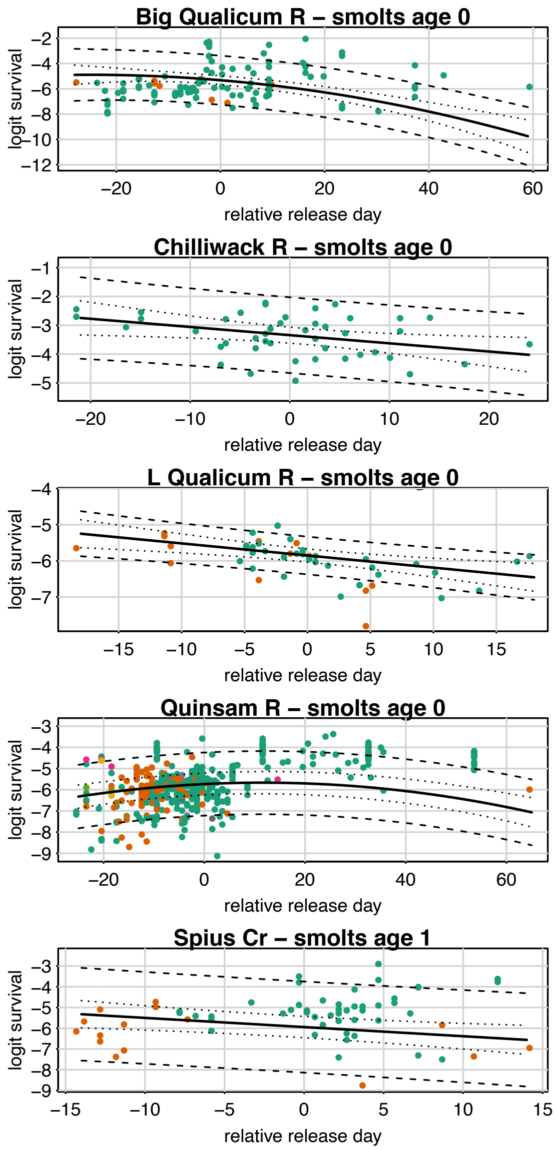


Figure A.3. Mean logit survival (solid line) for Chinook at release days for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). The zero day indicates the mean release date for a hatchery and different colours indicate different stocks.

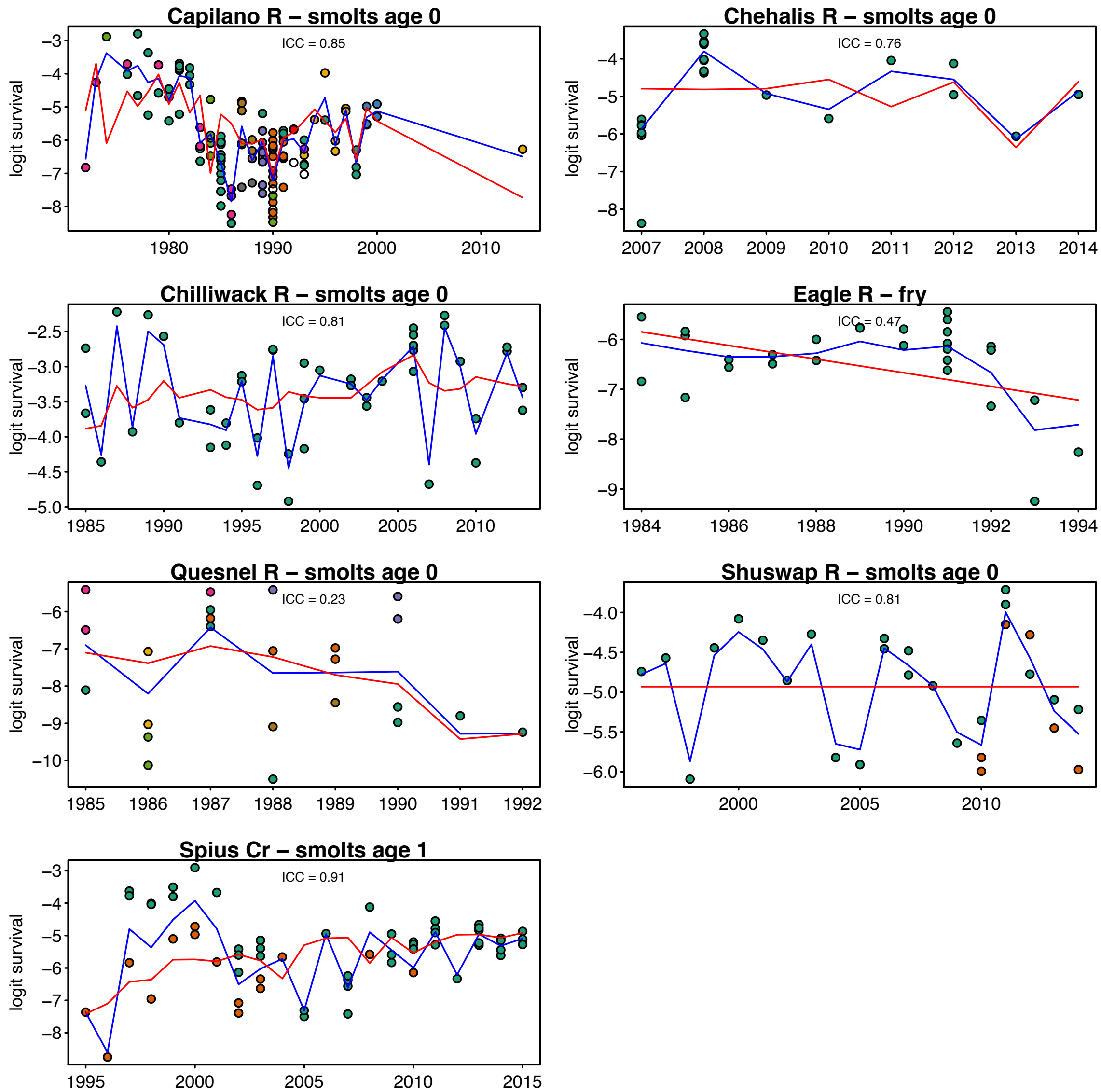


Figure A.4. Top model fits for Mainland BC hatcheries' average **Chinook logit survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects.

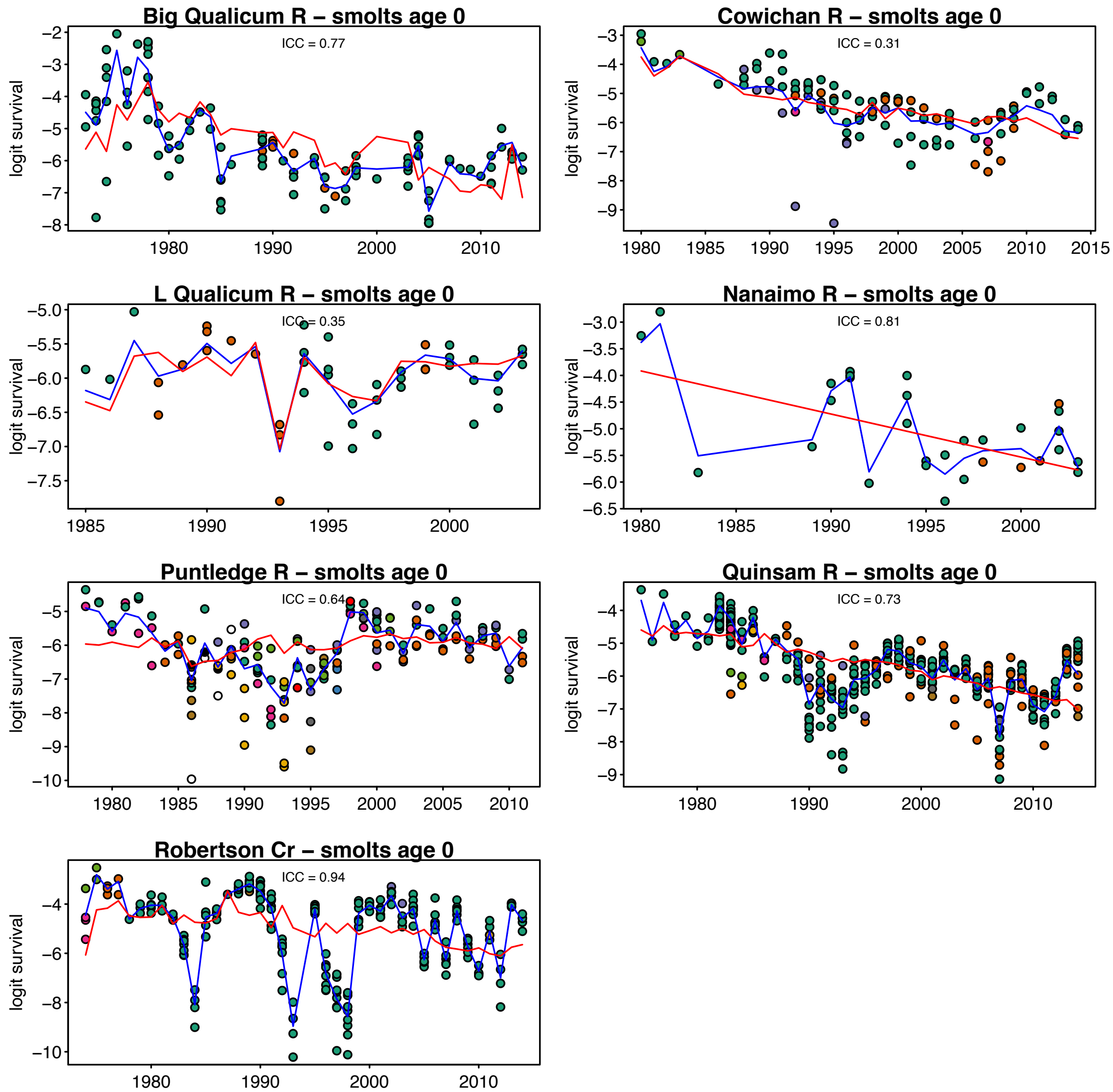


Figure A.5. Top model fits for Vancouver Island hatcheries' average **Chinook logit survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects.

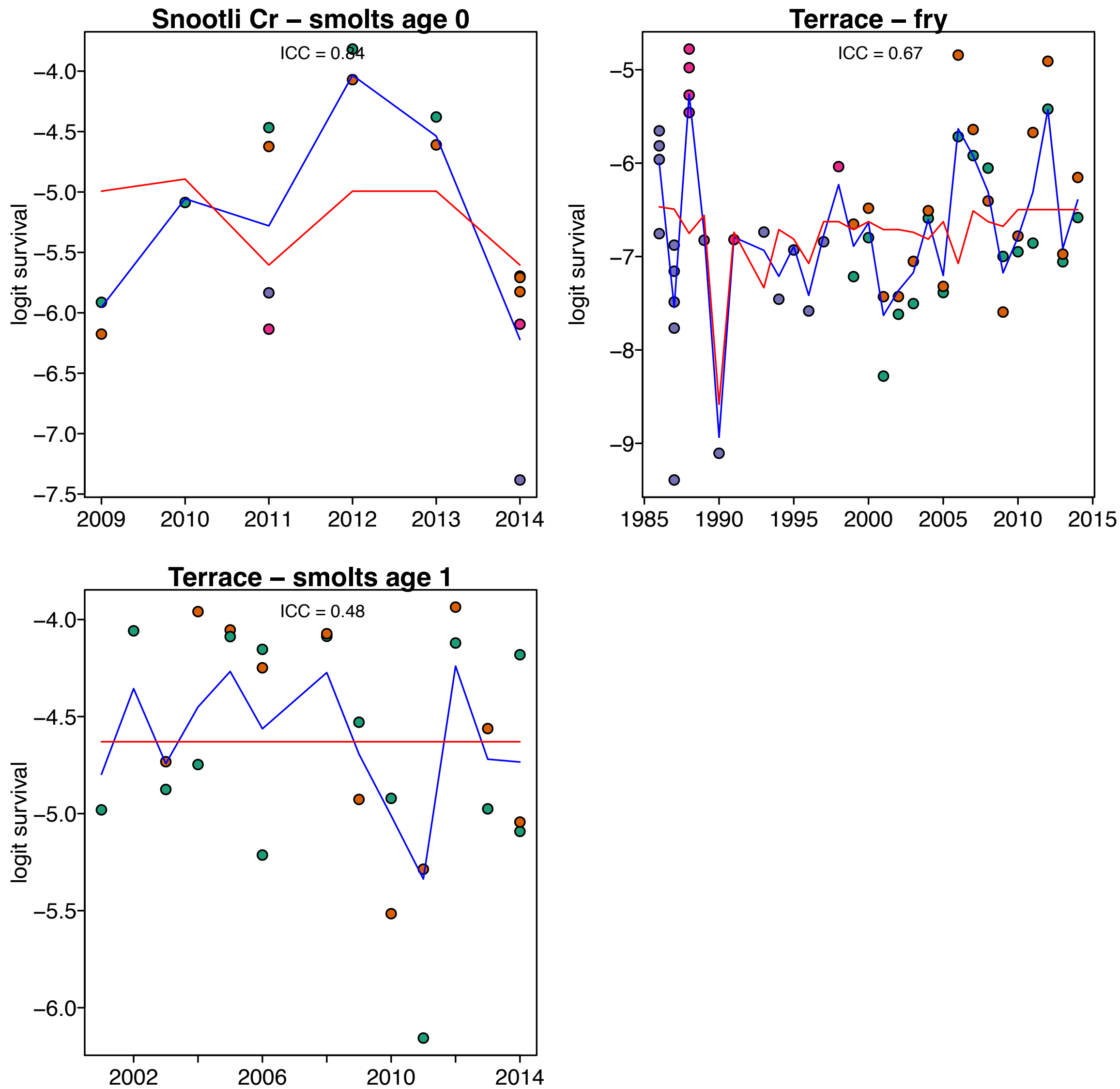


Figure A.6. Top model fits for Northern BC hatcheries' average **Chinook logit survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects.

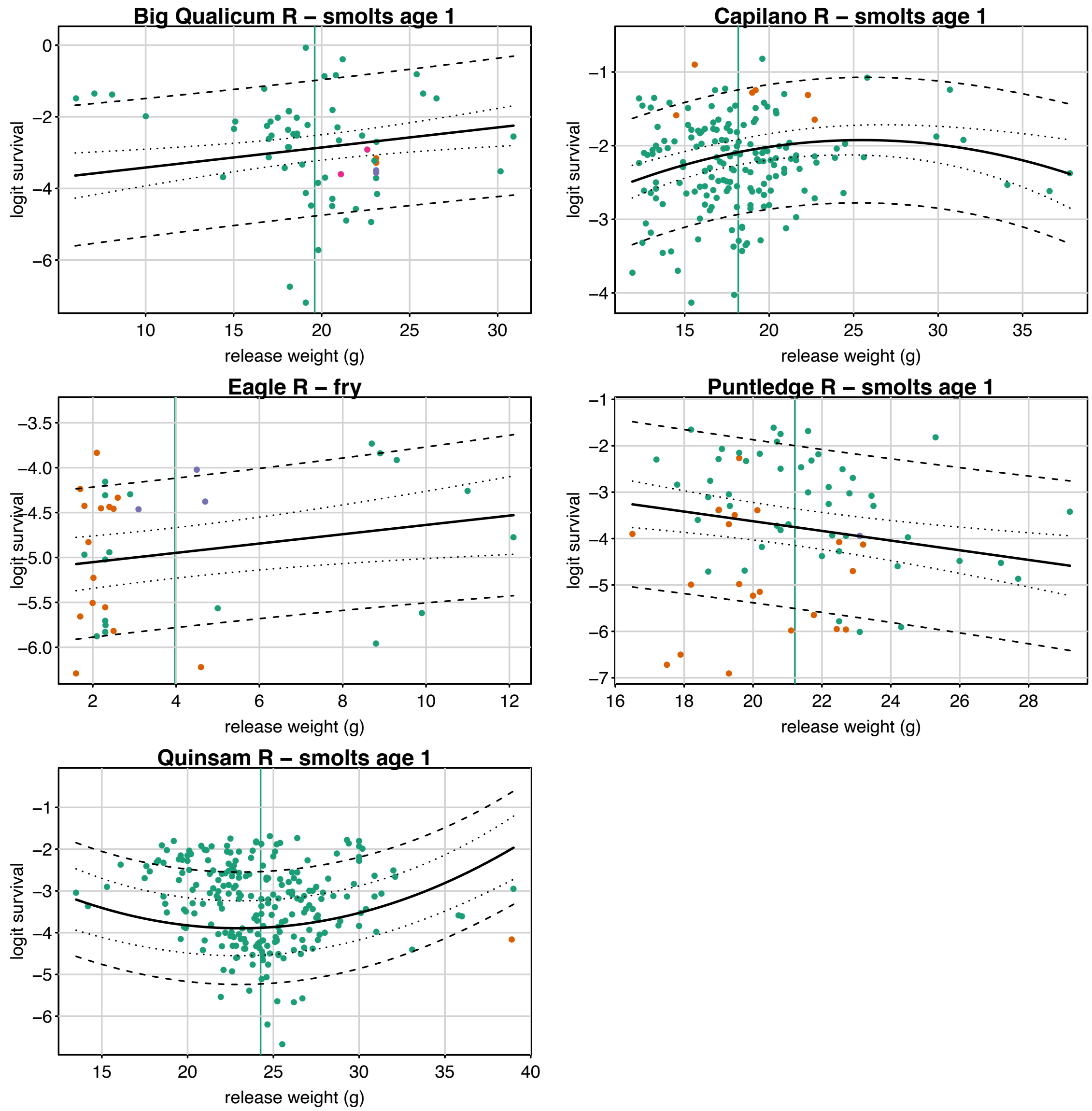


Figure A.7. Mean **logit survival** (solid line) for **Coho** at different release weights for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). Different colours indicate different stocks released and the solid green vertical line indicates the mean weight-at-release.

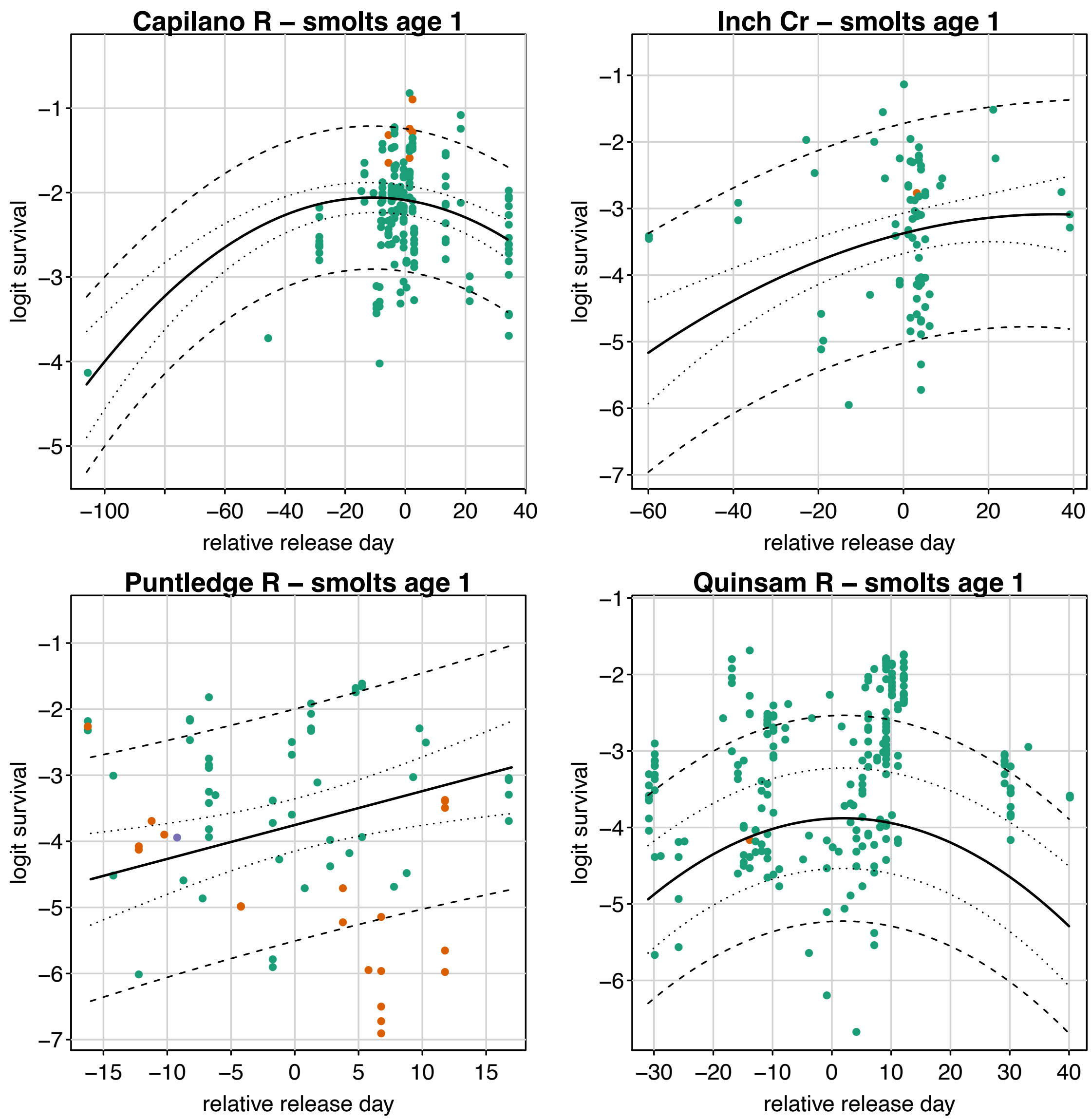


Figure A.8. Mean **logit survival** (solid line) for **Coho** at release days for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). The zero day indicates the mean release date for a hatchery and different colours indicate different stocks.

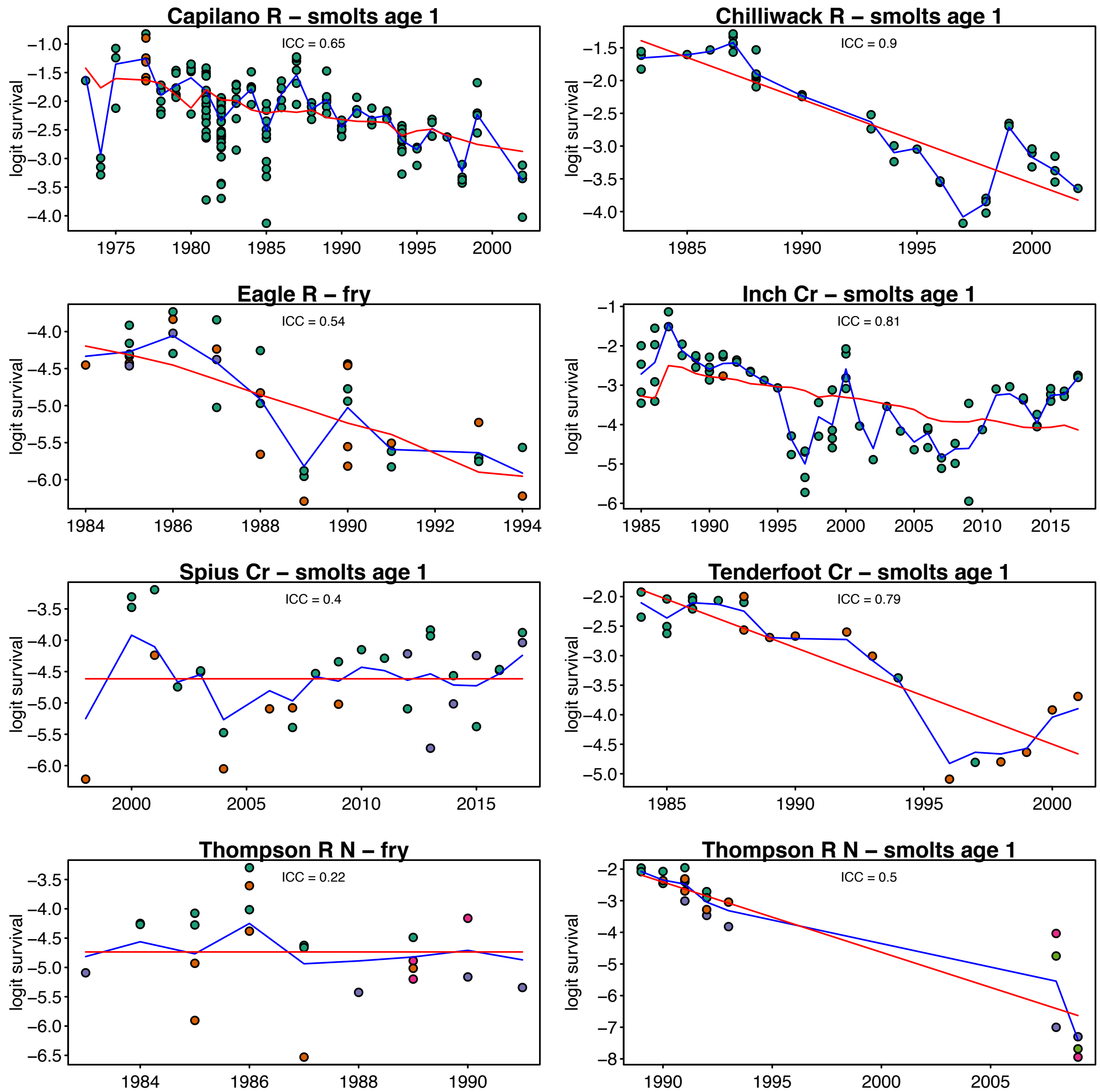


Figure A.9. Top model fits for Mainland BC hatcheries' average **Coho logit survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects.

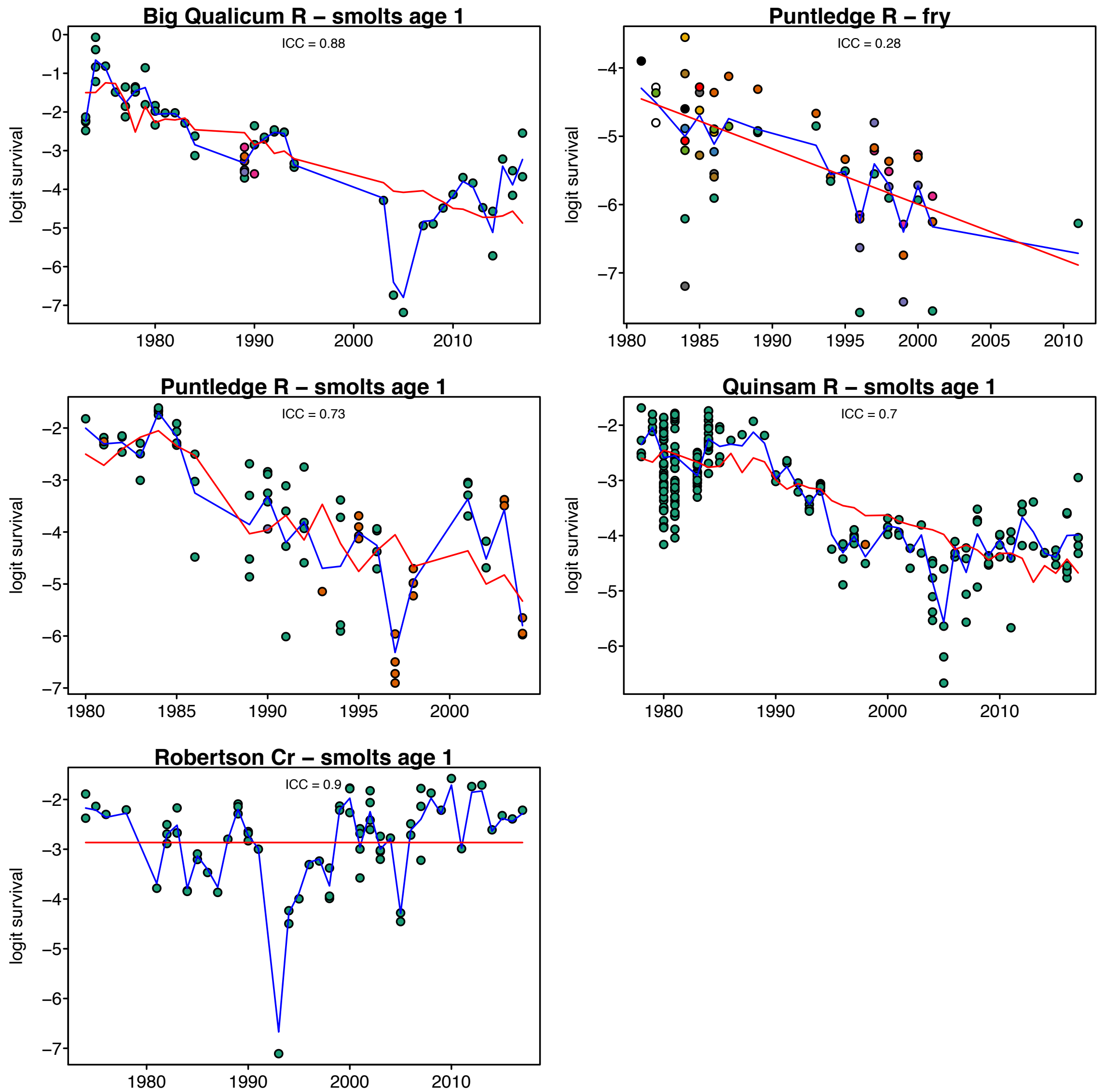


Figure A.10. Top model fits for Vancouver Island hatcheries' average **Coho logit survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects.

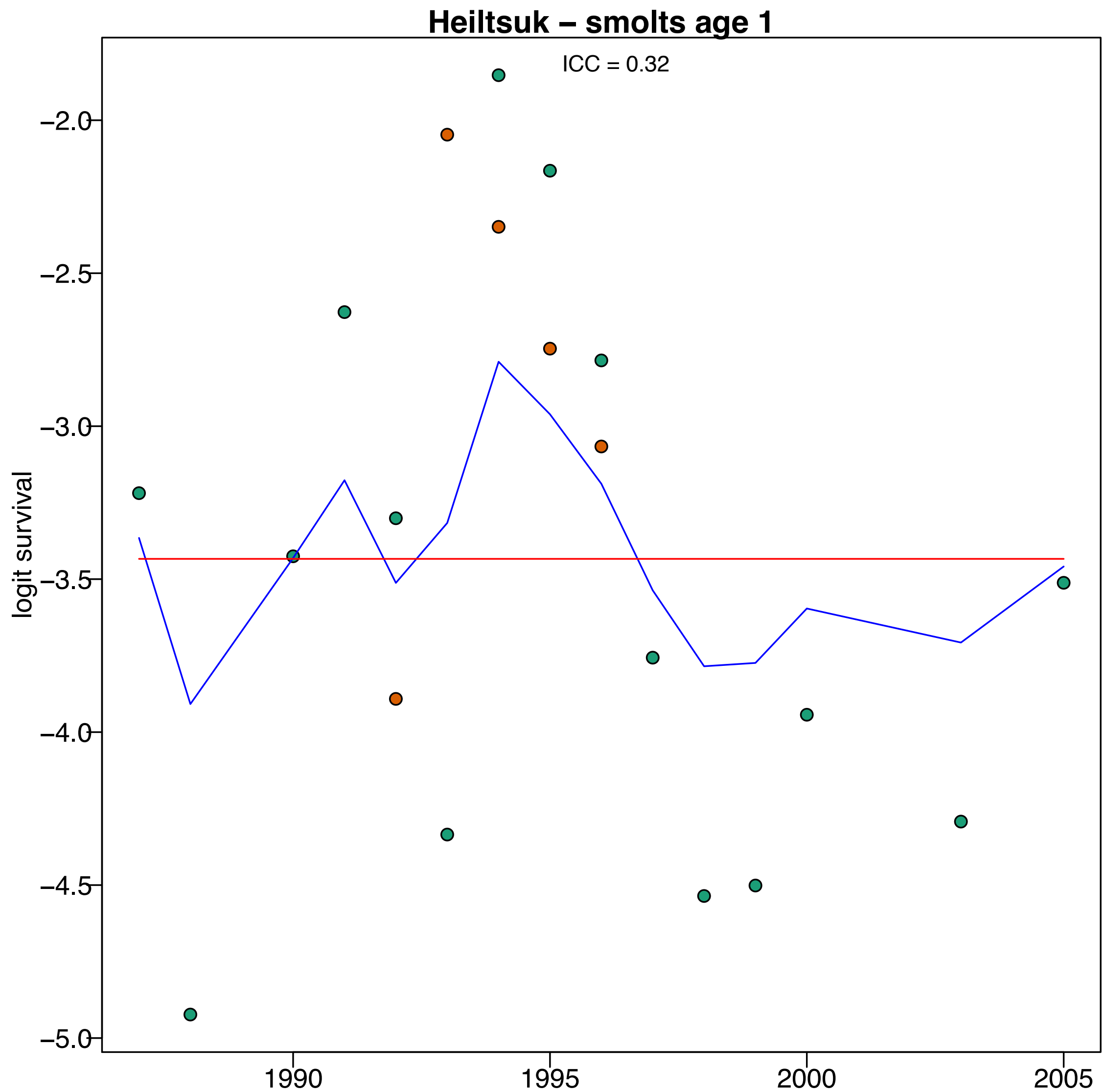


Figure A.11. Top model fits for Northern BC hatcheries' average **Coho logit survival** over time, accounting for all predictors (e.g. weight, day, year, stock, and release site) with (blue) and without (red) random year effects.

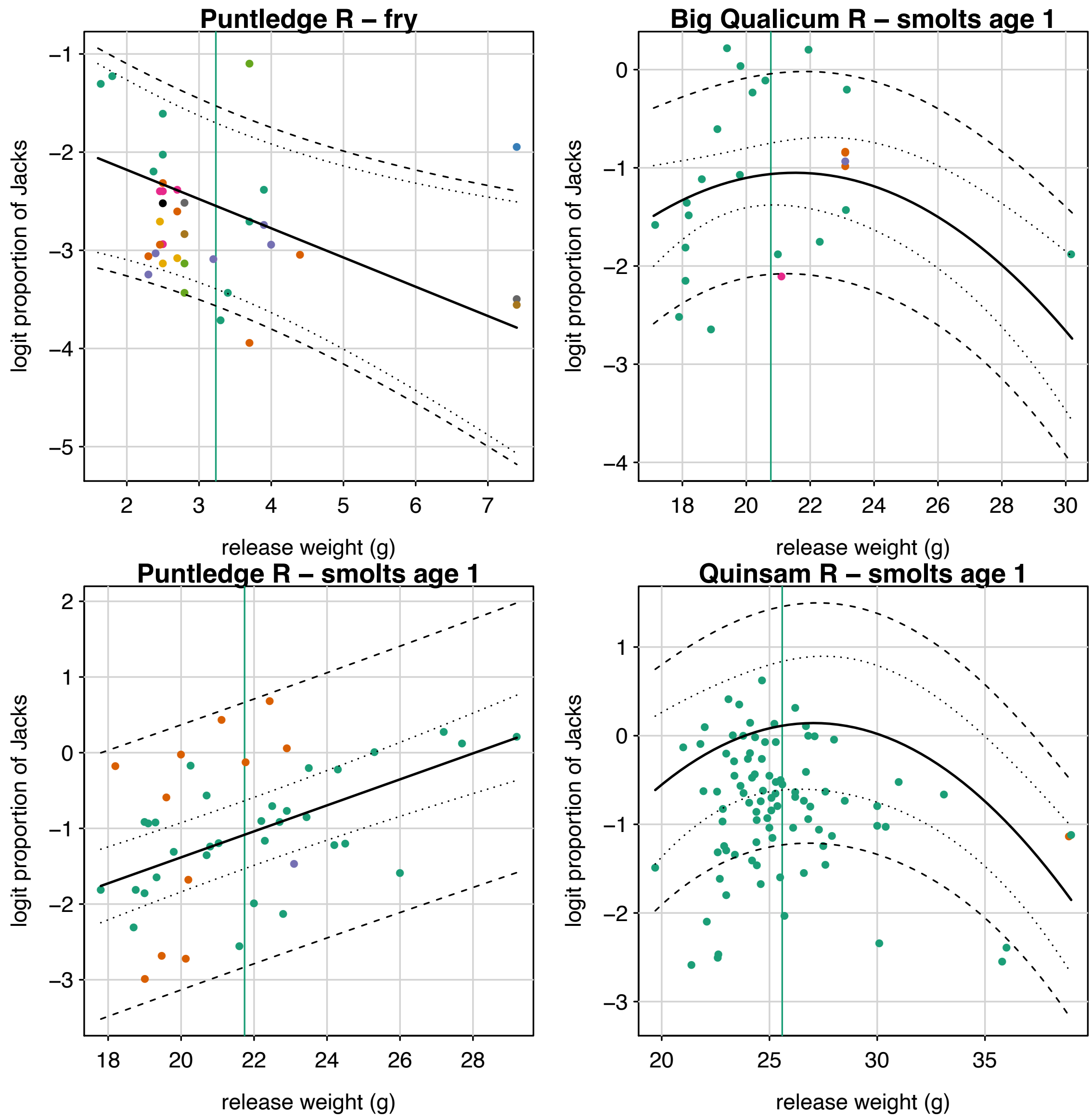


Figure A.12. Mean **logit proportion of age age-2 male returns** (solid line) for **Coho** at different release weights for hatchery and life-stage specific model fits. The 95% CIs are shown for fixed effects only (dotted lines) and for both fixed and random year effects (dashed lines). Different colours indicate different stocks released and the solid green vertical line indicates the mean weight-at-release.

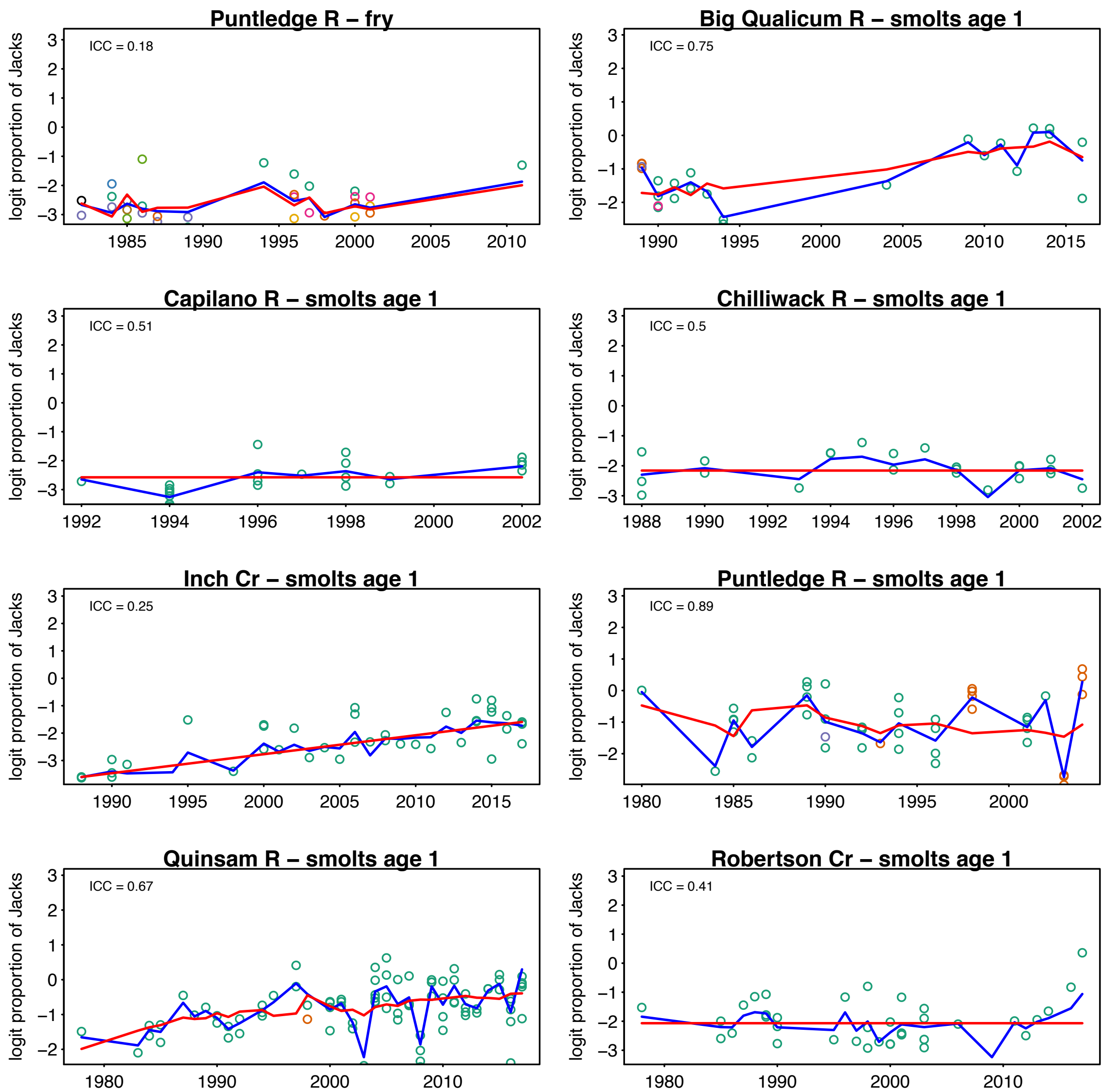


Figure A.13. Top model fits for BC hatcheries' **logit proportion of age-2 males** in **Coho** returns over time, accounting for all predictors (e.g. weight, proportion of females, stock and release site) with (blue) and without (red) random year effects.

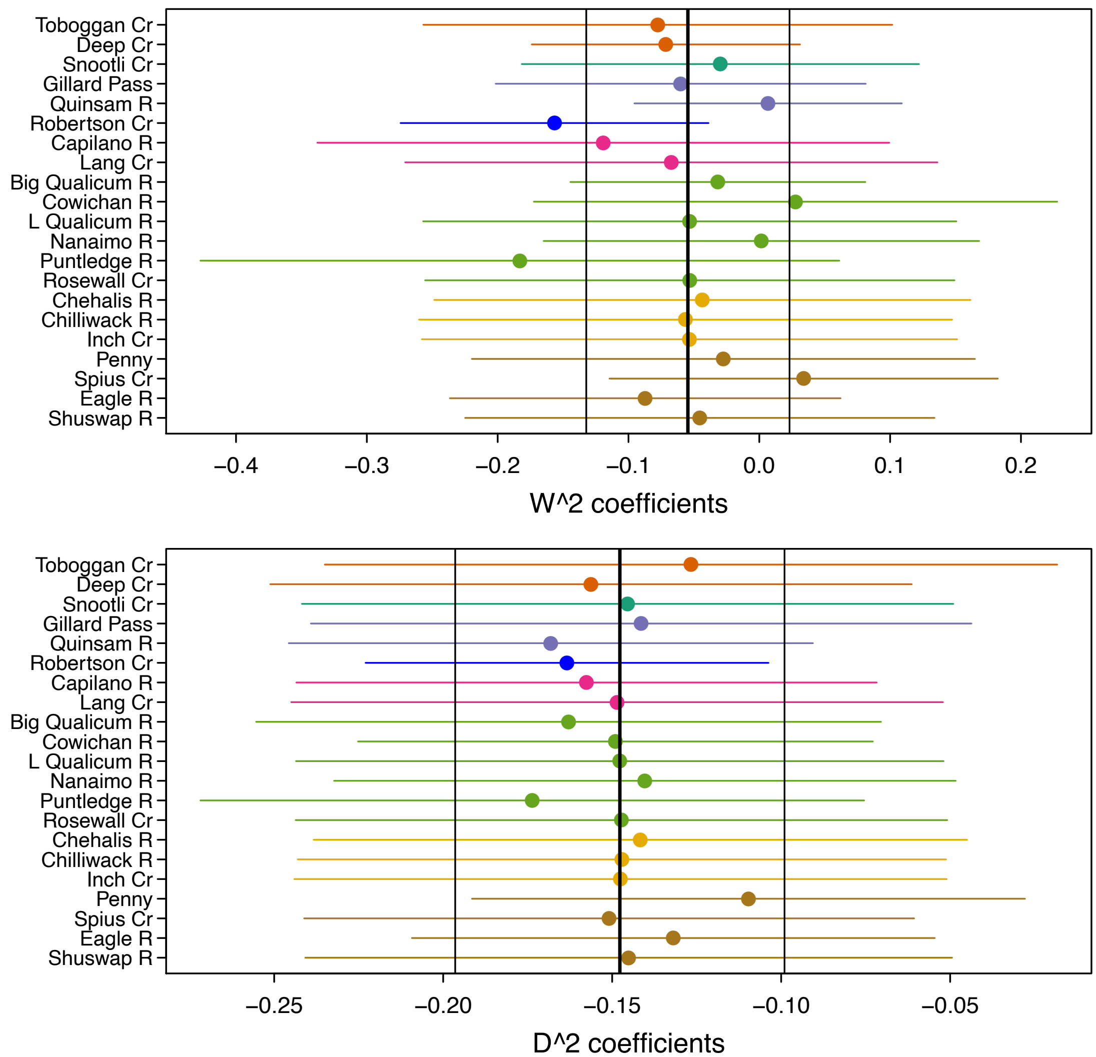


Figure A.14. Multi-hatchery Chinook survival model coefficient estimates for initial model fits including hatchery deviations for quadratic terms for *Weight* (W^2) and *Day* (D^2) at-release. The circles indicate hatchery specific estimates along with 95% CIs, while the vertical lines indicate the average effect (thick black line) across all hatcheries with 95% CIs (thin black lines).

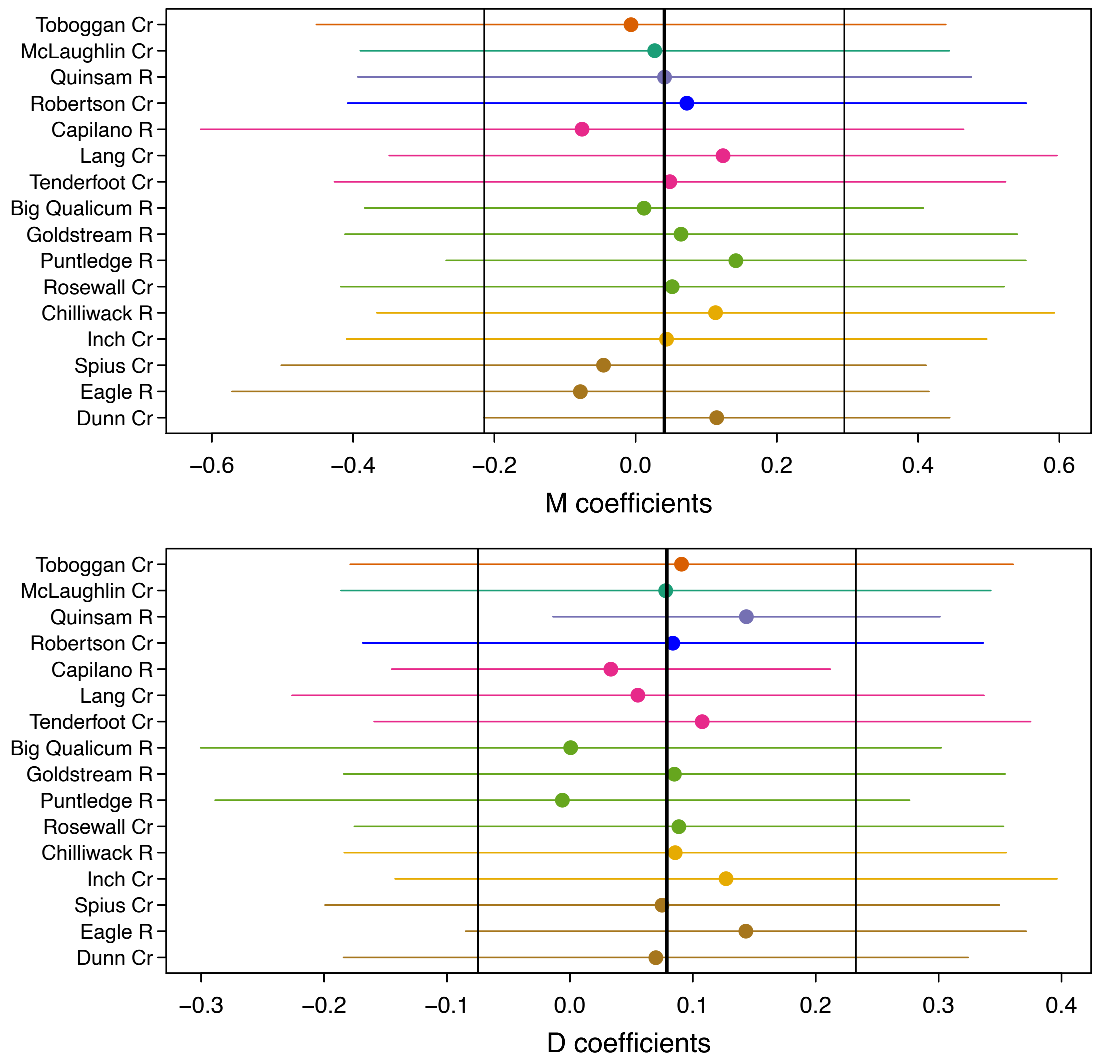


Figure A.15. Multi-hatchery Coho survival model coefficient estimates for initial model fits including hatchery deviations for river migration distance (*M*) and linear terms for *Day* (*D*) at-release. The circles indicate hatchery specific estimates along with 95% CIs, while the vertical lines indicate the average effect (thick black line) across all hatcheries with 95% CIs (thin black lines).

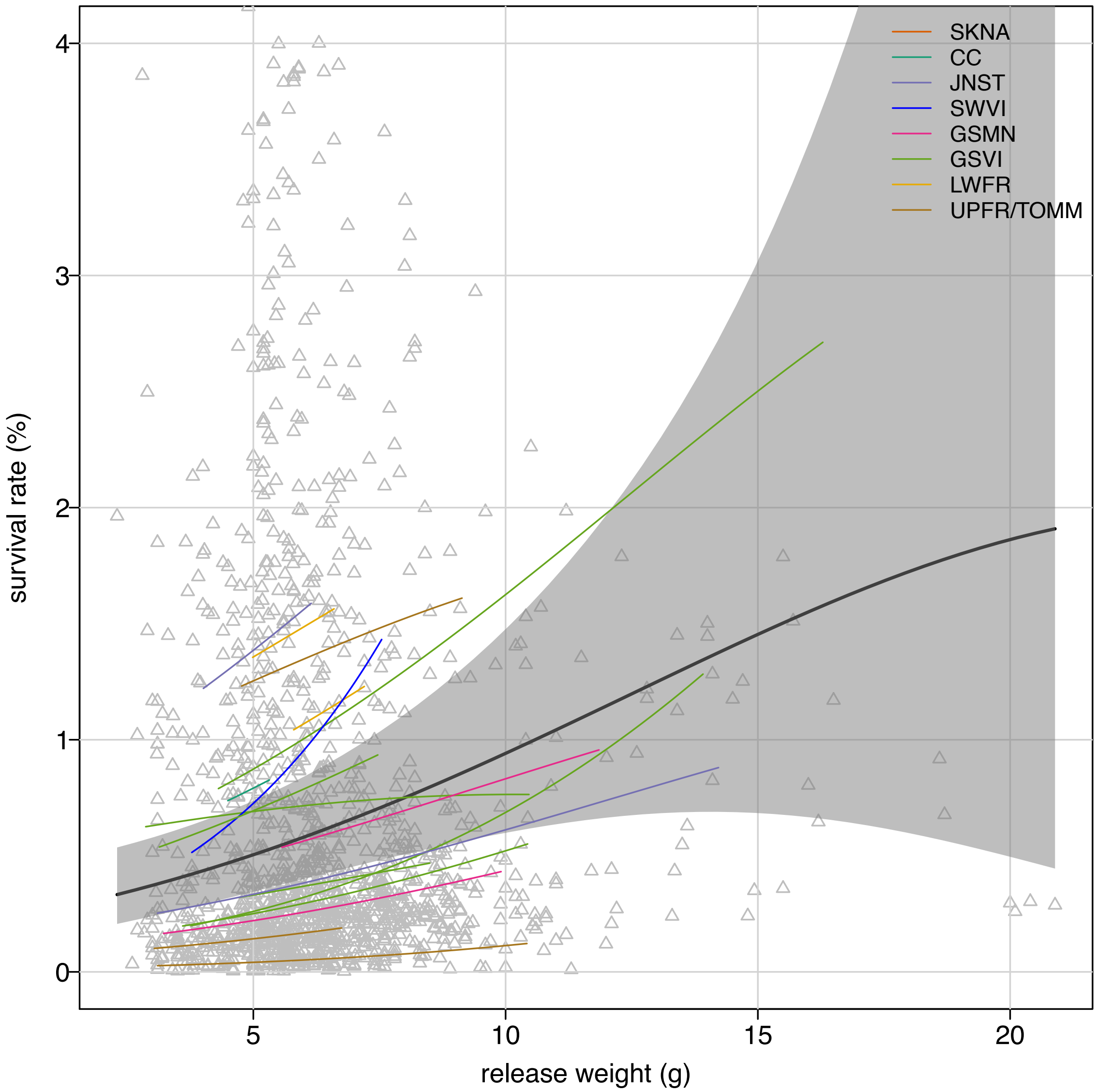


Figure A.16. Hatchery average **Chinook** survival and hatchery-specific survival responses for the central 95% distribution of observed weights-at-release for each hatchery for models fit with only **sub-yearling smolt data**. The black line (MLE) and shaded areas (95% CI) indicate the average weight effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLEs). Note observations with survival rates greater than 4% are not shown.

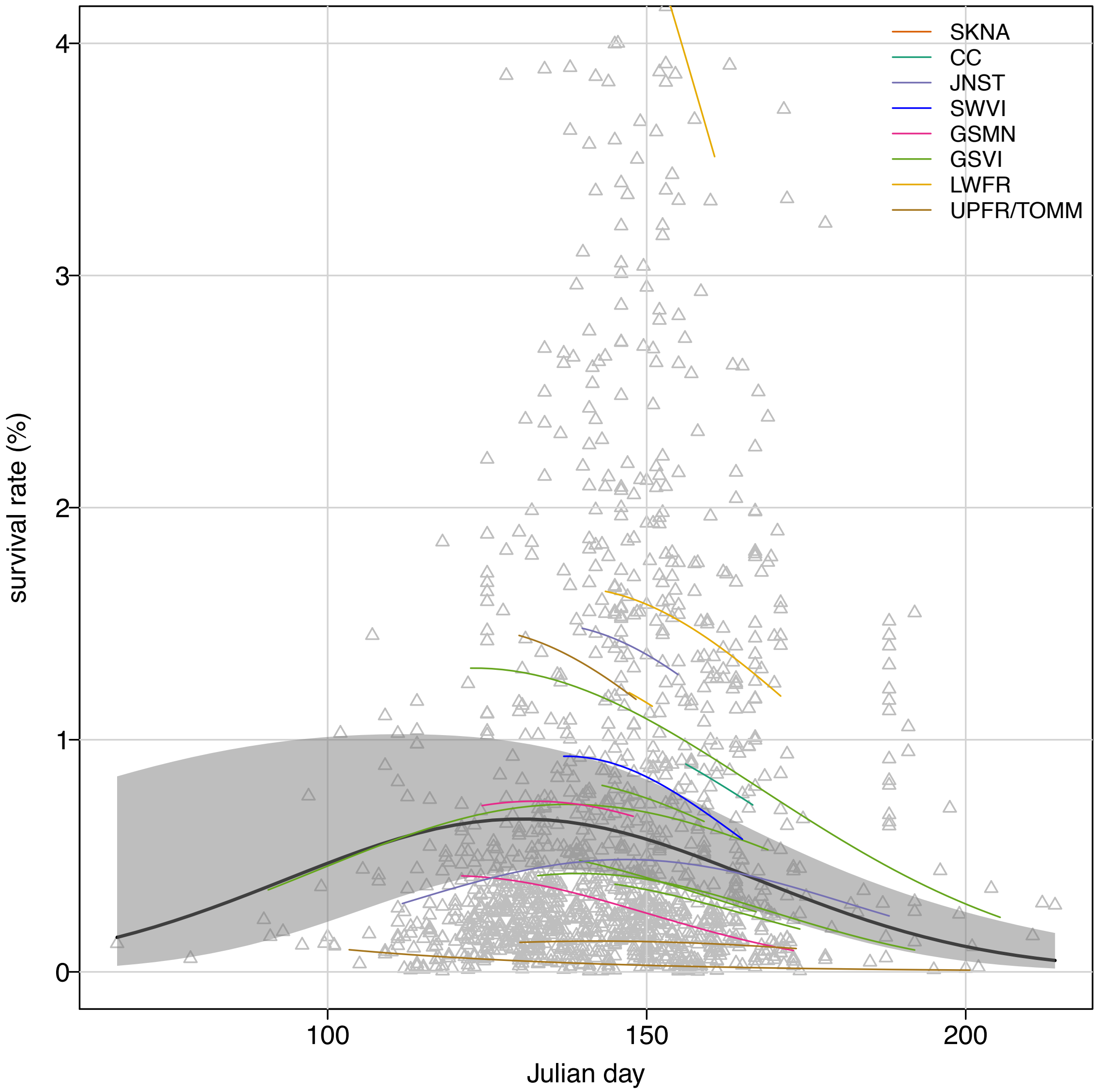


Figure A.17. Hatchery average **Chinook** survival and hatchery-specific survival responses for the central 95% distribution of observed days-at-release for each hatchery for models fit with only **sub-yearling smolt data**. The black line (MLE) and shaded areas (95% CI) indicate the average day effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLEs). Note observations with survival rates greater than 4% are not shown.

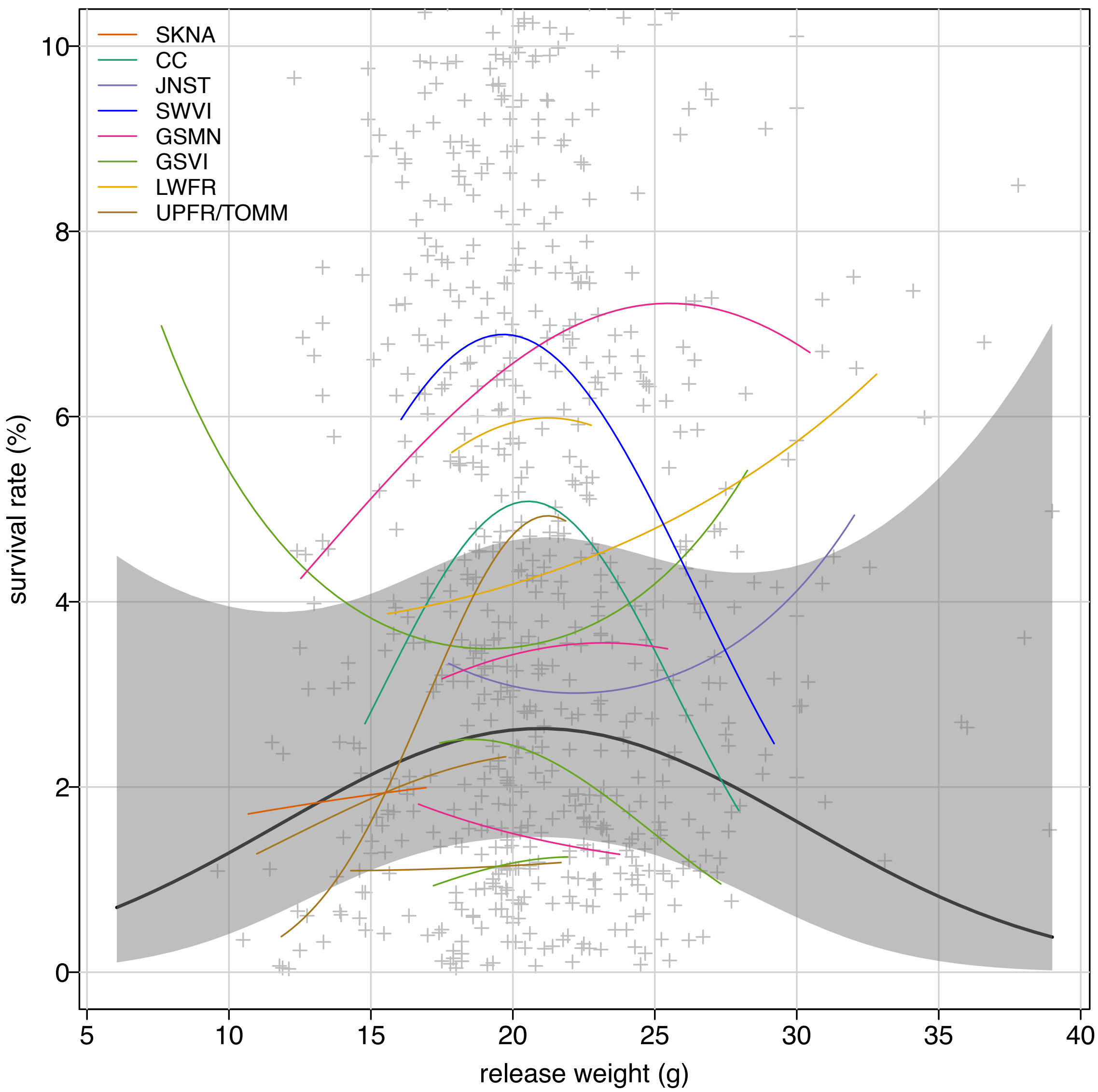


Figure A.18. Hatchery average **Coho** survival and hatchery-specific survival responses for the central 95% distribution of observed weights-at-release for each hatchery for models fit with only **yearling smolt data**. The black line (MLE) and shaded areas (95% CI) indicate the average weight effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLEs). Note observations with survival rates greater than 10% are not shown.

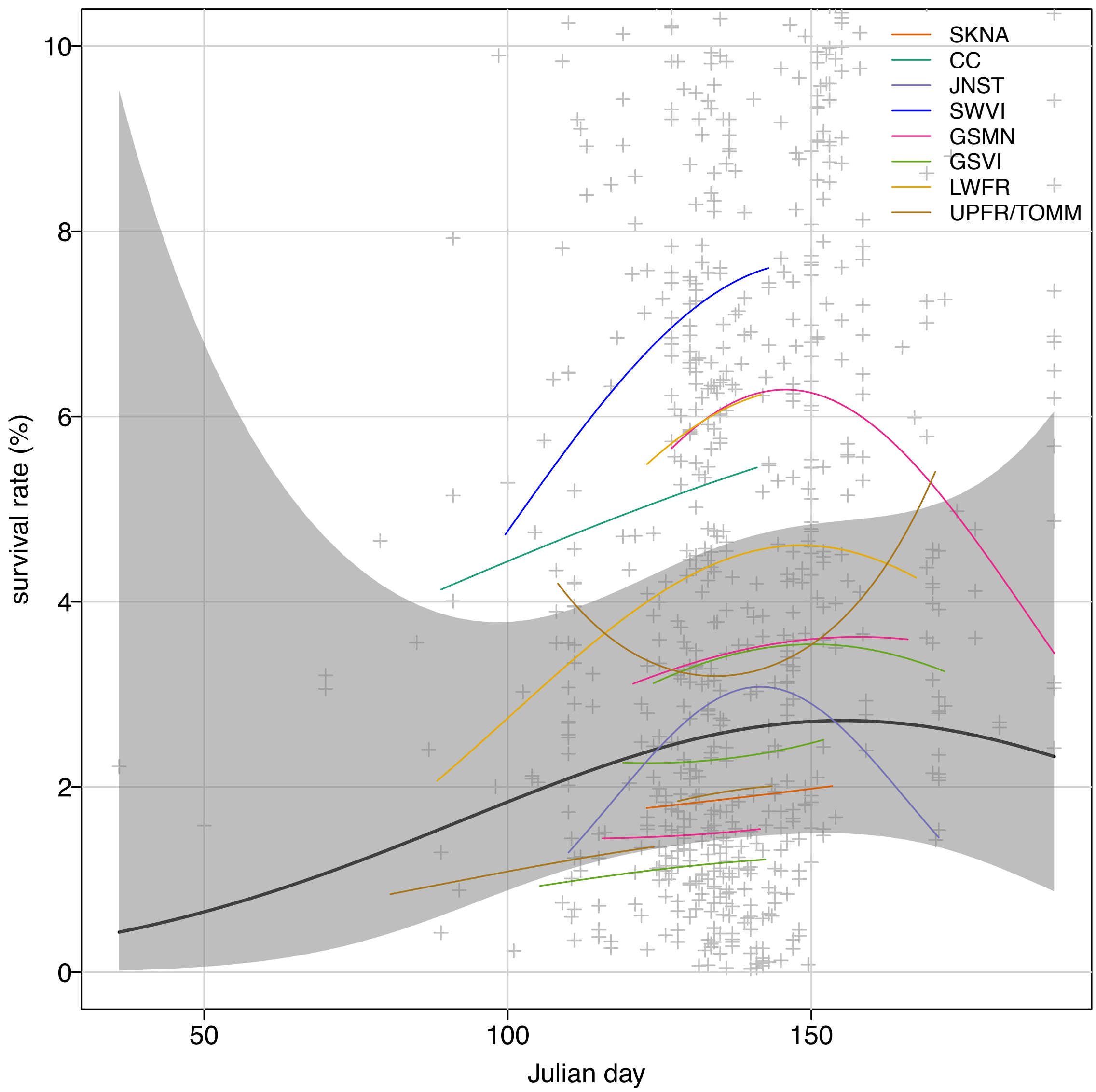


Figure A.19. Hatchery average **Coho** survival and hatchery-specific survival responses for the central 95% distribution of observed days-at-release for each hatchery for models fit with only **yearling smolt data**. The black line (MLE) and shaded areas (95% CI) indicate the average day effect on survival across all hatcheries, while coloured lines show hatchery-specific estimates (MLEs). Note observations with survival rates greater than 10% are not shown.

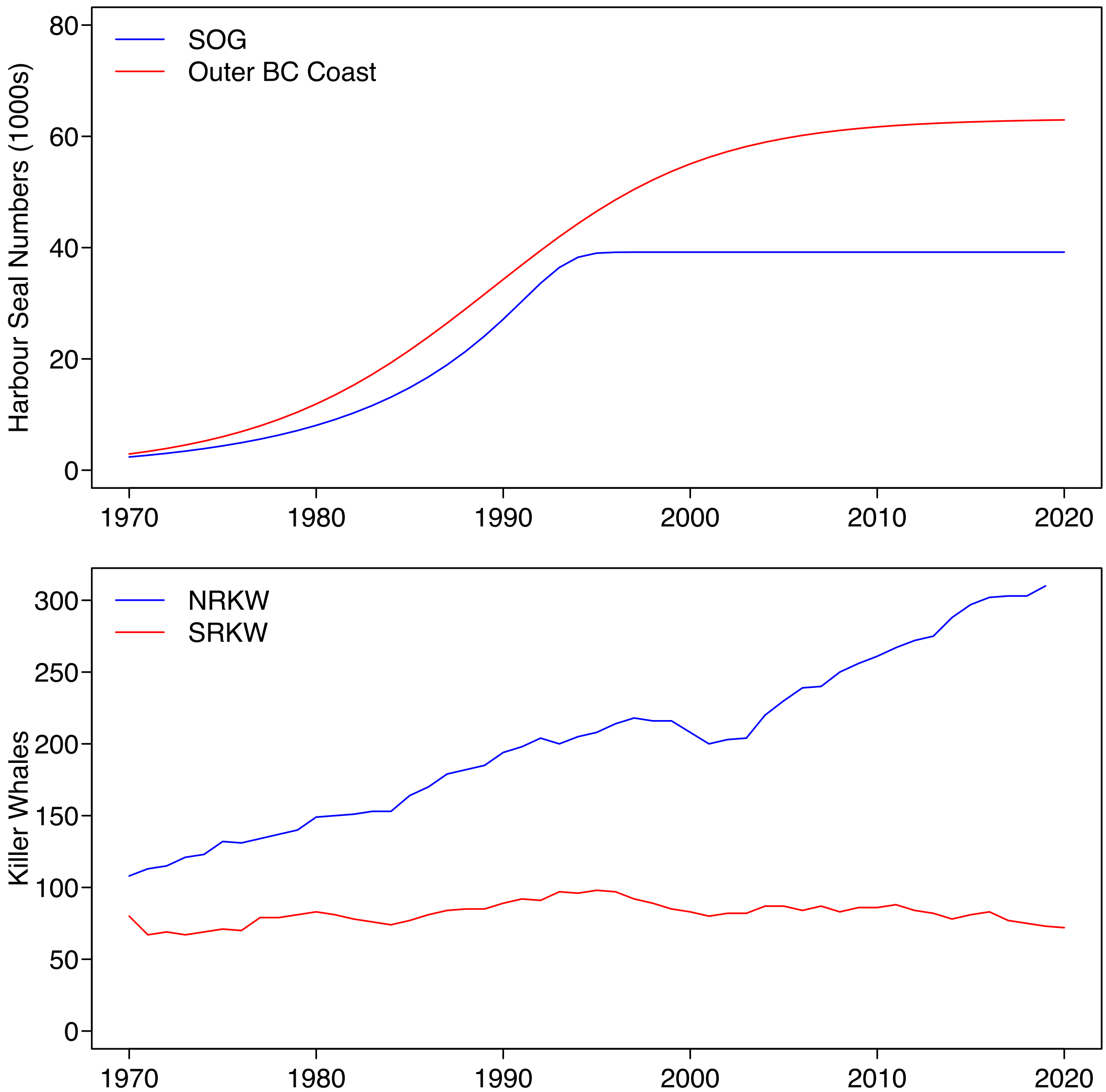


Figure A.20. Top: Harbour Seal numbers for the Strait of Georgia (SOG) and outer BC coast for 1970-2020 based on models from Olesiuk et al. 2010. Bottom: Annual numbers of Northern Resident Killer Whales (NRKW, Chasco et al. 2017, Towers et al. 2020) and Southern Resident Killer Whales (SRKW, Centre of Whale Research Data).

Appendix B

Maps of hatchery release sites

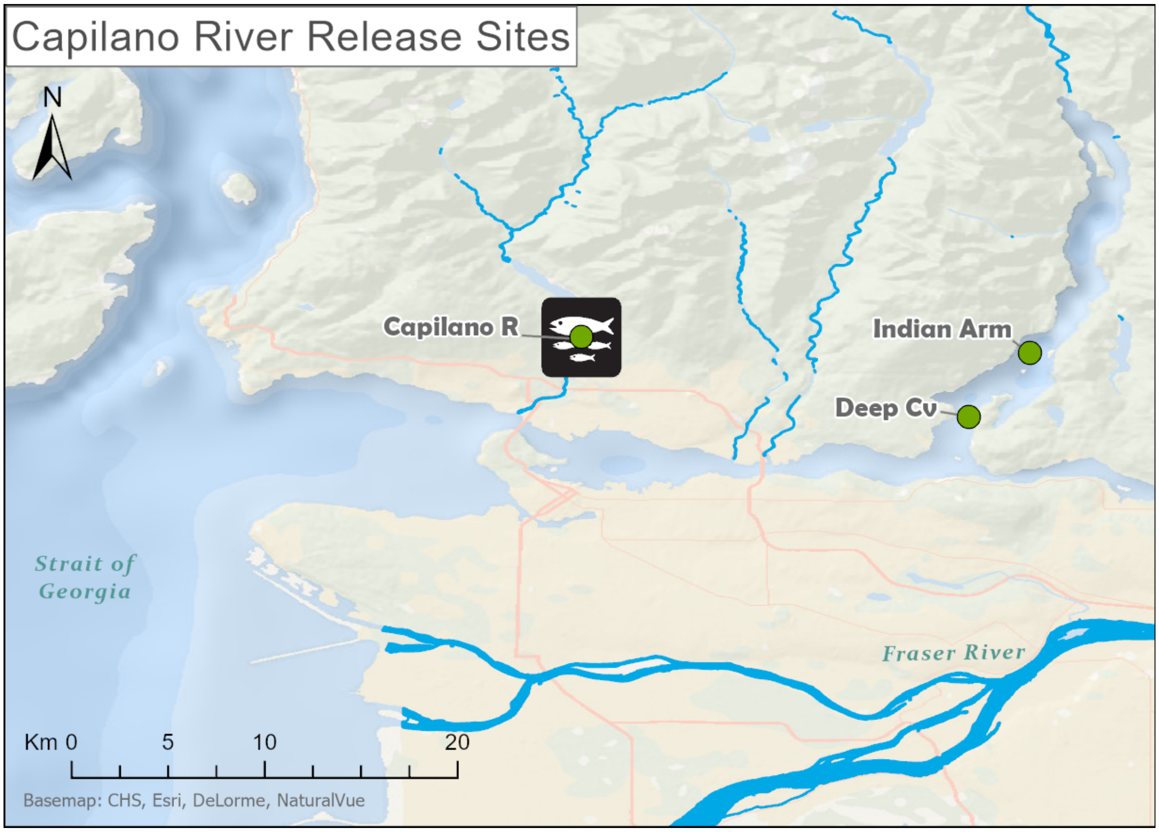


Figure B.1. Capilano River hatchery release sites

Figure B.2. Cowichan River hatchery release sites

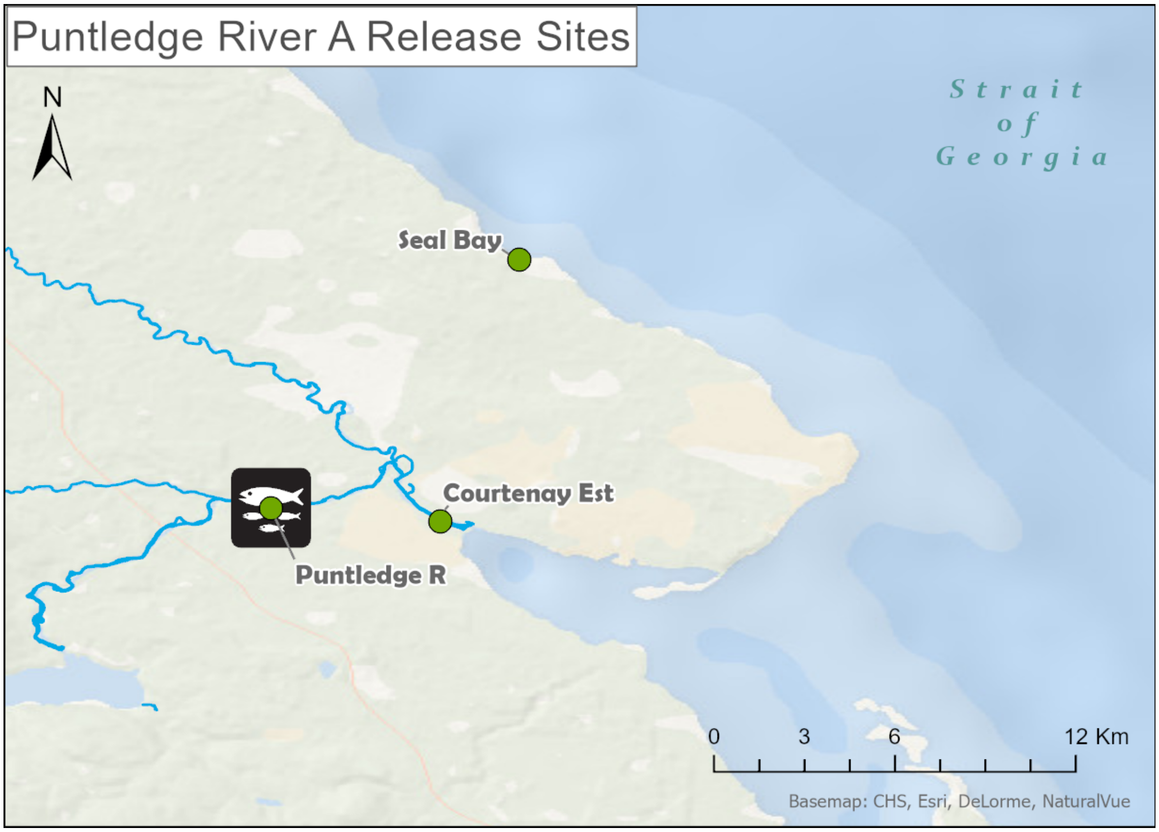


Figure B.3. Puntledge River hatchery release sites for Chinook sub-yearling smolts

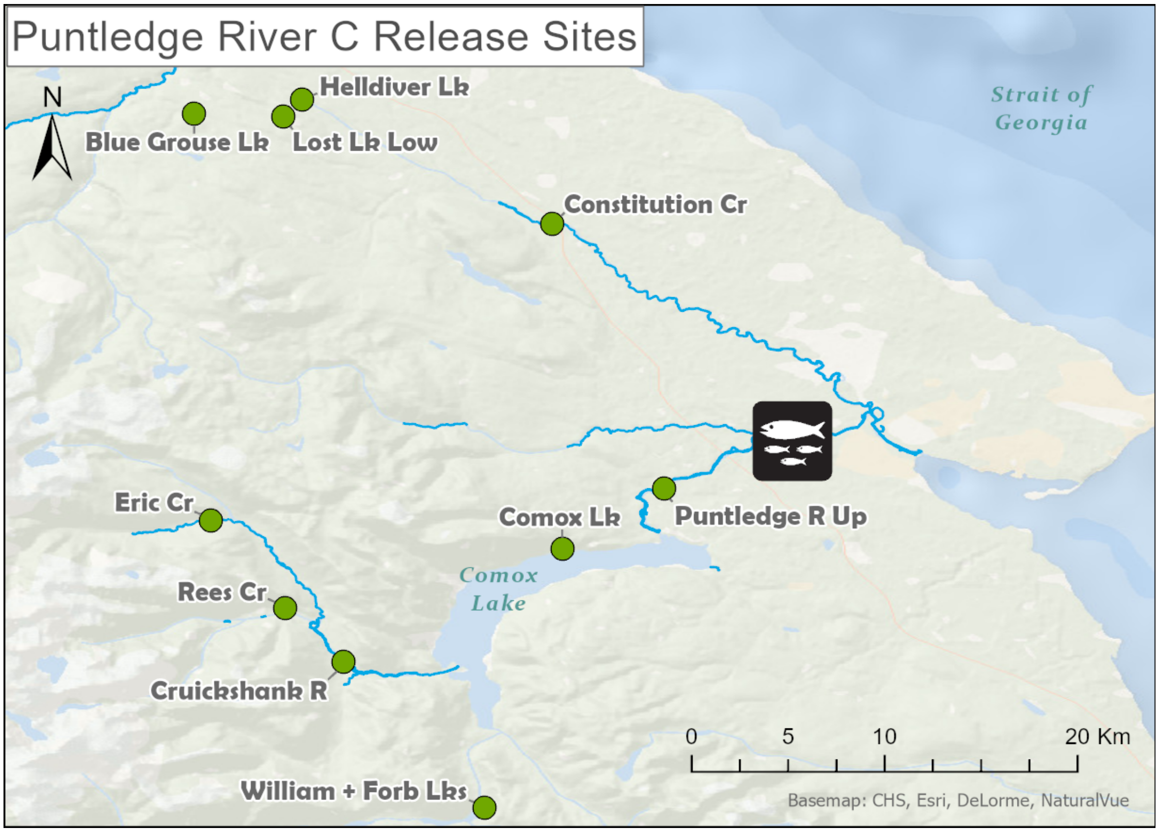


Figure B.4. Puntledge River hatchery release sites for Coho fry

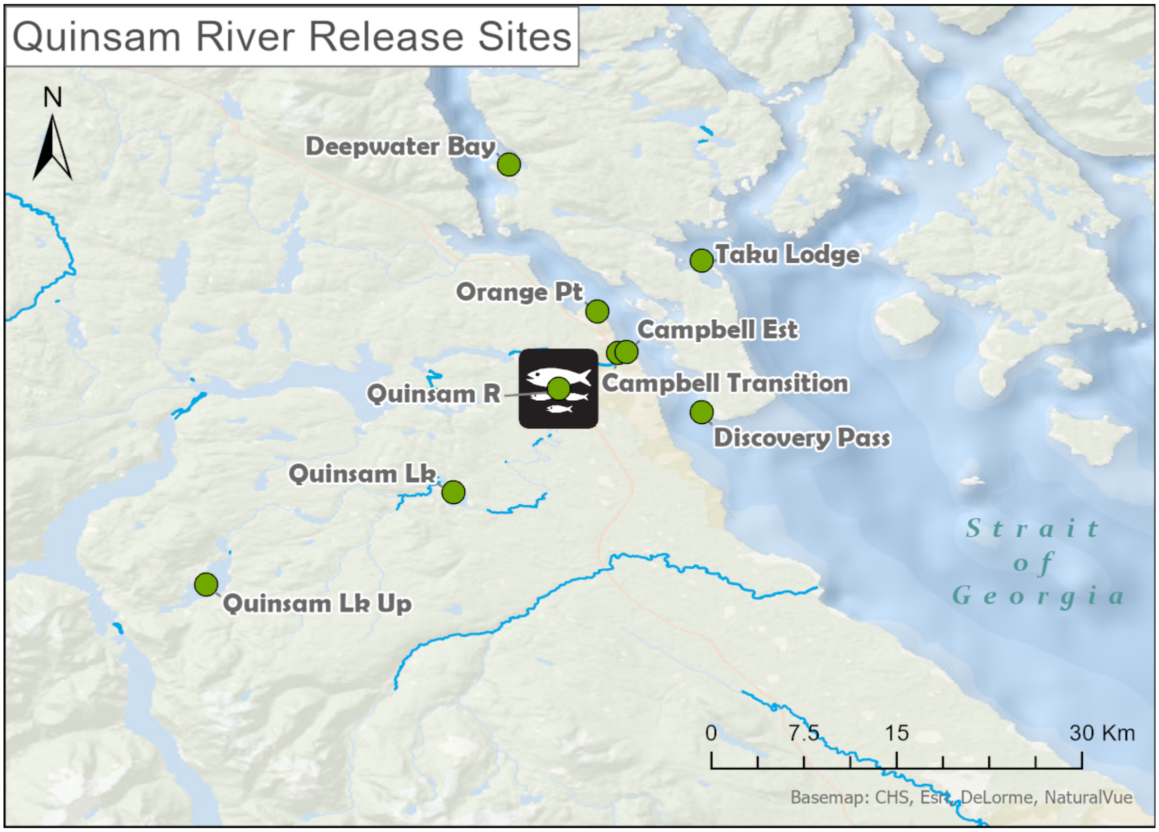


Figure B.5. Quinsam River hatchery release sites

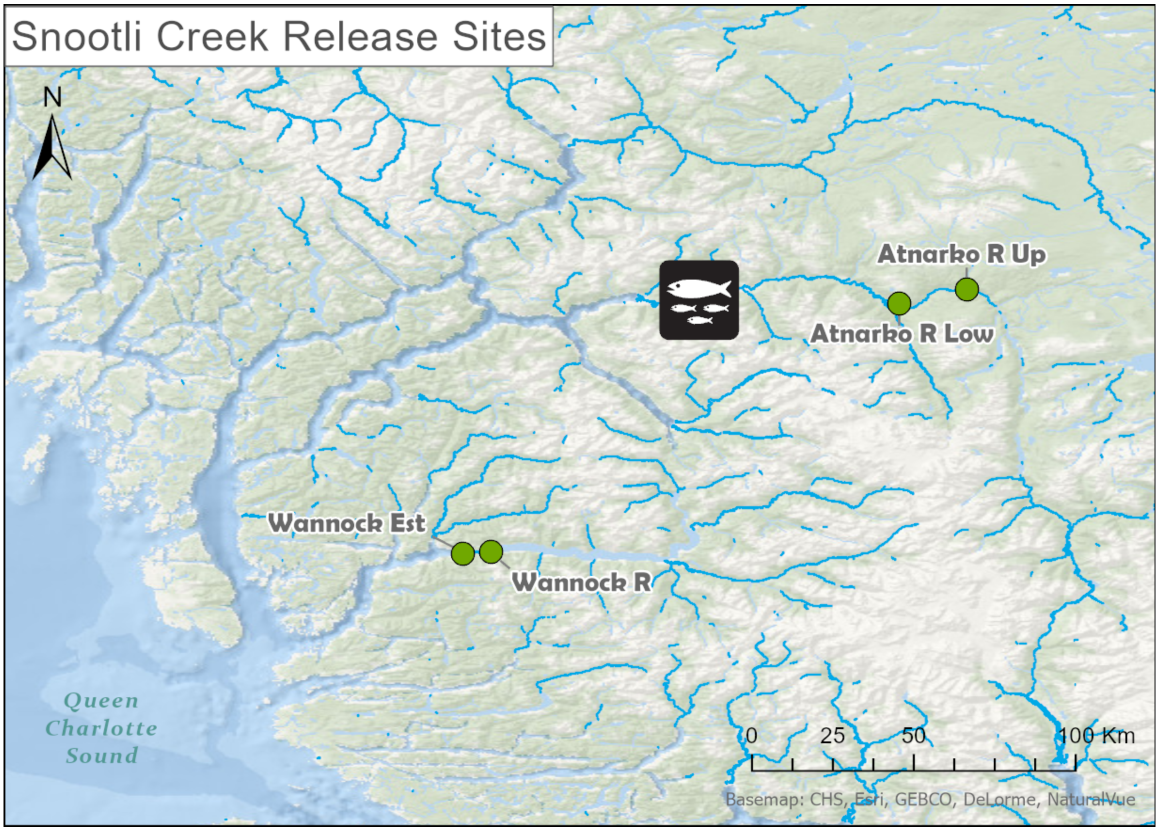


Figure B.6. Snootli Creek hatchery release sites

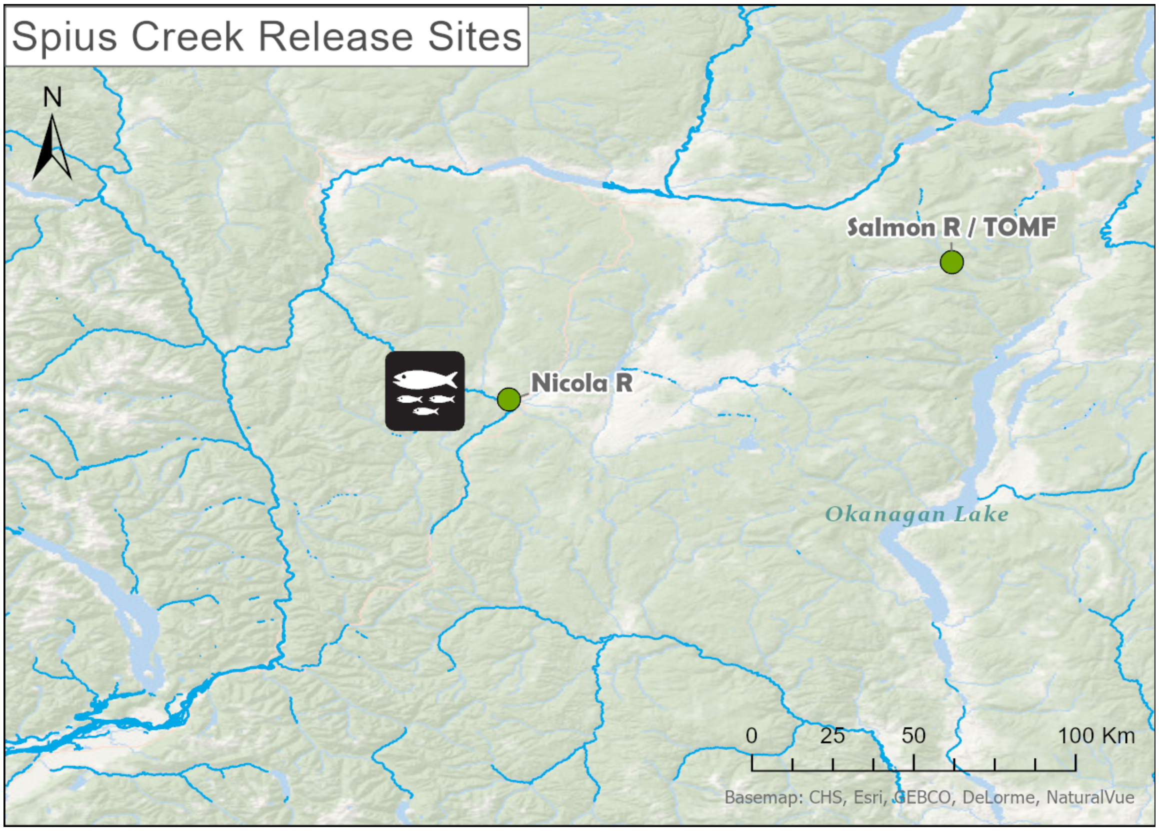


Figure B.7. Spius Creek hatchery release sites

Appendix C

Estimating salmon outmigration distance and duration from release sites to regions of early ocean residence, by Kyla Sheehan (Pacific Salmon Foundation) and Beau Doherty (Landmark Fisheries Research)

This appendix describes the methods used to define saltwater and ocean entry sites, regions of early ocean residence, river migration distance, and ocean arrival dates. These data were used to derive release site-specific river migration and the sea surface temperature predictor variables that were used in multi-hatchery survival models for Coho and Chinook. The migration distances, polygons for early ocean residence, saltwater entry coordinates, and ocean entry coordinates were compiled and provided by PSF (K Sheehan).

Saltwater and ocean entry sites

Saltwater entry points for each release site were identified as the location where the river migration route met the ocean boundary of coastal watershed polygons (Canadian Geographic Watersheds, www.canadiangeographic.com/watersheds/map/). Some saltwater entry points occurred in coastal inlets or estuaries, for which we also identified the nearest ocean entry point along the expected migration route that was outside the inlet or estuary. This ocean entry point was used as the centre point for estimating areas of early ocean residence.

Regions of early ocean residence

Ocean entry points were used to define the centre of a rectangular area of early ocean residence for juvenile salmon that was +/- 40 km in directions perpendicular to the shoreline and +/- 125 km in directions parallel to the shoreline. A maximum distance of 40 km off the coast was based on findings that the highest catches of juvenile salmon occurred within 40 km of the shore in Southeast Alaska (Orsi et al. 2003).

River and coastal migration distance

Migration distances were measured using QGIS software by tracing the route down the centre of waterways and calculating the total distance of line. Freshwater and coastal migration distances were measured from each release site to their point of saltwater and ocean entry, respectively.

Ocean arrival dates

The river and coastal migration distances were used to estimate the number of days it took for salmon to migrate from the release site to ocean entry points based on mean travel speeds for Chinook (CN) and Coho (CO) from Melnychuk et al. 2010 (their figure 4). Estimates for the Fraser River (CN: 47 km/day, CO: 36 km/day), were much higher than speeds for other rivers (CN: 8 km/day, CO: 8 km/day) and coastal areas (CO: 4 km/day). There were no estimates of Chinook travel speeds for coastal areas, so we used the Coho estimates (4 km/day) to estimate the duration of coastal migration distances (i.e., travel time between saltwater and ocean entry points) for both species.

Literature Cited

Malick, M. J., Cox, S. P., Mueter, F. J., and Peterman, R. M. (2015). Linking phytoplankton phenology to salmon productivity along a north–south gradient in the northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences, 72(5):697–708.

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Appendix D

Hatchery returns for release strategies with maximum survival rates

Table D.1. Estimated % increase in average **Chinook returns** for 2000-2015 ocean entry years for release weight and day that maximize survival (W_S, D_S) relative to the mean release weight and day ($\overline{W}$, $\overline{D}$) over the last 20 years. For each hatchery, median posterior and 95% credible intervals for % increases in returns are shown for different combinations of release weights and days for the life-stage most commonly released. Mean release weights and days are calculated from CWT releases without experimental and seapen releases for brood years after 2000, with the exception of Lang Creek (1991-1997) and Eagle River (1984-1992).

Hatchery	Life Stage	Weight (g) and Julian day at release				% increase in returns for different release strategies		
		W_S	$\overline{W}$	D_S	$\overline{D}$	$\overline{W}, D_S$	$W_S, \overline{D}$	W_S, D_S
Big Qualicum R	sub-yearling	13.9	6.3	134	145	4 (-9,20)	229 (106,450)	245 (101,518)
Capilano R	sub-yearling	9.9	7.5	121	145	69 (28,123)	35 (11,62)	128 (56,228)
Chehalis R	sub-yearling	6.6	5.8	145	159	7 (-29,51)	11 (-5,24)	18 (-23,69)
Chilliwack R	sub-yearling	6.3	5.4	122	140	18 (-18,77)	14 (-1,30)	35 (-10,107)
Cowichan R	sub-yearling	10.5	6.3	135	131	0 (-3,5)	18 (-26,77)	18 (-24,74)
Eagle R	sub-yearling	6.8	4.6	139	142	0 (-5,5)	47 (20,82)	47 (23,79)
Gillard Pass	sub-yearling	6.1	4.6	140	144	6 (-5,22)	33 (13,58)	42 (19,71)
Inch Cr	sub-yearling	7.2	7	147	150	3 (-5,12)	3 (-1,7)	6 (-2,16)
L Qualicum R	sub-yearling	8.5	7.7	140	150	22 (-5,66)	10 (-2,21)	34 (2,84)
Nanaimo R	sub-yearling	16.3	5.8	130	141	4 (-13,25)	213 (7,796)	224 (2,935)
Penny	yearling	14.1	10.3	109	95	62 (30,102)	33 (-21,107)	116 (15,269)
Lang Cr	sub-yearling	11.9	7.3	133	140	1 (-17,23)	59 (-23,191)	62 (-23,202)
Puntledge R	sub-yearling	10.4	6	145	153	11 (2,22)	98 (49,167)	120 (61,204)
Quinsam R	sub-yearling	14.2	6	146	130	9 (-5,27)	113 (37,229)	134 (63,230)
Robertson Cr	sub-yearling	7.5	5.3	137	145	10 (1,20)	68 (40,101)	84 (54,122)
Rosewall Cr	sub-yearling	7.5	5.5	143	149	6 (-14,28)	31 (-2,73)	39 (-2,94)
Shuswap R	sub-yearling	9.1	6.7	130	137	8 (-7,28)	27 (-5,62)	37 (1,81)
Snootli Cr	sub-yearling	5.3	5	156	162	12 (-7,37)	7 (3,10)	20 (-1,46)
Spius Cr	yearling	18.3	15.5	124	111	16 (-8,48)	4 (-17,31)	21 (-13,69)
Deep Cr	fry	3.4	2.6	157	150	2 (-8,14)	27 (17,38)	29 (12,51)
Toboggan Cr	yearling	15.6	13.2	106	125	26 (-24,158)	9 (-24,46)	38 (-20,180)

Table D.2. Estimated average annual **Chinook returns** for 2000-2015 ocean entry years for release weight and day that maximize survival (W_S, D_S) relative to the mean release weight and day ($\overline{W}, \overline{D}$) over the last 20 years. For each hatchery, median posterior and 95% credible intervals for returns are shown for the average annual releases for different combinations of release weights and days for the life-stage most commonly released. Mean release weights and days are calculated from CWT releases without experimental and seapen releases for brood years after 2000, with the exception of Lang Creek (1991-1997) and Eagle River (1984-1992). Annual releases shown are averages for 2000-2018 brood years, with the exception of Eagle River (1983-1993).

Hatchery	Life Stage	Weight (g) and Julian day at release				Annual releases (1E6)	Average annual returns (1000s)			
		W_S	$\overline{W}$	D_S	$\overline{D}$		$\overline{W}, \overline{D}$	$\overline{W}, D_S$	$W_S, \overline{D}$	W_S, D_S
Big Qualicum R	sub-yearling	13.9	6.3	134	145	3.67	4 (1.5,9.4)	4.2 (1.5,9.9)	13.2 (4.6,34.5)	13.8 (4.6,37.1)
Capilano R	sub-yearling	9.9	7.5	121	145	0.53	3.8 (1.8,7.8)	6.4 (3,13.9)	5.1 (2.4,10.7)	8.7 (3.8,19.4)
Chehalis R	sub-yearling	6.6	5.8	145	159	1.11	6.8 (2,23)	7.3 (2.2,25.1)	7.5 (2.2,25.7)	8 (2.4,27.5)
Chilliwack R	sub-yearling	6.3	5.4	122	140	1.54	14 (3.4,46.1)	16.5 (3.8,60.6)	16 (4,52.5)	19 (4.4,69)
Cowichan R	sub-yearling	10.5	6.3	135	131	1.16	6.3 (2.6,15.7)	6.3 (2.6,15.7)	7.3 (2.6,21.4)	7.4 (2.7,21.3)
Eagle R	sub-yearling	6.8	4.6	139	142	0.6	0.7 (0.2,3.6)	0.7 (0.2,3.6)	1 (0.3,5.3)	1 (0.3,5.3)
Gillard Pass	sub-yearling	6.1	4.6	140	144	0.13	0.7 (0.2,2.1)	0.7 (0.2,2.2)	0.9 (0.3,2.7)	0.9 (0.3,2.9)
Inch Cr	sub-yearling	7.2	7	147	150	0.23	1.4 (0.4,5.4)	1.4 (0.4,5.5)	1.4 (0.4,5.5)	1.5 (0.4,5.7)
L Qualicum R	sub-yearling	8.5	7.7	140	150	2.59	6.2 (2.7,14)	7.7 (3.4,17)	6.8 (2.9,15.6)	8.4 (3.6,19)
Nanaimo R	sub-yearling	16.3	5.8	130	141	0.55	2.6 (0.9,7.9)	2.7 (0.9,8.4)	8.1 (1.9,35.9)	8.5 (1.9,39.7)
Penny	yearling	14.1	10.3	109	95	0.13	0.2 (0.1,0.9)	0.3 (0.1,1.5)	0.3 (0.1,1.3)	0.5 (0.1,2.1)
Lang Cr	sub-yearling	11.9	7.3	133	140	0.78	2.4 (0.7,7.9)	2.4 (0.7,8.2)	3.7 (1,13.2)	3.8 (0.9,13.7)
Puntledge R	sub-yearling	10.4	6	145	153	2.73	6.9 (4,11.8)	7.7 (4.5,12.9)	13.6 (7.7,23.7)	15.1 (8.6,26.2)
Quinsam R	sub-yearling	14.2	6	146	130	3.89	9.2 (5.4,15.4)	10.1 (5.9,17.1)	19.6 (10.1,37.6)	21.4 (11.8,39)
Robertson Cr	sub-yearling	7.5	5.3	137	145	6.33	11.3 (6.5,18.6)	12.3 (7.2,20.7)	18.8 (11,31.5)	20.7 (12.1,34.6)
Rosewall Cr	sub-yearling	7.5	5.5	143	149	1.82	5.5 (2.2,13.4)	5.8 (2.4,14.3)	7.3 (2.9,17.6)	7.6 (3.1,18.6)
Shuswap R	sub-yearling	9.1	6.7	130	137	0.8	5.3 (1.4,19.6)	5.8 (1.5,21.3)	6.8 (1.8,24.8)	7.3 (1.9,27.2)

Hatchery	Life Stage	Weight (g) and Julian day at release				Annual releases (1E6)	Average annual returns (1000s)			
		W_S	$\overline{W}$	D_S	$\overline{D}$		$\overline{W}, \overline{D}$	$\overline{W}, D_S$	$W_S, \overline{D}$	W_S, D_S
Snootli Cr	sub-yearling	5.3	5	156	162	2.2	8.4 (2.8,24.6)	9.5 (3.4,26.8)	9 (3,26.2)	10.1 (3.6,28.5)
Spius Cr	yearling	18.3	15.5	124	111	0.41	4.2 (1.2,22.6)	4.9 (1.4,25)	4.4 (1.2,23.8)	5.1 (1.4,27.1)
Deep Cr	fry	3.4	2.6	157	150	0.22	0.3 (0.1,1)	0.3 (0.1,1.1)	0.3 (0.1,1.3)	0.4 (0.1,1.4)
Toboggan Cr	yearling	15.6	13.2	106	125	0.05	0.3 (0.1,1.1)	0.4 (0.1,1.6)	0.3 (0.1,1.3)	0.4 (0.1,1.8)

Table D.3. Estimated % increase in average **Coho returns** for 2000-2017 ocean entry years for release weight and day that maximize survival (W_S, D_S) relative to the mean release weight and day ($\overline{W}$, $\overline{D}$) over the last 20 years. For each hatchery, median posterior and 95% credible intervals for % increases in returns are shown for different combinations of release weights and days for the life-stage most commonly released. Mean release weights and days are calculated from CWT releases without experimental and seapen releases for brood years after 2000, with the exception of Eagle River (1983-1993), McLaughlin Creek (1990-1994), and Tenderfoot Creek (1982-1999). The NA values occur for hatcheries (Quinsam, Toboggan Cr) where there are no estimates of optimal release day or weight since the W^2 *or* D^2 coefficients are positive.

Hatchery	Life Stage	Weight (g) and Julian day at release				% increase in returns for different release strategies		
		W_S	$\overline{W}$	D_S	$\overline{D}$	$\overline{W}, D_S$	$W_S, \overline{D}$	W_S, D_S
Big Qualicum R	yearling	28.3	20.4	155	134	9 (1,19)	22 (-27,108)	34 (-20,131)
Capilano R	yearling	24.7	18.3	156	147	1 (-2,4)	10 (-6,29)	11 (-5,31)
Chilliwack R	yearling	22.8	18.4	142	128	8 (-3,21)	13 (-26,84)	22 (-21,102)
Eagle R	fry	11.1	3.9	183	181	0 (-1,1)	61 (-5,167)	61 (-5,166)
Goldstream R	yearling	21.9	19.3	142	129	7 (-3,17)	14 (-15,68)	22 (-10,81)
McLaughlin Cr	yearling	18.8	17.8	141	116	18 (-3,45)	1 (-7,9)	19 (-1,44)
Inch Cr	yearling	32.8	20.4	156	133	9 (1,17)	48 (-15,153)	61 (-6,174)
Lang Cr	yearling	16.7	24	142	115	14 (-25,47)	50 (-26,299)	69 (-25,359)
Puntledge R	yearling	18	20.7	152	145	2 (-1,4)	4 (-7,17)	6 (-6,20)
Quinsam R	yearling	NA	24.9	160	132	9 (-1,20)	NA	NA
Robertson Cr	yearling	18.2	19.6	143	130	8 (4,13)	1 (-7,10)	10 (-1,21)
Rosewall Cr	fry	2.4	2.1	162	150	1 (-6,8)	4 (-2,10)	5 (-4,14)
Spius Cr	yearling	19.8	15.2	144	136	3 (-1,8)	25 (-12,79)	29 (-8,85)
Tenderfoot Cr	yearling	25.4	20.8	160	139	5 (-3,12)	4 (-35,71)	9 (-32,78)
Dunn Cr	yearling	21.9	14.1	170	142	8 (-2,18)	141 (34,350)	160 (42,391)
Toboggan Cr	yearling	16.9	14.1	NA	136	NA	12 (-14,47)	NA

Table D.4. Estimated average annual **Coho returns** for 2000-2017 ocean entry years for release weight and day that maximize survival (W_S, D_S) relative to the mean release weight and day ($\bar{W}, \bar{D}$) over the last 20 years. For each hatchery, median posterior and 95% credible intervals for returns are shown for the average annual releases for different combinations of release weights and days for the life-stage most commonly released. Mean release weights and days are calculated from CWT releases without experimental and seapen releases for brood years after 2000, with the exception of Eagle River (1983-1993), McLaughlin Creek (1990-1994), and Tenderfoot Creek (1982-1999). The NA values occur for hatcheries (Quinsam, Toboggan Cr) where there are no estimates of optimal release day or weight since the *W^2 or D^2* coefficients are positive. Annual releases shown are averages for 2000-2018 brood years, with the exception of Eagle River (1983-1993).

Hatchery	Life Stage	Weight (g) and Julian day at release				Annual releases (1E6)	Average annual returns (1000s)			
		W_S	$\bar{W}$	D_S	$\bar{D}$		$\bar{W}, \bar{D}$	$\bar{W}, D_S$	$W_S, \bar{D}$	W_S, D_S
Big Qualicum R	yearling	28.3	20.4	155	134	0.93	11.6 (5.8,21)	12.7 (6.5,23)	13.9 (5.9,32.5)	15.3 (6.4,35.8)
Capilano R	yearling	24.7	18.3	156	147	0.65	8.9 (5,15.1)	9 (5,15.3)	9.8 (5.4,16.9)	9.9 (5.5,17.2)
Chilliwack R	yearling	22.8	18.4	142	128	1.28	13.6 (5.6,30.2)	14.6 (6,32.7)	15.4 (5.6,40.8)	16.6 (6.1,44.3)
Eagle R	fry	11.1	3.9	183	181	0.69	3.3 (1.4,8.2)	3.3 (1.4,8.2)	5.3 (2.1,13.9)	5.3 (2.1,13.9)
Goldstream R	yearling	21.9	19.3	142	129	0.1	1.2 (0.5,2.6)	1.3 (0.5,2.8)	1.3 (0.5,3.3)	1.4 (0.6,3.5)
McLaughlin Cr	yearling	18.8	17.8	141	116	0.06	0.7 (0.3,1.8)	0.8 (0.3,2.2)	0.7 (0.3,1.9)	0.8 (0.3,2.2)
Inch Cr	yearling	32.8	20.4	156	133	0.54	10.9 (5.5,26.6)	11.9 (6,28.9)	16.3 (6.7,42.8)	17.8 (7.4,46.4)
Lang Cr	yearling	16.7	24	142	115	0.28	2.3 (0.8,6.3)	2.6 (0.9,6.5)	3.5 (1.7,8.1)	4 (2,8.3)
Puntledge R	yearling	18	20.7	152	145	1.1	12.8 (7.2,21.7)	13.1 (7.3,22.1)	13.4 (7.6,22.3)	13.6 (7.7,22.8)
Quinsam R	yearling	NA	24.9	160	132	0.99	11 (6.1,18.8)	12 (6.6,20.5)	NA	NA
Robertson Cr	yearling	18.2	19.6	143	130	0.49	3.4 (1.9,5.9)	3.7 (2,6.4)	3.5 (1.9,5.9)	3.8 (2,6.5)
Rosewall Cr	fry	2.4	2.1	162	150	0.79	2.1 (0.5,9.7)	2.1 (0.5,9.9)	2.2 (0.5,9.8)	2.2 (0.5,9.9)
Spius Cr	yearling	19.8	15.2	144	136	0.3	3.5 (1.5,8.4)	3.6 (1.6,8.6)	4.4 (1.9,10.6)	4.6 (1.9,10.9)
Tenderfoot Cr	yearling	25.4	20.8	160	139	0.43	6.3 (2.9,13.6)	6.6 (3,14.3)	6.6 (2.5,17.7)	6.9 (2.6,18.3)
Dunn Cr	yearling	21.9	14.1	170	142	0.05	0.4 (0.2,1.1)	0.5 (0.2,1.2)	1.1 (0.4,2.7)	1.1 (0.4,2.9)
Toboggan Cr	yearling	16.9	14.1	NA	136	0.05	0.7 (0.3,1.7)	NA	0.8 (0.3,1.8)	NA

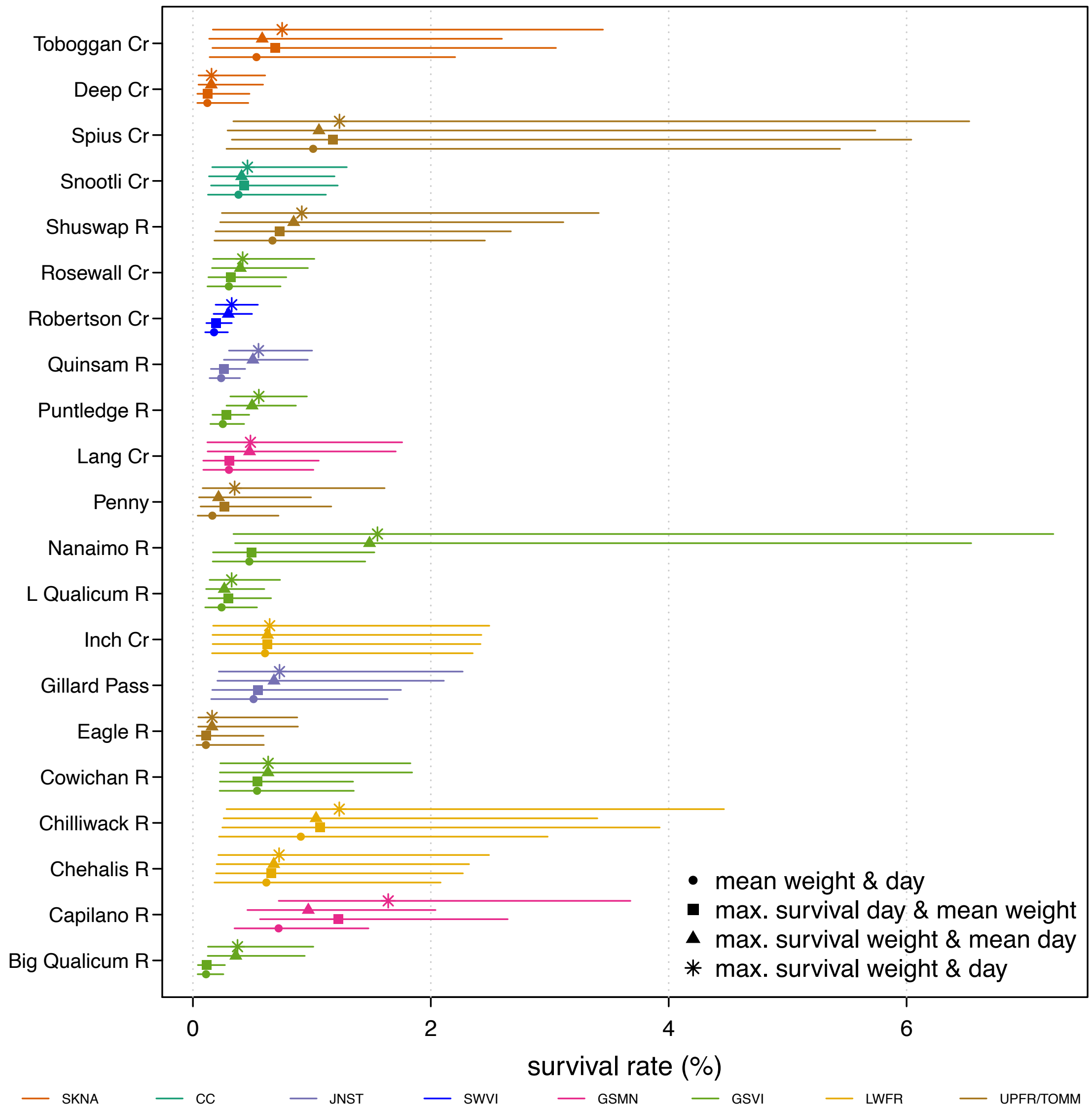

Figure D.1. Predicted **Chinook** smolt-to-adult survival rates for 2000-2015 ocean entry years for different release weights and days relative to the mean release weight and day (●). For each hatchery, the survival rates are estimated for release weights and/or days within the historical observations that are expected to maximize survival for the life-stage most commonly released. Points indicate median posterior estimates, while error bars show 95% credible intervals. Values shown are for fry (Deep Cr), yearling smolts (Penny Creek, Spius Cr, Toboggan Cr) and sub-yearling smolts (all others).

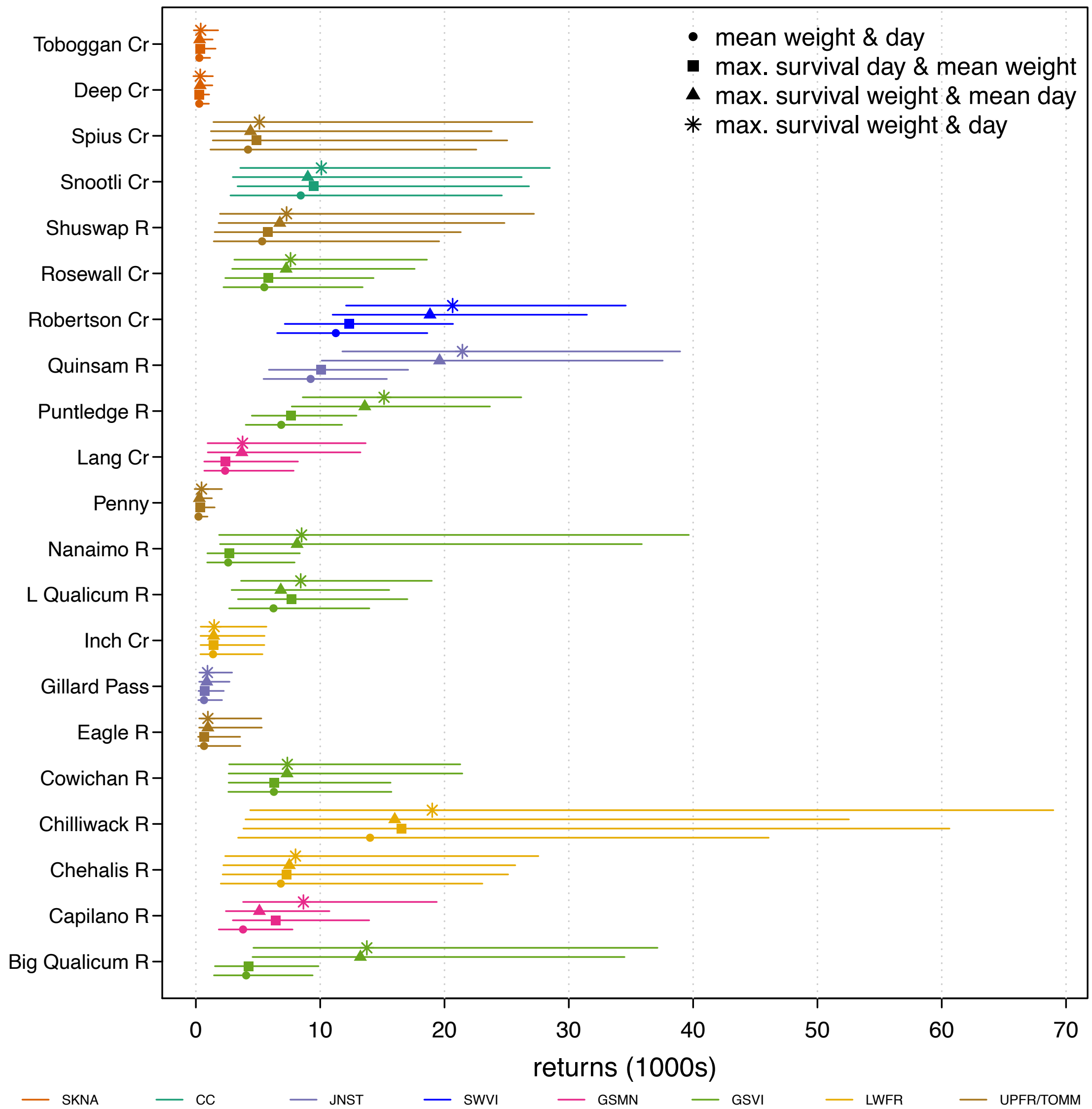

Figure D.2. Predicted Chinook returns for 2000-2015 ocean entry years for different release weights and days relative to the mean release weight and day (●). For each hatchery, the returns are estimated for the average annual releases for release weights and/or days within the historical observations that are expected to maximize survival for the life-stage most commonly released. Points indicate median posterior estimates, while error bars show 95% credible intervals. Values shown are for fry (Deep Cr), yearling smolts (Penny Creek, Spius Cr, Toboggan Cr) and sub-yearling smolts (all others).

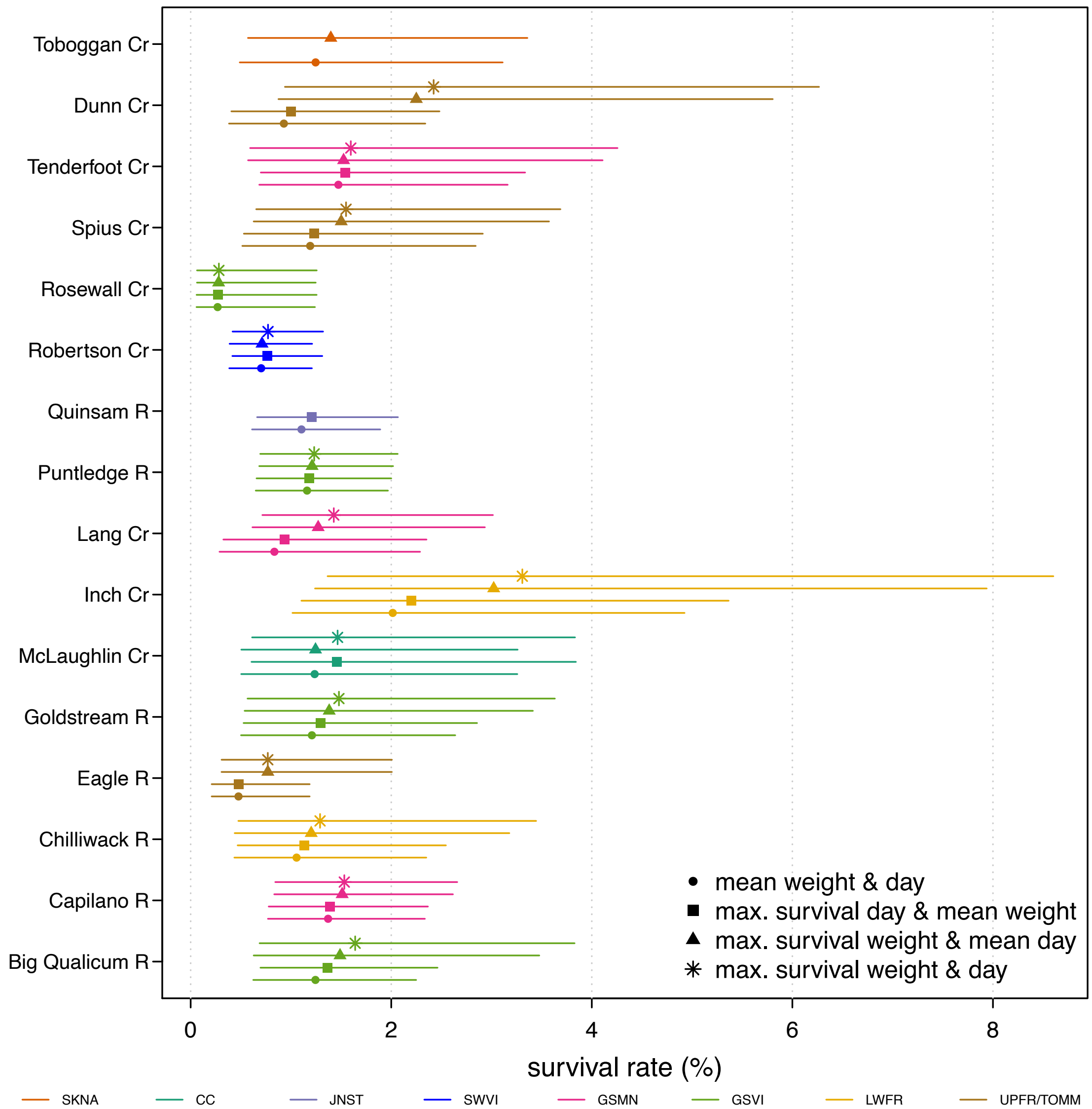

Figure D.3. Predicted **Coho** smolt-to-adult survival rates for 2000-2017 ocean entry years for different release weights and days relative to the mean release weight and day (●). For each hatchery, the survival rates are estimated for release weights and/or days within the historical observations that are expected to maximize survival for the life-stage most commonly released. Points indicate median posterior estimates, while error bars show 95% credible intervals. Values shown are for fry releases at Eagle River and Rosewall Creek, and yearling smolts for all other hatcheries.

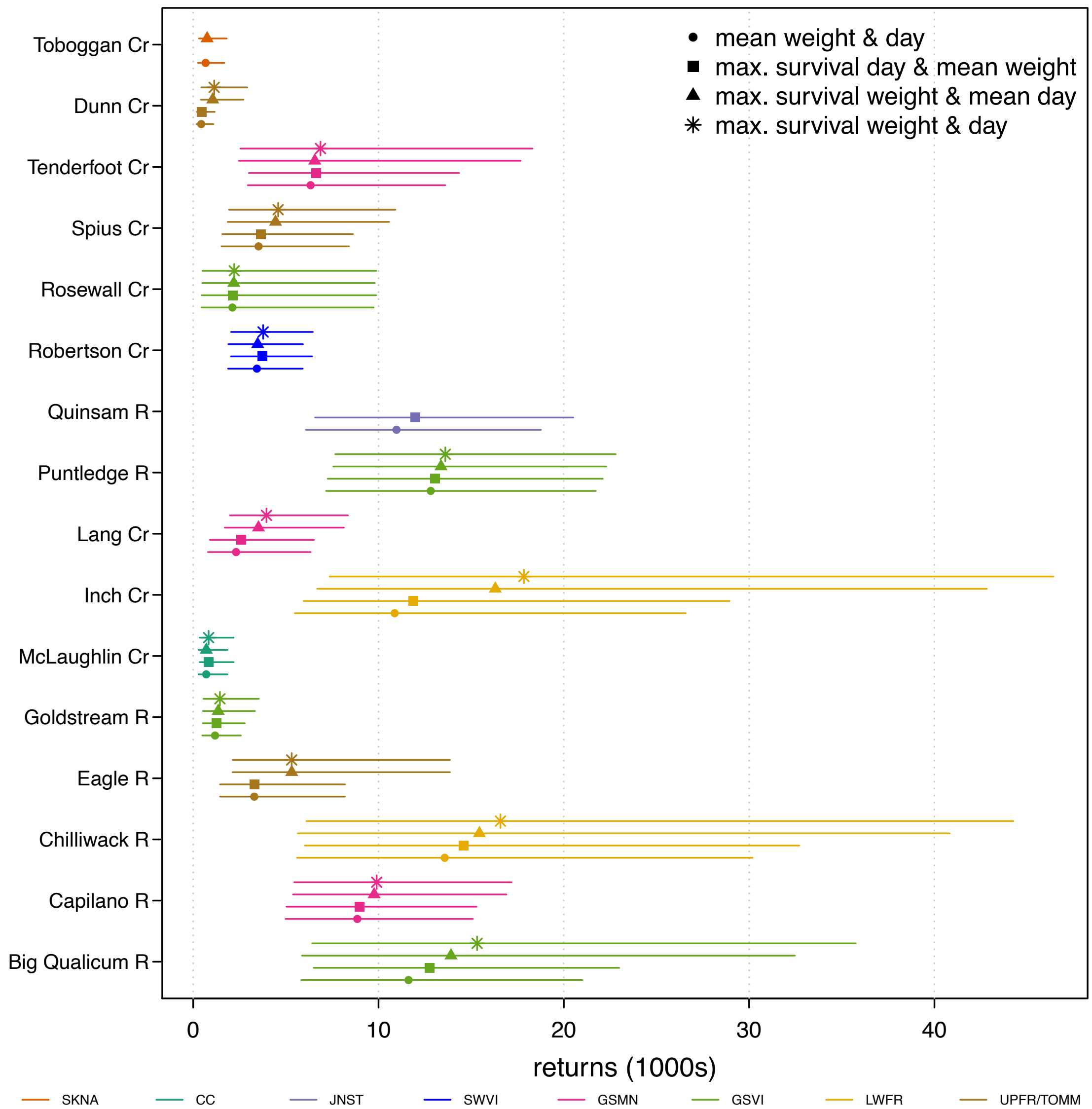

Figure D.4. Predicted Coho returns for 2000-2017 ocean entry years for different release weights and days relative to the mean release weight and day (●). For each hatchery, the returns are estimated for the average annual releases for release weights and/or days within the historical observations that are expected to maximize survival for the life-stage most commonly released. Points indicate median posterior estimates, while error bars show 95% credible intervals. Values shown are for fry releases at Eagle River and Rosewall Creek, and yearling smolts for all other hatcheries.

Appendix E

Hatchery-specific variance components

Methods

We used a Bayesian approach to estimate hatchery-specific variance components for random year effects ($\sigma^2_{\Delta_{t,h}}$) and fixed effects ($\sigma^2_{f,h}$) for each posterior sample of the parameter estimates from the multi-hatchery hierarchical survival models as follows:

(E.1) $\sigma^2_{\Delta_{t,h}} = \mathrm{var}(\Delta_{t,h})$

(E.2) $\sigma^2_{f,h} = \mathrm{var}\left(\alpha + \alpha_h + \ \omega_l + \sum_{j=1}^{6} (\theta_j + \theta_{jh}) X_{jh} \ + \ \phi t \right)$

where $\sigma^2_{\Delta_{t,h}}$ is calculated as the variance of the random year deviations Δ_t for release years t at each hatchery h, and $\sigma^2_{f,h}$ is the conditional variance of the hatchery-average fixed effects (α, ϕt_i , ω_l, θ_j) and hatchery-specific deviations (α_h, θ_{jh}) for release strategies. The fixed effects variance is calculated as the variance of the model fitted values for each hatchery release observation generated without the random year effects (Snijders and Bosker 1999, Nakagawa and Schielzeth 2013).

We estimate the proportion of variance ρ_h in average annual logit survival rates that is explained by the random year effects as:

(E.3) $\rho_h = \frac{\sigma^2_{\Delta_{t,h}}}{\sigma^2_{\Delta_{t,h}} + \sigma^2_{f,h}}$

We exclude the hierarchical model residual variance σ^2_ε from calculations of ρ_h since we are interested in the proportion of variance explained by random year effects for the average annual survival rates.

To evaluate whether the proportion of variance in average survival that is explained by random year effects has changed over time, we calculated ρ_h for three different time periods: i) release events from 1972-1999 (i.e., early years), ii) release events since 2000 (i.e., recent years), and iii) the full time series of release events for each hatchery (i.e., all years).

Results

The mean proportion of variance in average annual logit-survival that is explained by random year effects ranged from 13-91% and 10-80% for Chinook and Coho, respectively, when estimated for all release years (Tables E.1-E.2, Figures E.1-E.4).

Most hatcheries did not have statistically significant differences in ρ_h for the three different time periods, as indicated by the large overlap of 95% credible intervals for ρ_h (Fig. E.5-E.6), with a few exceptions for Chinook (Big Qualicum, Quinsam, Shuswap) and Coho (Big Qualicum, Inch Creek, Quinsam, Robertson Creek, Spius Creek). Paradoxically, Chinook survival models for Big Qualicum and Quinsam had a greater proportion of variance explained by random year effects for recent years than for all years even though the random year effects variance decreased by 30% and 41%, respectively. Rather than increased variability in random year effects, the higher ρ_h at Big Qualicum and Quinsam in recent years is due to less variability in release strategies as the fixed effects variance decreased by 85% and 79%, respectively. Shuswap Chinook survival had a greater proportion of variance explained by random year effects for early years, which is due to reduced fixed effects variance from a small sample size of 4 releases events from 1972-2015. For Coho, survival models for Quinsam, Inch Creek, and Robertson Creek had a greater proportion of variance explained by random year effects for recent years than all years, due to moderate increases in random year effects variance (25-43%) and large decreases (67-84%) in the fixed effects variance. Big Qualicum Coho survival also had higher ρ_h for recent years than all years, due to a 91% increase in random year effects variance and a 56% decrease in the fixed effects variance. The low ρ_h for Coho survival at Spius Creek for the early period is due to the small sample size for early years (n=2), which has a large fixed effects variance.

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Table E.1. Proportion of variance (ρ_h) in average Chinook annual logit-survival rates that is explained by the random year effects for periods with different ocean entry years (OEY). The mean posterior ρ_h with 95% credible intervals, the number of years with release events (nT), and the number of release events used for model fitting (n) are shown for each hatchery and time period.

Hatchery	All Years (1972-2015 OEY)			Early Years (1972-1999 OEY)			Recent Years (2000-2015 OEY)		
	nT	n	ρ_h	nT	n	ρ_h	nT	n	ρ_h
Big Qualicum R	36	114	0.39 (0.28,0.54)	24	79	0.45 (0.28,0.63)	12	35	0.75 (0.56,0.89)
Capilano R	29	133	0.54 (0.41,0.68)	27	129	0.54 (0.39,0.69)	2	4	0.14 (0.00,0.49)
Chehalis R	8	22	0.85 (0.63,0.97)	0	0		8	22	0.85 (0.63,0.97)
Chilliwack R	26	45	0.70 (0.52,0.82)	14	23	0.71 (0.55,0.84)	12	22	0.76 (0.49,0.93)
Cowichan R	31	108	0.49 (0.39,0.60)	17	60	0.64 (0.48,0.80)	14	48	0.52 (0.39,0.65)
Eagle R	9	25	0.44 (0.26,0.65)	9	25	0.44 (0.26,0.65)	0	0	
Gillard Pass	4	9	0.13 (0.01,0.48)	0	0		4	9	0.13 (0.01,0.48)
Inch Cr	5	6	0.91 (0.70,0.98)	1	1		4	5	0.93 (0.75,0.98)
L Qualicum R	19	46	0.72 (0.53,0.86)	15	34	0.70 (0.46,0.87)	4	12	0.69 (0.27,0.94)
Nanaimo R	17	34	0.47 (0.28,0.68)	12	24	0.58 (0.34,0.82)	5	10	0.26 (0.06,0.56)
Penny	19	20	0.30 (0.18,0.47)	12	12	0.47 (0.29,0.71)	7	8	0.16 (0.06,0.32)
Lang Cr	5	5	0.54 (0.17,0.87)	5	5	0.54 (0.17,0.87)	0	0	
Puntledge R	34	171	0.48 (0.38,0.61)	22	108	0.63 (0.48,0.77)	12	63	0.41 (0.27,0.57)
Quinsam R	40	397	0.40 (0.31,0.54)	25	226	0.57 (0.42,0.72)	15	171	0.65 (0.54,0.75)
Robertson Cr	40	240	0.48 (0.37,0.61)	25	141	0.66 (0.53,0.79)	15	99	0.42 (0.29,0.55)
Rosewall Cr	3	10	0.29 (0.01,0.84)	0	0		3	10	0.29 (0.01,0.84)
Shuswap R	20	29	0.70 (0.50,0.83)	4	4	0.94 (0.82,0.99)	16	25	0.67 (0.44,0.83)
Snootli Cr	6	20	0.16 (0.05,0.37)	0	0		6	20	0.16 (0.05,0.37)
Spius Cr	22	63	0.60 (0.45,0.74)	6	13	0.57 (0.35,0.79)	16	50	0.55 (0.35,0.75)
Deep Cr	28	82	0.27 (0.18,0.38)	13	26	0.33 (0.22,0.45)	15	56	0.17 (0.11,0.25)
Toboggan Cr	16	18	0.49 (0.29,0.72)	9	9	0.73 (0.45,0.95)	7	9	0.32 (0.12,0.61)

Table E.2. Proportion of variance (ρ_h) in average Coho annual logit-survival rates that is explained by the random year effects for periods with different ocean entry years (OEY). The mean posterior ρ_h with 95% credible intervals, the number of years with release events (nT), and the number of release events used for model fitting (n) are shown for each hatchery and time period.

Hatchery	All Years (1973-2017 OEY)			Early Years (1973-1999 OEY)			Recent Years (2000-2017 OEY)		
	nT	n	ρ_h	nT	n	ρ_h	nT	n	ρ_h
Big Qualicum R	32	64	0.20 (0.14,0.29)	18	45	0.28 (0.15,0.46)	14	19	0.52 (0.33,0.73)
Capilano R	27	175	0.31 (0.21,0.43)	26	171	0.32 (0.22,0.45)	1	4	
Chilliwack R	16	38	0.52 (0.32,0.72)	13	31	0.61 (0.37,0.82)	3	7	0.82 (0.29,0.99)
Eagle R	10	48	0.21 (0.08,0.39)	10	48	0.21 (0.08,0.39)	0	0	
Goldstream R	8	10	0.80 (0.59,0.91)	0	0		8	10	0.80 (0.59,0.91)
McLaughlin Cr	15	20	0.75 (0.55,0.88)	12	17	0.75 (0.47,0.93)	3	3	0.92 (0.79,0.99)
Inch Cr	33	76	0.44 (0.33,0.57)	15	40	0.55 (0.36,0.75)	18	36	0.74 (0.61,0.85)
Lang Cr	6	7	0.46 (0.18,0.78)	5	6	0.68 (0.32,0.94)	1	1	
Puntledge R	25	129	0.16 (0.11,0.22)	19	108	0.16 (0.10,0.23)	6	21	0.20 (0.10,0.31)
Quinsam R	41	241	0.31 (0.22,0.44)	23	175	0.56 (0.40,0.71)	18	66	0.73 (0.61,0.84)
Robertson Cr	40	70	0.41 (0.30,0.53)	22	37	0.24 (0.14,0.38)	18	33	0.85 (0.77,0.91)
Rosewall Cr	5	14	0.73 (0.32,0.93)	0	0		5	14	0.73 (0.32,0.93)
Spius Cr	19	32	0.54 (0.35,0.71)	2	2	0.01 (0.00,0.05)	17	30	0.67 (0.53,0.79)
Tenderfoot Cr	16	23	0.59 (0.39,0.76)	14	21	0.65 (0.43,0.82)	2	2	0.80 (0.05,0.99)
Dunn Cr	13	47	0.10 (0.04,0.18)	11	41	0.04 (0.02,0.08)	2	6	0.33 (0.00,0.77)
Toboggan Cr	12	12	0.40 (0.18,0.71)	8	8	0.66 (0.41,0.87)	4	4	0.88 (0.51,1.00)

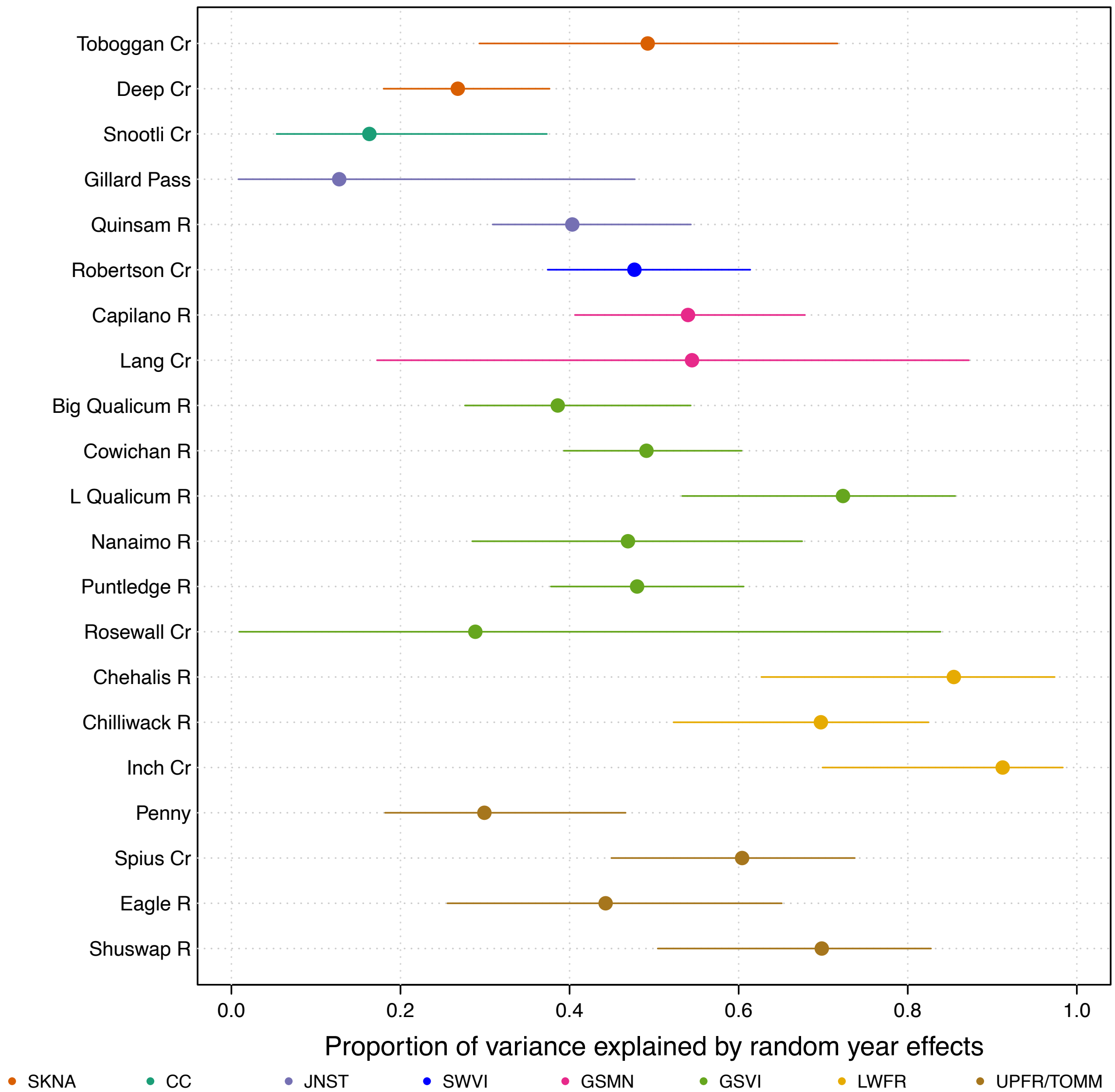

Fig E.1. Proportion of variance (ρ_h) in average Chinook annual logit-survival rates that is explained by the random year effects for all ocean entry years (1972-2015). The mean posterior ρ_h with 95% credible intervals is shown for each hatchery.

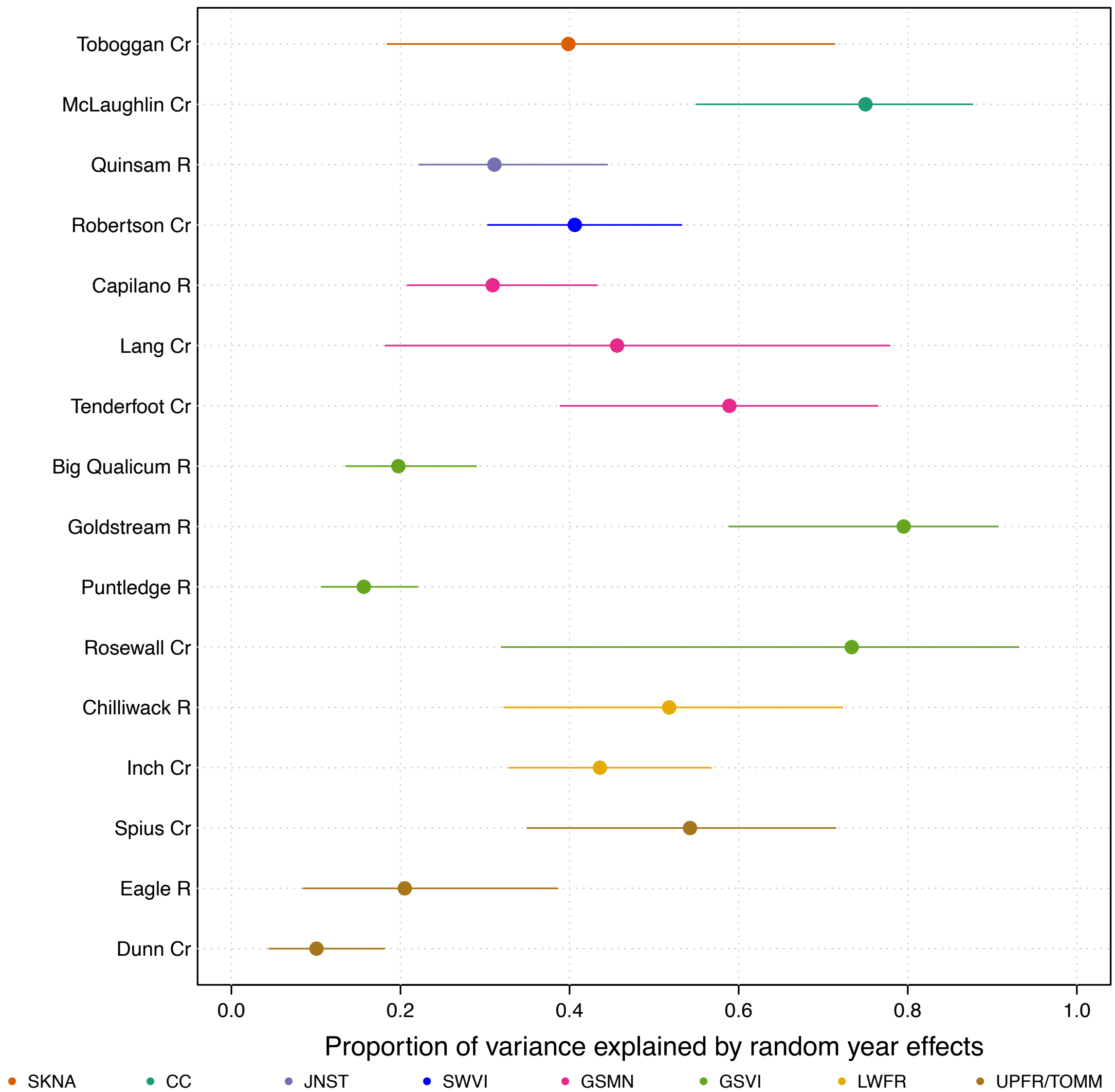

Fig E.2. Proportion of variance (ρ_h) in average Coho annual logit-survival rates that is explained by the random year effects for all ocean entry years (1973-2017). The mean posterior ρ_h with 95% credible intervals is shown for each hatchery.

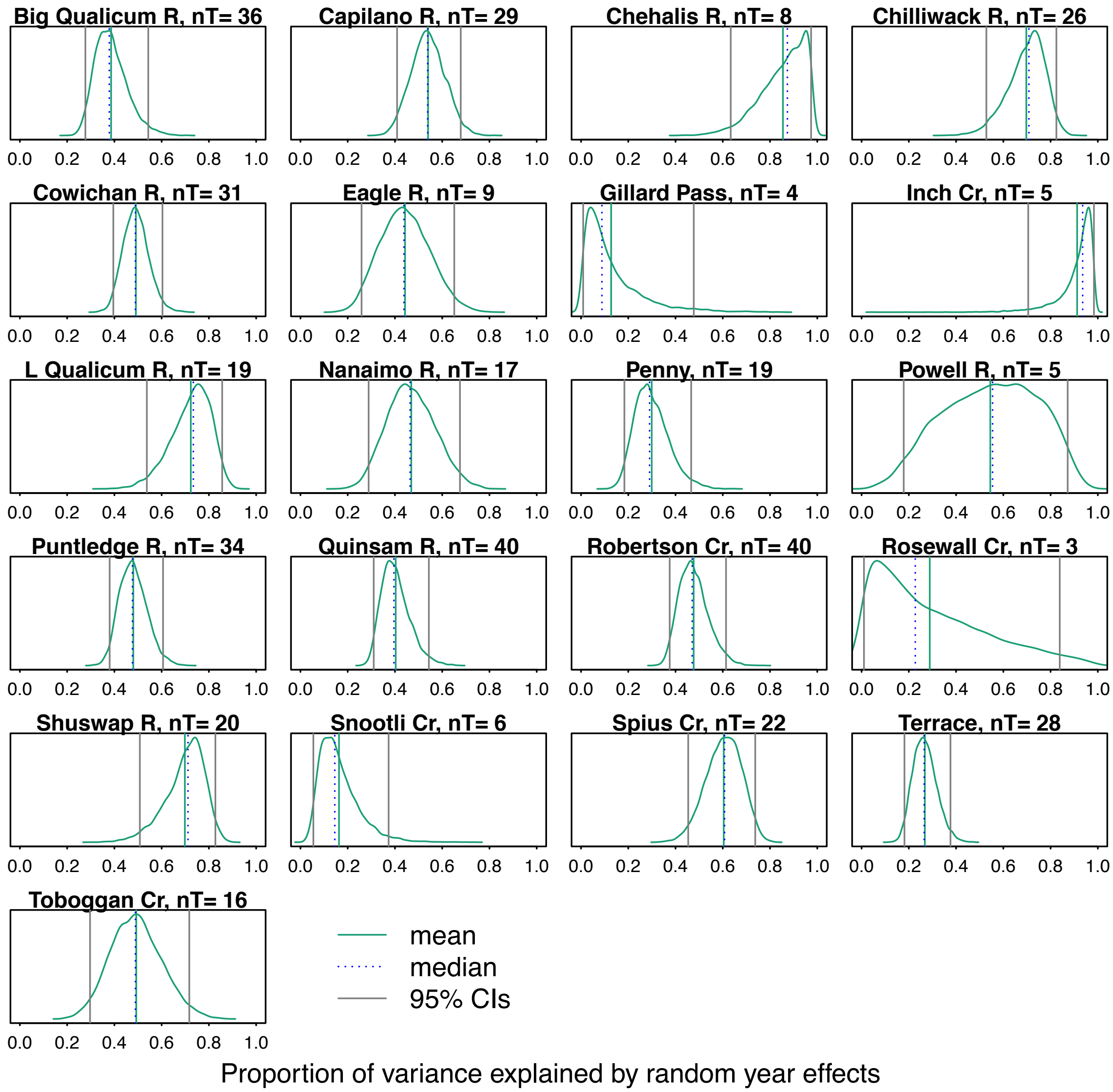

Fig E.3. Kernel density plots of posteriors for the proportion of variance (ρ_h) in average Chinook annual logit-survival rates that is explained by the random year effects for all ocean entry years (1972-2015). The number of years with release events for model fitting (nT) is indicated in the plot title for each hatchery.

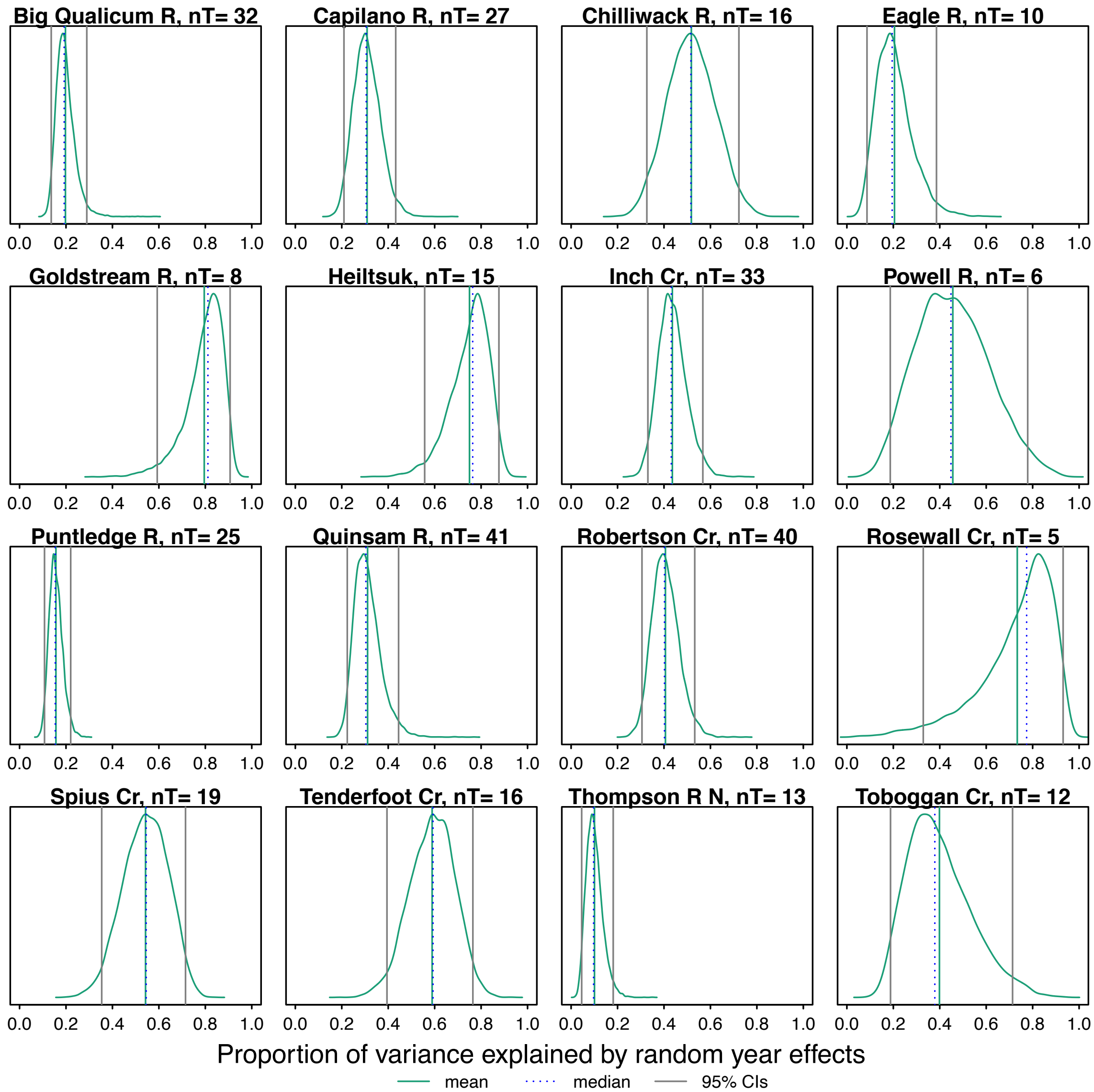

Fig E.4. Kernel density plots of posteriors for the proportion of variance (ρ_h) in average Coho annual logit-survival rates that is explained by the random year effects for all ocean entry years (1973-2017). The number of years with release events for model fitting (nT) is indicated in the plot title for each hatchery.

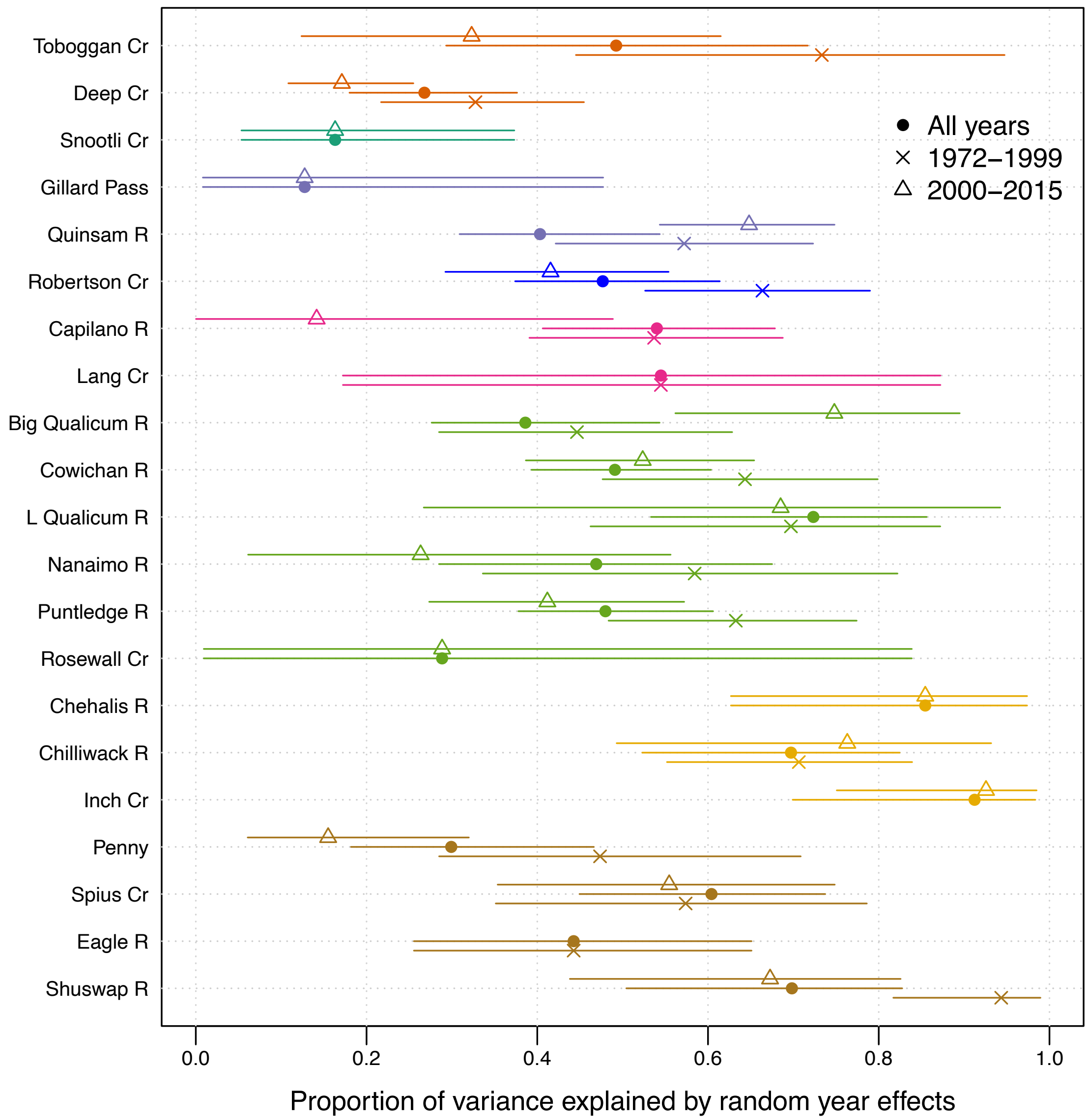

Fig E.5. Proportion of variance (ρ_h) in average Chinook annual logit-survival rates that is explained by the random year effects for different periods of ocean entry years. The mean posterior ρ_h with 95% credible intervals is shown for each hatchery and time period.

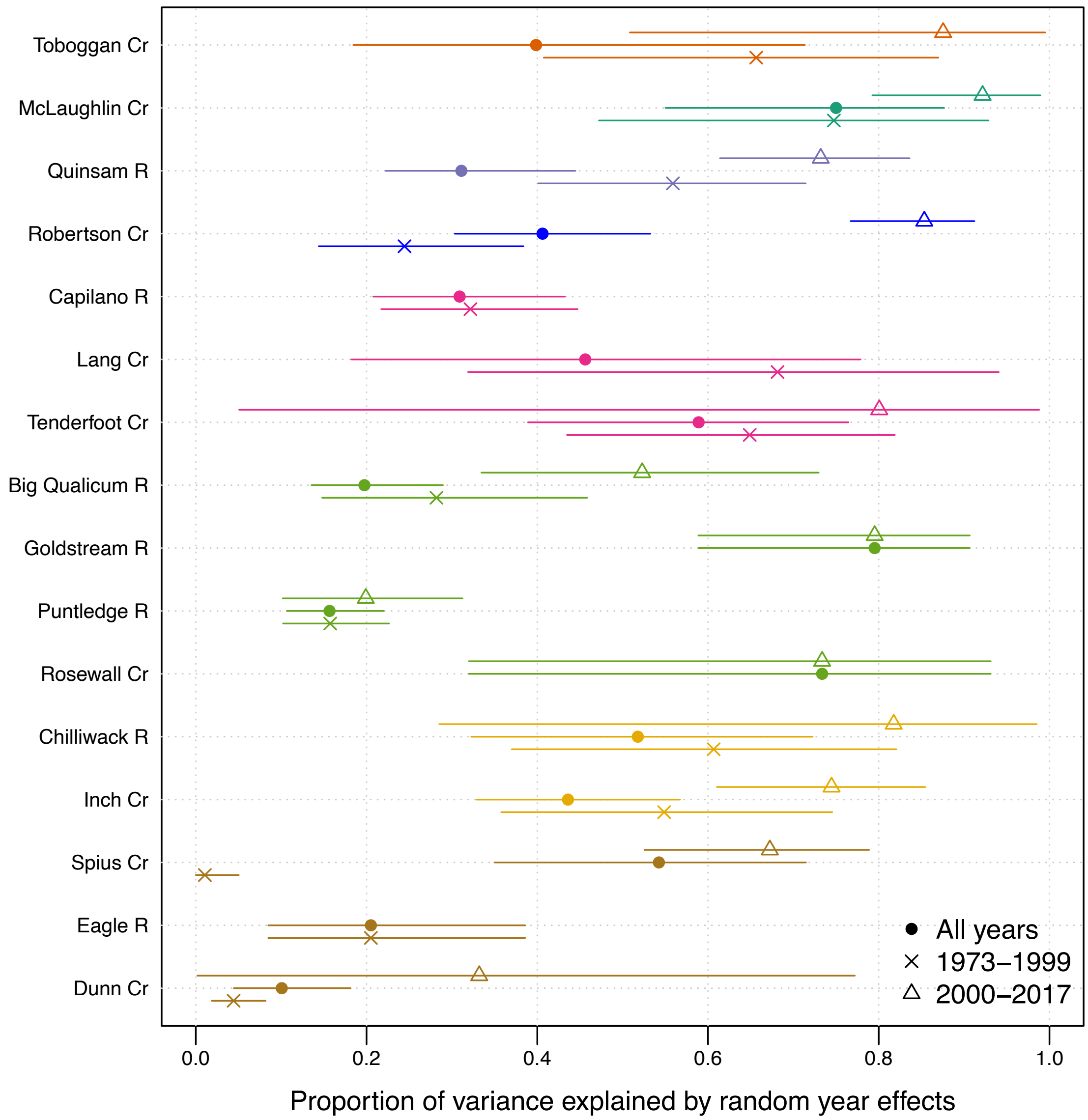

Fig E.6. Proportion of variance (ρ_h) in average Coho annual logit-survival rates that is explained by the random year effects for different periods of ocean entry years. The mean posterior ρ_h with 95% credible intervals is shown for each hatchery and time period.