HATCHERY EFFECTIVENESS REVIEW

REVIEW OF RELEASE STRATEGIES

EVALUATION OF HATCHERY EXPERIMENTS IN BRITISH COLUMBIA, 2000-2018

Photo credit: Eiko Jones

Prepared by Sam James

May 2021

PACIFIC SALMON FOUNDATION
1682 W 7TH AVE
VANCOUVER, BC, V6J 4S6

TABLE OF CONTENTS

BACKGROUND

This report provides an evaluation of experimental hatchery releases of Chinook and Coho salmon from Fisheries and Oceans Canada's (DFO) Major Operational and community-led enhancement facilities from 2000 to present. The evaluation was conducted by the Pacific Salmon Foundation as part of a 3-part science-based review of enhancement programs in BC funded by the BC Salmon Restoration and Innovation Fund (BCSRIF), including:

1. a review of cutting-edge research and molecular tools that may be applied to understand and improve the productivity of hatchery-reared salmon in the future (Environmental Dynamics Inc. 2020);
2. *an evaluation of hatchery release strategies* and the resulting marine survival of hatchery-released salmon; and
3. a comprehensive review of hatchery effectiveness and impacts on wild populations.

This report is part of the evaluation of hatchery release strategies. This evaluation also has 3 components: a literature review (Part 1), this evaluation of release strategies since 2000 by hatchery and species (Part 2), and a third more complex modelling exercise that includes all hatcheries in BC by species (Part 3).

There are a number of release strategies that have been used to achieve management objectives (see *Part I: Review of Pacific Salmon Hatchery Release Strategies in Canada and the United States* for more information on the literature available on release strategies). These include varying the weight at release, date of release, life history or stage released, release location, numbers released, or rearing conditions. For this report, the list of experiments was obtained through discussion with staff of the Salmonid Enhancement Program (SEP) (Dave Willis, Cheryl Lynch, Esther Guimond), and careful review of the Enhancement Planning and Assessment Database (EPAD). The details of the experiments were obtained through the SEP data compendiums, provided by SEP staff, as well as interviews with Watershed Enhancement Managers (WEMs). The data compendiums provide summaries of the operations and data trends at each facility.

Herein, we review 25 experimental releases; seven on releases of multiple Chinook life stages, four on Chinook release times and sizes at release, eight on Coho release times and sizes at release, and six on the effects of seapen releases. We grouped time and size of release experiments together since several of the release timing experiments also included different weights-at-release, which sometimes led to confounding effects. We focus on experiments using CWT data as most of the experiments conducted have used CWTs and the data were better suited to our analyses (i.e. standardized recovery program for tags in fisheries). While our focus was on experiments conducted since 2000, two experiments on the time of release of Chilliwack Coho and Chinook were added that extended further back in time. Today, the

Chilliwack River Hatchery sees some of the highest Chinook survival rates; therefore, we chose to evaluate these experiments to learn more about the parameters associated with survival rates at that facility. Finally, data from pre-2000 were included for the Cowichan experiments so that more could be learned about temporal changes in the effects of release strategies from such a long, continuous time series.

The main objective of this evaluation is to determine which release strategies have achieved their desired outcomes over the past 20 years, and to synthesize the methods and outcomes of these experiments to inform future decision-making.

DATA AND METHODS

Release and recovery data for brood years 2000–2018 (1981–2018 for Chilliwack; 1989–2018 for Cowichan) of tagged Chinook and Coho salmon from BC hatcheries was extracted from SEP's Recovery by Tagcode Report (provided by Cheryl Lynch, SEP). The Recovery by Tagcode Report provides release and escapement data from EPAD and catch data from the MRP (Mark Recovery Program of CWT data) database. These data provide information on each release event, such as the release location, the average weight at release, the start and end dates of release, and the numbers released. They also include information on the ages and numbers of returns in commercial and recreational fisheries, in escapement surveys, and to the hatchery, which SEP uses to calculate survival and exploitation rates by age class of each brood year using estimated tag numbers. Estimated numbers account for tags in the *unsampled* part of the catch or escapement and are calculated as:

$$Estimate = \frac{\#\ observed\ tags}{sample\ rate} \quad (1)$$

where the sample rate is the portion of a catch strata directly sampled for CWT recoveries (target sample rate is typically 20%). Survival rates (S_i) are calculated for each release group *i* as:

$$S_i = \frac{1}{r_i}\sum_a^A C_{ai} + E_{ai} \quad (2)$$

where r_i is the total number of tagged releases for group *i*, *a* and *A* are the minimum and maximum return ages, respectively, C_{ai} is the estimated catch-at-age (in number of fish) of group *i* in both US and Canadian fisheries, and E_{ai} is the estimated escapement-at-age of group *i* to their natal hatchery or stream. Exploitation rates (U_i) are calculated for each release group *i* as:

$$U_i = \frac{1}{\sum_a^A C_{ai} + E_{ai}}\sum_a^A C_{ai} \quad (3)$$

wherein the sum of the catch-at-age is divided by the sum of the catch-at-age plus escapement-at-age.

NOTE that the estimates for S_i and U_i are *not* equivalent to other estimation methods applied annually for the Chinook and Coho technical committees within the Pacific Salmon Commission.

In addition to the experimental releases recommended by SEP staff, we systematically searched the releases in EPAD for those with more than one strategy in a given release year (i.e. more than one release weight or date). We also searched the release comments for anything that might suggest an experimental release. Any potential experiments were then confirmed and details obtained from hatchery staff.

The EPAD contains release and recovery data for both BC and the Yukon, however our analyses focus on experimental releases in BC. Therefore, the EPAD data were filtered to remove missing data, data from beyond BC, or data unsuitable for estimating survival or exploitation rates (indicated in the recovery report by usability flags). To do this, the following filters were applied:

- SURVIVAL_CODE = Y
- EXPLOITATION_CODE = Y
- MARK_TYPE_CODE = CWT
- Age, ExplRate, TotCatch+Esc, SurvRate, AVE_WEIGHT != NA
- STOCK_NAME != Yukon R

In addition, we calculated the duration of the release as the difference between the start and end of release dates and removed any releases where the duration was greater than 14 days (as recommended by Cheryl Lynch, SEP). Releases over longer periods make it difficult to reliably determine the date of release and compare release timing between groups and may have been a result of problems that arose during the release event.

Given that multiple tagcodes can be applied within a given release group, releases of the same stock from the same location with the same weight and date of release were aggregated and treated as a single release group.

For each experiment, we provide a summary of survival trends over time (calculated from EPAD recoveries using equation (2)) for the stock of interest highlighting experimental and most recent years, a summary table of release and return metrics, and plots comparing the survival rate, exploitation rate, and return age (Chinook) or proportion of jacks (Coho) between treatments. For comparisons of subyearling and yearling Chinook releases (where subyearlings were the natural life history type), mean marine age (years at sea) was also assessed. Yearlings are typically expected to return at older ages due to the additional year of freshwater rearing, however they may spend fewer years at sea, reducing growth and subjecting them to different fishing pressures. Therefore, marine ages allow us to better understand these dynamics. All return metrics were statistically compared between groups using parametric (e.g. t-test or ANOVA) or non-parametric (e.g. Kruskall-Wallis or generalized linear model) analyses.

Where experiments had sufficient data, we worked with Landmark Fisheries Research to develop the following linear mixed effects model to explore the relationships between release parameters (life stage, weight at release, and day of release) and survival:

$$Y_i = \alpha + t_i + \delta_i + \theta_1 W_i + \theta_2 W_i^2 + \beta_1 D_i + \beta_2 D_i^2 + \varepsilon_i \quad (4)$$

where *Yi* is the logit-transformed survival rate for release group *i*, α is the intercept or hatchery average logit-survival before accounting for other covariates, t_i is the effect of ocean entry year, δ_i is the life stage effect, θ_1 is the coefficient or effect size for a continuous weight at release (*W*), β_1 is the coefficient for a continuous day of release (*D*), and ε_i is an independent and identically distributed Gaussian residual (i.e., $\varepsilon_i \sim N(0, \sigma^2)$). Quadratic terms for both weight (θ_2) and day (β_2) of release were included to account for non-linear relationships with survival.

The release day covariate (D) was centered by subtracting the hatchery-specific mean Julian day-at-release. Thus, coefficient β_1 can be interpreted as the change in logit-survival per 1-day deviation from the average release day for a particular hatchery. Where all releases of an experimental study at a hatchery occurred within a 15-day period, D was excluded from the model to reduce misleading relationships between survival and day of release. Only single life stages or life history types were used in the time and size at release experiments; therefore, the life stage effect was excluded from these models. Fixed year effects were included in all models, with year added as a random effect when the size of the variation in survival rates varied between years. And finally, when an experiment sought to compare releases across different locations, release site was added as a fixed effect. Thus, the model used here is the same as that used for the single hatchery analyses in *Part III: Rearing strategy effects on survival and return ages for British Columbia Chinook and Coho hatchery releases, 1972-2017*, only here it is applied to specific experimental periods. A more detailed description of the model development can be found in Part III.

Using the full survival model, we performed an all subsets selection procedure to fit all possible combinations of fixed effects. Model performance was evaluated using the Akaike Information Criterion corrected for small sample size (AICc) and the number of predictor terms for each model (Hurvich & Tsai 1989, Burnham & Anderson 2002). The model with $\Delta AICc < 2$ and the fewest predictor variables was selected as the top model for each experiment.

Data distributions and model fits are provided for each experiment where modelling was possible. Residuals are a useful measure of model fit, where a normal distribution of the difference between observed and predicted values and a roughly linear QQ-plot would suggest an appropriate model fit. Therefore, model residuals are also presented. All analyses were conducted in R (R Core Team 2019).

EXPERIMENTS

The following tables summarize the experimental releases of different life history types or life stages (Table 1), release times and weights (Table 2), and seapen releases (Table 3) evaluated for this report. Experiments with insufficient data for modelling are highlighted in orange. Note that some of these 'experiments' actually represent regular production (e.g. early and late releases of Cowichan River Chinook to reflect natural life history of the stock), however we include them as experiments in this report because of the use of multiple release groups in a given year. By looking across all cases (experimental or not) where multiple strategies are implemented allows us to further our understanding of the effects of release strategies.

The objectives behind each experimental release varied by facility and stock. The main objectives in the release of multiple life stages has been either to mimic the natural life history of the stock and increase returns to historical spawning areas throughout the watershed of interest, or simply to increase survival rates (Table 1). Releases of later/larger fish were inspired by recent research suggesting that a late life history strategy could survive better than the current release dates used by most hatcheries (Beamish et al. 2010). Thus, the objectives of most trials involving different release times were to determine whether releasing fish later than has been historically done could increase survival, affect marine distributions, or change interactions with wild fish (Table 2). The objectives behind seapen releases were varied and included increasing fish available for local fisheries, increasing survival rates, avoiding poor freshwater conditions, or reducing competition with wild salmon (Table 3).

Three additional experiments were found but not reviewed due to data quality flags in EPAD. Time and size at release trials were done on Harrison River Chinook at Chehalis River Hatchery from release years 2001-2003. Smaller releases of Kitimat River Chinook were trialed in release years 2001, 2003, 2016, and 2018-2019. And finally, time of release trials from Conuma River seapens were tried with Conuma River Chinook from 2001-2003. It is unclear why these experiments had inadequate data, although it is believed that poor or absent escapement surveys prevented the accurate estimation of survival rates.

Table 1: List of stocks and facilities that have released multiple life stages concurrently from their facility in certain ocean entry years (OEY) with details and objectives of the release. The experimental life stage for each stock is bolded while the natural life history is not. Experiments with insufficient data for statistical analyses are highlighted orange.

SPECIES	STOCK	FACILITY	OEY	EXPERIMENT	OBJECTIVE
CN	Atnarko R Low/Up	Snootli Cr	2009-2013	subyearling vs **yearling**	increase survival
CN	Cheakamus R	Tenderfoot Cr	2016-2019	fed fry vs yearlings	mimic the natural life history of the stock
CN	Phillips R	Phillips R	2011, 2012, 2014	subyearling vs **yearling**	increase survival
CN	Puntledge R	Puntledge River H	2002, 2003, 2005	**fed fry** (released at multiple locations) vs hatchery subyearlings	encourage imprinting and return to historical habitats
CN	Quinsam R	Quinsam River H	2001-2007, 2015-2018	release of **fed fry** to Quinsam Lk vs hatchery subyearlings	encourage imprinting and return to historical habitats
CN	Robertson Cr	Robertson Creek H	2004-2007, 2017-2018	subyearling vs **yearling**	reduce returns of jacks and jimmies
CN	Shuswap R Mid	Shuswap R Mid H	2015-2018	subyearling vs **yearling**	mimic historical life history and compare survivals

Table 2: List of stocks and facilities that have conducted time or size at release trials in certain ocean entry years (OEY) with details and objectives of the release. The bolded release strategy represents the experimental group, while non-bolded releases are the controls or conventional releases. Experiments with insufficient data for statistical analyses are highlighted orange.

SPECIES	STOCK	FACILITY	OEY	EXPERIMENT	OBJECTIVE
CN	Big Qualicum R	Big Qualicum River H	2011-2013, 2015-2017	normal vs **late/large**	evaluate effects on survival, marine distribution, interaction with wilds
CN	Chilliwack R	Chilliwack R H	1993-1995	early vs **late**	improve survival
CN	Cowichan R	Cowichan River H	1990-1995, 1998, 2001-2004, 2006, 2008-2009, 2011-2016	early and late, at two release locations	mimic natural life history of the stock
CN	Quinsam R	Quinsam R H	2015-2017, 2019	normal vs **late/large**	evaluate effects on survival, marine distribution, interaction with wilds
CO	Big Qualicum R	Big Qualicum R	2016-2018	normal vs **late/large**	evaluate effects on survival, marine distribution, interaction with wilds
CO	Chilliwack R	Chilliwack River H	1983, 1990-1991, 2000-2001	**early** vs mid vs **late**	reduce competition with wilds
CO	Inch Cr	Inch Cr	2006-2008	**early** vs normal	evaluate effects on survival rates to determine whether practices should change
CO	Inch Cr	Inch Cr	2012-2014	**small** vs normal	evaluate effects on survival rates to determine whether practices should change
CO	Inch Cr	Inch Cr	2015-2017	normal vs **late/large**	evaluate effects on survival, marine distribution, interaction with wilds
CO	Quinsam R	Quinsam R	2002-2012	**early** vs normal vs **late**	update the Bilton et al. time and size at release studies from the 80s
CO	Quinsam R	Quinsam R	2010-2012	normal vs **large**	update the Bilton et al. time and size at release studies from the 80s
CO	Quinsam R	Quinsam R	2016-2020	normal vs **late/large**	evaluate effects on survival, marine distribution, interaction with wilds

Table 3: List of stocks and facilities that have released fish from their hatcheries and seapens concurrently in certain ocean entry years (OEY) with details and objectives of the release. Experiments with insufficient data for statistical analyses are highlighted orange.

SPECIES	STOCK	FACILITY	OEY	EXPERIMENT	OBJECTIVE
CN	Chilliwack R	Capilano R	2014-2017	Sandy Cove seapen	Produce fish for harvest
CN	Cowichan R	Cowichan R	1992-2004, 2006-2009	Cowichan estuary seapen	Avoid river predation and increase returns
CN	Puntledge	Puntledge R	2000, 2002-2003, 2006-2009	Comox Bay seapen	Improve survival rates
CN	Quinsam R	Quinsam	2000-2018	Seapens throughout Discovery Passage	Increase local harvest rates
CN	Robertson Cr	Robertson Cr	2002-2004, 2014-2018	Harbour Quay seapen (02-04), Alberni Inlet Seapen (14-18)	Avoid poor freshwater conditions and reduce competition with wild populations
CN	Wannock R	Snootli Cr	2010-2011, 2014-2015, 2018-2019	Wannock Estuary seapen	Rebuilding while reducing competition with wilds

RESULTS

LIFE STAGE EXPERIMENTS

The following table summarizes the findings of the seven facilities releasing multiple life stages with detailed information and analyses on each experiment following.

Table 4: Summary of relationships found between experimental life stage released (bolded) and survival rates, exploitation rates, and return ages. The best release strategies for predicting survival in the top mixed linear effects models for each hatchery are provided in the 'Survival' column. Green cells represent significantly higher outcomes for the experimental release group, red cells represent significantly lower outcomes, and grey cells represent no difference between release groups. Rows in orange had insufficient data for conducting statistical analyses.

SPECIES	STOCK	OEY	EXPERIMENT	SURVIVAL	EXPLOITATION	AGE
CN	Atnarko R Low/Up	2009-2013	subyearling vs **yearling**	life stage		
CN	Cheakamus R	2016-2019	fed fry vs yearlings	insufficient data		
CN	Phillips R	2011, 2012, 2014	subyearling vs **yearling**	insufficient data		
CN	Puntledge R	2002, 2003, 2005	**fed fry** (released at multiple locations) vs hatchery subyearlings	size		
CN	Quinsam R	2001-2007, 2015-2018	release of **fed fry** to Quinsam Lk vs hatchery subyearlings	size, life stage		
CN	Robertson Cr	2004-2007, 2017-2018	subyearling vs **yearling**	size		
CN	Shuswap R Mid	2015-2018	subyearling vs **yearling**	insufficient data		

1. Atnarko River Summer Chinook

At Snootli Creek Hatchery, Atnarko River summer Chinook are produced to meet assessment and harvest objectives. Though they are one stock, Atnarko River is managed as two production groups: Atnarko River Upper and Atnarko River Lower, with target annual releases of approximately 950,000 each. Here, we analysed the upper and lower production groups together as a single Atnarko River stock. Reliable survival estimates were not available prior to the 2009 release, therefore we do not have a long time series of historic survival rates. When accurate records began, survival rates were extremely low at 0.24% (Figure 1). Since then, the mean survival rate increased to a peak of 2.0% for release year 2012 before returning to similarly low levels for releases in 2014 and 2015.

In years 2009 to 2013, Snootli Creek trialed the release of a yearling life history type in addition to the regular subyearling smolt releases. Data quality of the 2009 yearling release was flagged in the EPAD database as unsuitable for survival and exploitation estimates and was therefore excluded. The objective of these releases was to determine whether or not a yearling life history strategy would be effective. Subyearling smolts had a mean weight of 4.96 g (SD ± 0.15) and were typically released two weeks later than the yearlings (but in the season prior), which had a mean weight of 20.08 g (SD ± 0.49).

Over the 2010-2013 releases, yearlings had significantly higher mean survival rates than the subyearling smolt releases (t-test; $p = 0.02$) (Table 5; Figure 2-Figure 3). Exploitation rates were similar, with no significant difference between life history types (t-test; $p = 0.84$; Table 5; Figure 2-Figure 3). While return ages were significantly higher for the yearling release group (t-test; $p < 0.001$), the mean marine age (years at sea) was significantly lower (t-test; $p < 0.001$; Table 5; Figure 2-Figure 3).

We examined several release covariates (life stage, release weight, release day, ocean entry year) to determine which were best associated with the smolt-to-adult survival rate in the four years of this trial. Quadratic terms for weight and day of release were also added to account for non-linear responses. Given the annual variability in survival rates (Figure 2), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each life stage in Figure 4.

The best model contained only life stage as a covariate. The second model was equally as good as the first and contained only weight at release. Therefore, life history type (and thus release weight) are good indicators of variability in survival rates (Table 6). The intra-class correlation estimate was 53%, meaning that 53% of the total variation in the survival response could be explained by the random year effect (Figure 5). Therefore, accounting for the life history type released, as well as random variations associated with the year of ocean entry, will provide a better estimation of survival. Residuals and normal quantile-quantile plots for the top model are provided in Figure 6 and suggest an adequate model fit.

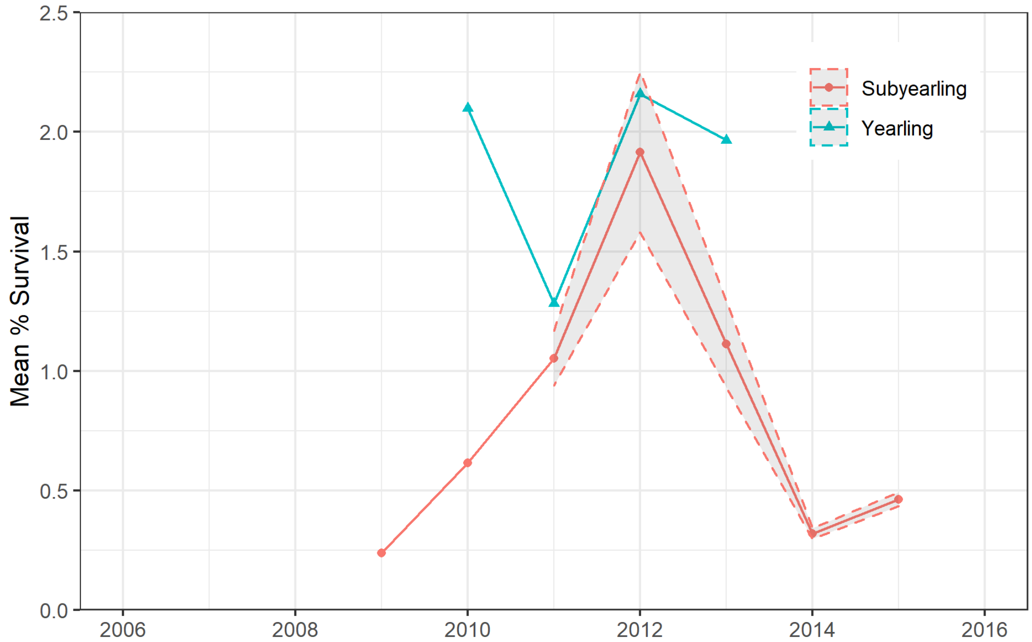

Figure 1: Mean percent survival of Atnarko River Chinook subyearling smolts (red circles) and yearlings (blue triangles) released by the Snootli Creek Hatchery by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 5: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean marine ages of Atnarko River Chinook subyearling and yearling smolt releases by Snootli Creek Hatchery in years 2009 to 2013. Standard deviation is given in parentheses for release events with > 1 release group.

OEY	STAGE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	MARINE AGE (YRS)
2009	Subyearling	4.9 (0.1)	161 (0)	2	151,608	0.24	40.98	4.2
2010	Subyearling	5.2	158	1	210,556	0.61	31.99	4.1
	Yearling	19.5	146	1	111,594	2.10	35.76	3.7
2011	Subyearling	5.0 (0.2)	166 (0)	2	402,192	1.05	28.42	4.2
	Yearling	20.1 (0.9)	153 (0)	2	103,145	1.29	34.75	3.6
2012	Subyearling	4.8 (0.3)	164 (0)	2	404,034	1.89	27.77	4.2
	Yearling	20.0	158	1	57,323	2.16	29.64	3.7
2013	Subyearling	4.9 (0.3)	164 (0)	2	399,204	1.13	26.92	3.9
	Yearling	20.7	149 (0)	2	37,446	1.98	30.83	3.6

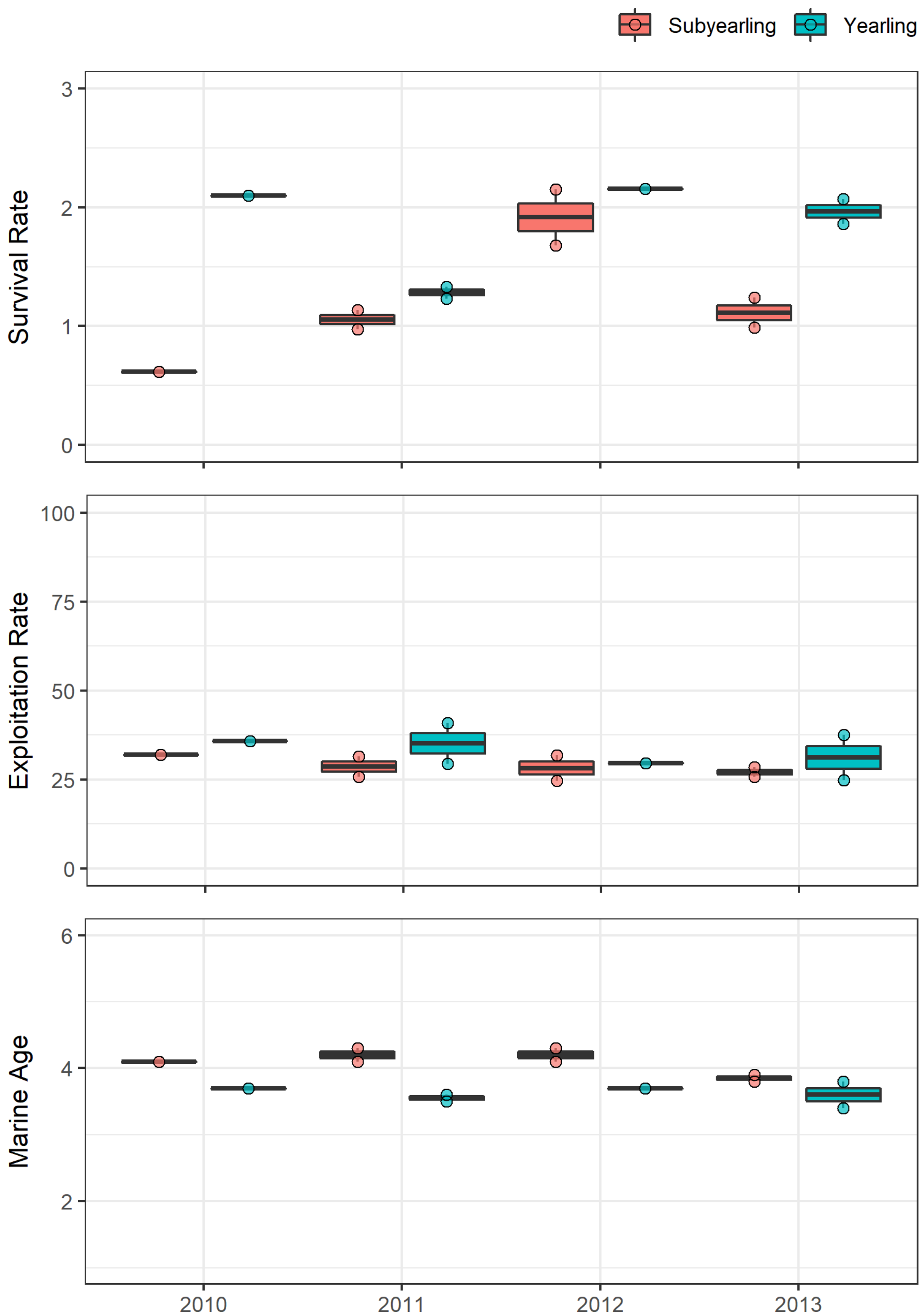

Figure 2: Survival rates (%), exploitation rates (%), and marine age of Atnarko River Chinook subyearling (red) and yearling (blue) smolts over time for ocean entry years 2010-2013. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value.

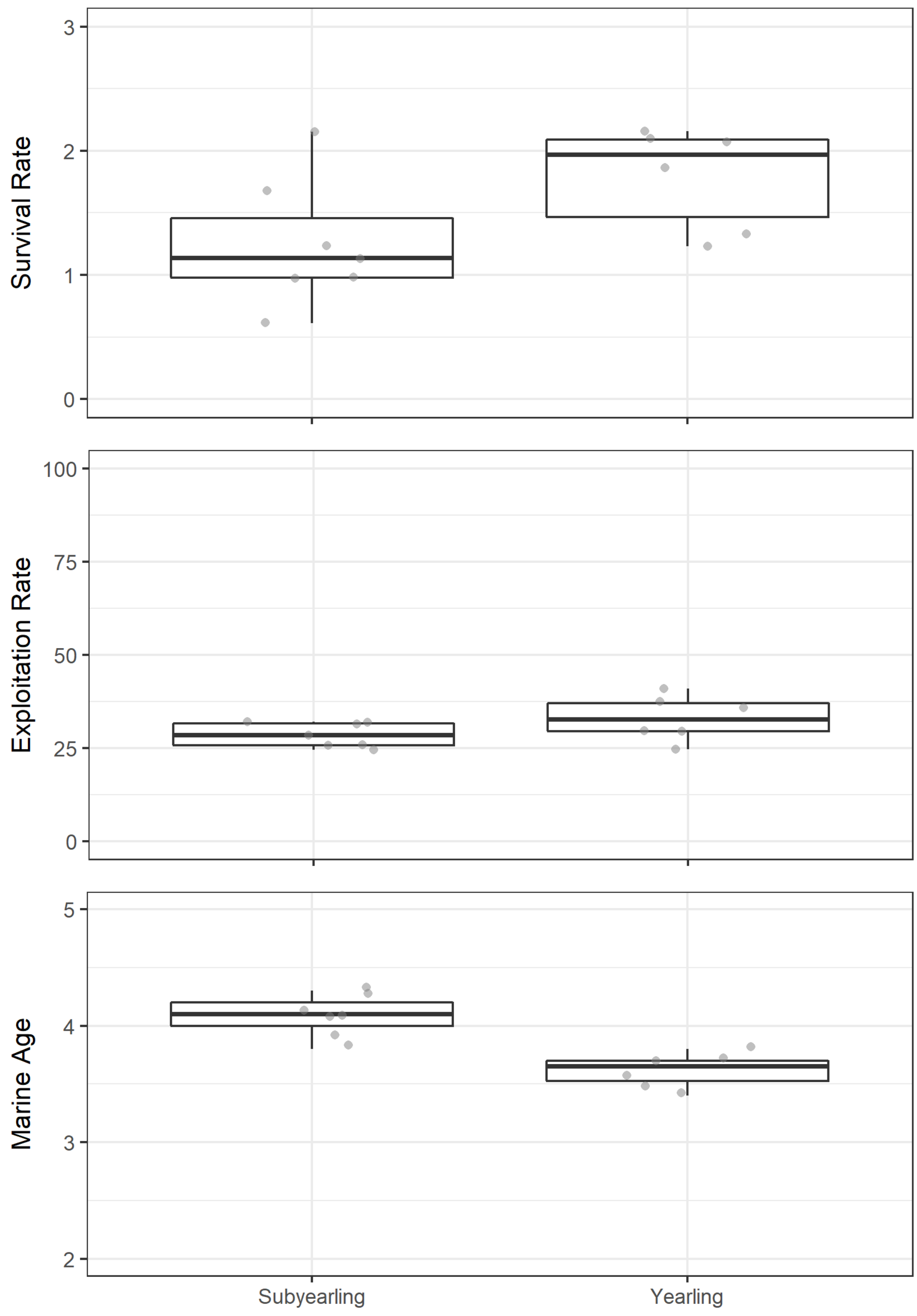

Figure 3: Survival rates (%), exploitation rates (%), and marine ages for Atnarko River Chinook subyearling and yearling smolts released by Snootli Creek Hatchery in years 2010-2013. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey.

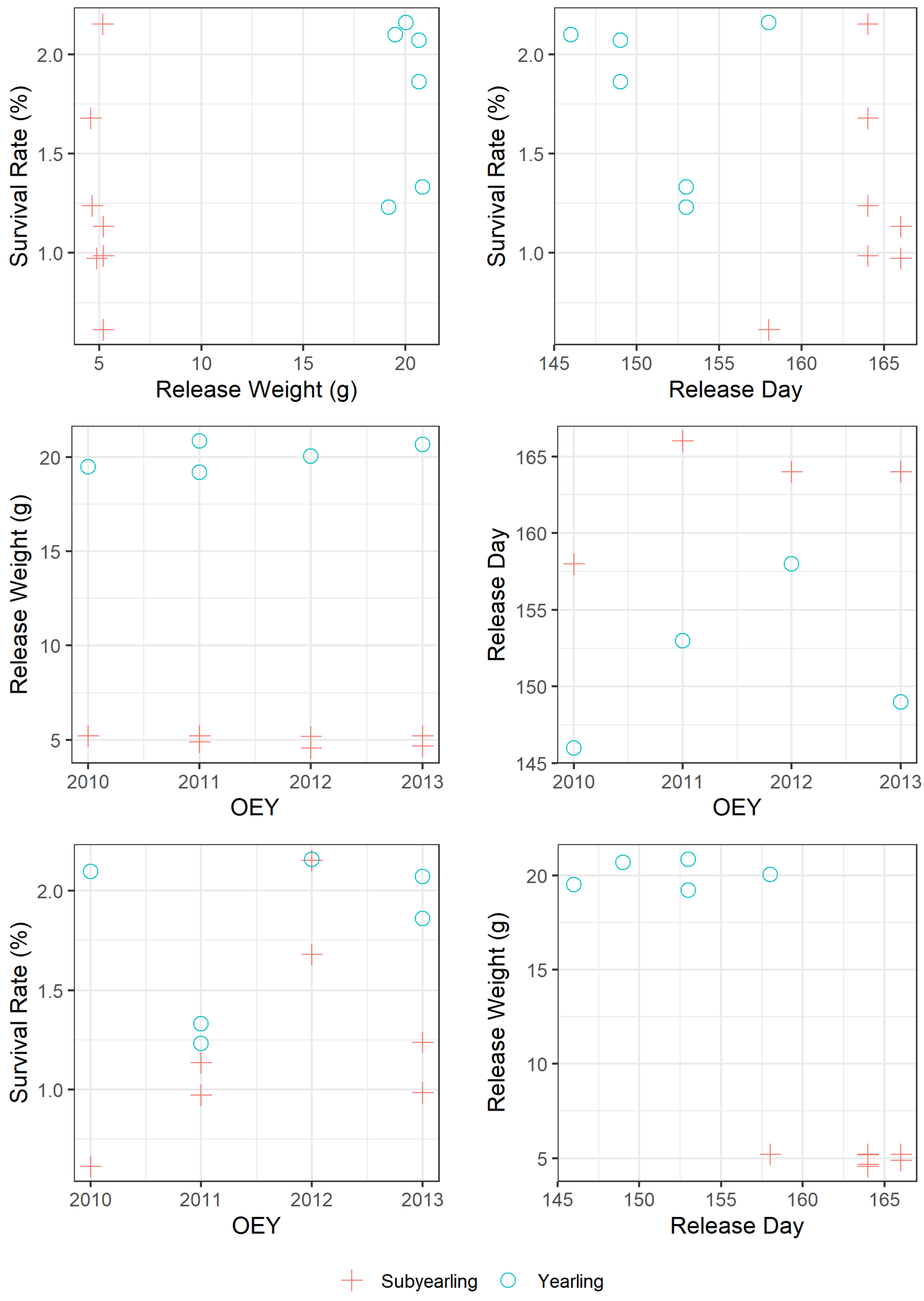

Figure 4: Data distributions of Atnarko River Chinook subyearling (red cross) vs yearling smolts (blue circle) released by Snootli Creek Hatchery during the yearling trial.

Table 6: Top three models showing fixed effects for predicting survival rates of Atnarko River Chinook salmon. The best model is bolded. ICC represents the intra-class correlation which describes the portion of the variation in the model attributed to the random ocean entry year effect.

Intercept	Size	$Size^2$	OEY	Stage	Day	Day^2	df	logLik	delta	ICC
-3.274	**-**	**-**	**-**	**+**	**-**	**-**	**4**	**11.72**	**0**	**0.53**
-3.324	0.01	-	-	-	-	-	4	11.68	0.07	0.53
-3.204	-	-	-	-	-	-	3	8.2	2.69	0.53

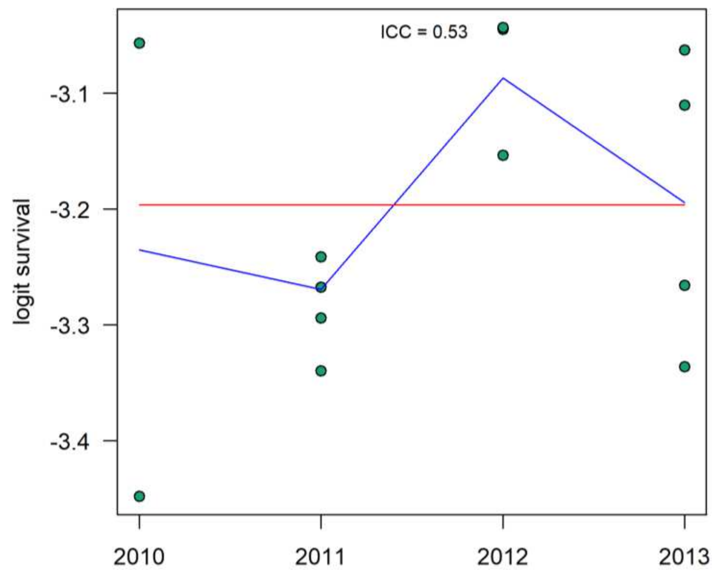

Figure 5: Estimated mean Atnarko River Chinook logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

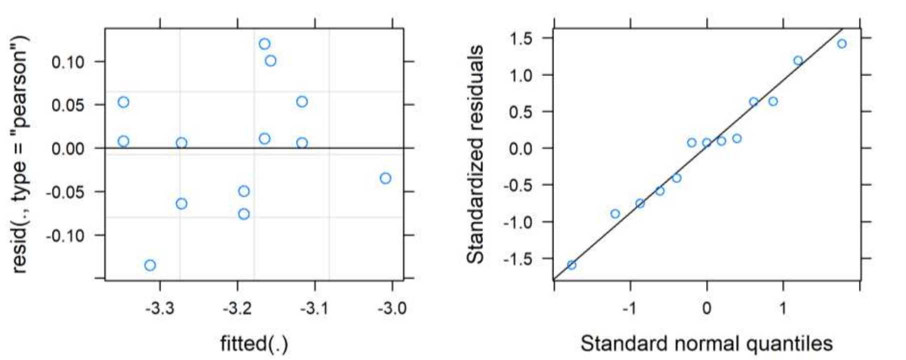

Figure 6: Residuals and quantile plot for the best Atnarko River Chinook model.

2. Cheakamus River Summer Chinook

In 2014, Tenderfoot Creek Hatchery significantly changed their operations, converting from an ocean-based, mixed stock, net-pen hatchery to a river-based hatchery with four different stocks of Chinook. Cheakamus River summer Chinook are being enhanced to meet population rebuilding objectives, with target releases of 80,000 fed fry and 50,000 yearling smolts each year. All four systems enhanced by Tenderfoot Creek are glacial-fed and cold, driving a yearling life history. However, the Cheakamus River is dammed, with warmer temperatures supporting more rapid growth. As a result, Cheakamus juveniles have developed two life history strategies, with some leaving in the late spring after a few a months of freshwater rearing, and others migrating in the fall. Therefore, the hatchery releases both fed fry and yearling Cheakamus Chinook to mimic the natural population and applies separate CWTs to each.

With only two years of preliminary recovery data, no modelling/statistical analyses can be conducted, however the data are summarized below. Further analyses should be conducted once the complete recovery data are available. Survival estimates, exploitation rates, and biological data (e.g. age at return) rely on complete data. We were notified by the hatchery manager that there have been some problems with data completeness, namely with a lack of escapement data. Therefore, exploitation rates could not be estimated.

For the 2016 and 2017 releases, little difference was observed in the survival and exploitation rates of fed fry versus yearlings (

Table 7; Figure 7). Overall, survival for both stages was higher for the 2016 release. The mean return age was higher for the yearling releases than for the fry releases in both years (

Table 7; Figure 7).

Table 7: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, the preliminary mean survival rates (%), and mean age at return (green = preliminary) for fry and yearling Cheakamus River releases from Tenderfoot Creek Hatchery in 2016 and 2017. Standard deviation is given in parentheses for release events with > 1 release group.

OEY	STAGE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2016	Fry	2.5 (0.1)	148 (0)	2	74,192	0.42	NA	3.0
	Yearling	20.8	112	1	38,981	0.38	NA	4.0
2017	Fry	4.9 (0.7)	178 (0)	2	46,232	0.15	NA	3.0
	Yearling	20.9	116	1	38,182	0.24	NA	3.5
2018	Fry	2.5	169	1	30,984	-	-	-
	Yearling	20.1	113	1	45,903	-	-	-

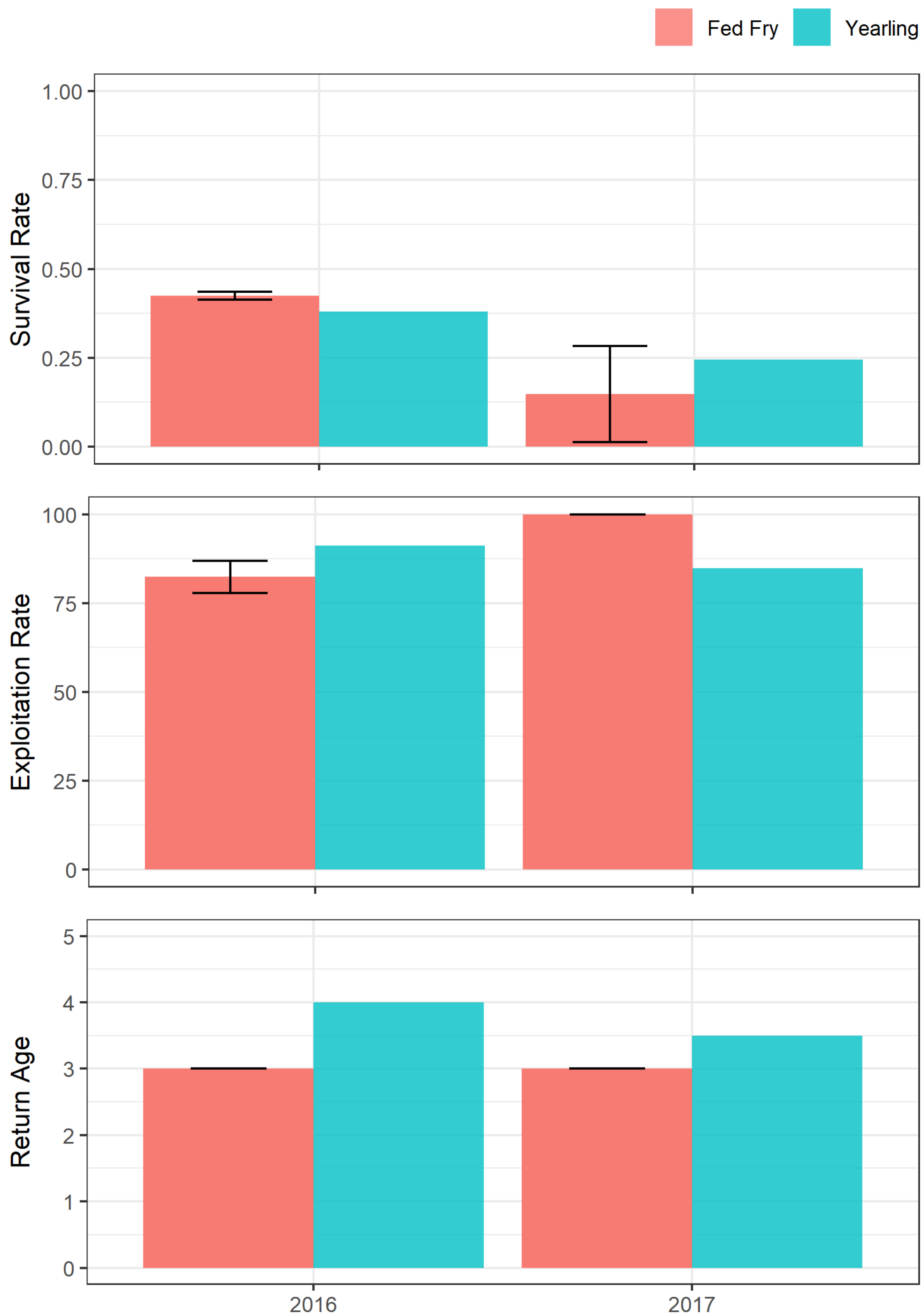

Figure 7: Preliminary survival rates (%), exploitation rates (%), and return ages over time for Cheakamus River Chinook fry vs yearlings released from Tenderfoot Creek Hatchery in 2016 and 2017.

3. Phillips River Fall Chinook

The Gillard Pass Fishery Association hatchery is a Designated Public Involvement facility run by the Gillard Pass Fisheries Association on Sonora Island. It has been releasing Phillips River Chinook since 1985 when local fishing lodges first expressed interest in getting involved and contributing to local enhancement. The original objective of enhancement of this stock was simply to produce more fish, however over time that focus has shifted towards re-building (Rupert Gale, personal communication). DFO have also used Phillips River Chinook as an informal indicator stock for the south coast mainland inlets. Wild escapements of Phillips River Chinook have been stable at approximately 700-1,500 over the past few years, therefore in 2019, target releases were reduced from 150,000 to 100,000 smolts. In 2020, it was decided that the rebuilding objectives had been met for this stock and that releases would be stopped. Wild river returns will now be monitored for the next few years to determine whether the Phillips River enhancement was able to successfully rebuild a self-sustaining natural population. Escapement is monitored through an intensive mark-recapture program on the Phillips River (Rupert Gale, personal communication).

Reliable survival estimates are not available prior to the 2011 release year due to data quality limitations.

Starting with brood year 2009, Phillips River conducted a five-year experimental yearling release strategy. At the time, there were concerns around low survival rates throughout the Salish Sea and uncertainty how to improve them. One idea at the time was that yearling releases, or 'stream-type' Chinook, might have better performance. Therefore, an arrangement was made with DFO to conduct a five-year trial. In 2007, significant improvements were made to the rearing facilities. Prior to the 2007 brood year, fish were reared at high densities in Capilano troughs. These were then replaced with three-meter circular tubs and changes were made to feeding and tank cleaning practices. Therefore, improved survival rates observed during the yearling experiment may also be attributed to facility and fish husbandry improvements.

Only four of the five years of the experiment have complete release and recovery data (Table 8). Yearlings were not released in 2013 and release weights were missing from the 2015 release. Therefore, modelling was not possible, however the data are described and survival rates, exploitation rates, and marine ages are compared. Subyearling smolts were reared at the hatchery on Sonora Island in circular tubs and transported to the outlet of Phillips Lake for release. Releases occurred between May 8th and June 3rd over the four years reviewed at a mean weight of 4.2 g (SD: ± 0.22 g). The facility on Sonora was not suitable for rearing yearling smolts, therefore yearlings were reared at the Omega facility on Great Central Lake and then transported to Phillips Lake for release between April 23rd and May 1st at a mean weight of 17.2 g (SD: ± 5.3 g) (Table 8).

The mean survival rates of the yearling release groups was significantly higher than for the subyearling release groups (t-test; $p = 0.009$) (Table 8; Figure 8-Figure 9). Mean exploitation rates were slightly lower for the yearling releases but the difference was not significant (Wilcoxon rank sum test; W = 7, $p = 0.37$, n = 8; Table 8; Figure 8-Figure 9). The mean return ages were also significantly higher for the yearling release groups than for the subyearling release groups (t-test; $p = 0.041$), although the mean marine age was significantly lower (t-test; $p < 0.001$; Figure 9).

The combination of improved rearing facilities and the yearling strategy was resulting in such high returns that concerns developed around the relatively small brood collection and the potential negative genetic effects on the natural population. Therefore, production reverted to the subyearling release strategy after completion of the yearling trial.

Table 8: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, the mean survival and exploitation rates (%), and mean marine age for subyearling and yearling Phillips River Chinook smolt releases.

OEY	STAGE	SIZE (G)	DAY	RELEASE GROUPS	TOT CWT RELEASED	SURVIVAL (%)	EXPLOITATION (%)	MARINE AGE (YRS)
2011	Subyearling	4.1	154	1	49,774	0.74	21.68	4.3
	Yearling	11.1	114	1	23,895	3.15	12.73	3.3
2012	Subyearling	4.0	155	1	81,104	1.58	31.99	3.9
	Yearling	20.4	122	1	39,300	2.63	22.15	3.4
2014	Subyearling	4.5	148	1	144,007	0.76	31.72	4.0
	Yearling	20.0	118	1	49,029	2.93	28.35	3.3
2015	Subyearling	4.2	128	1	213,125	0.31	34.00	3.8
	Yearling	-	113	1	35,713	1.52	34.64	3.2

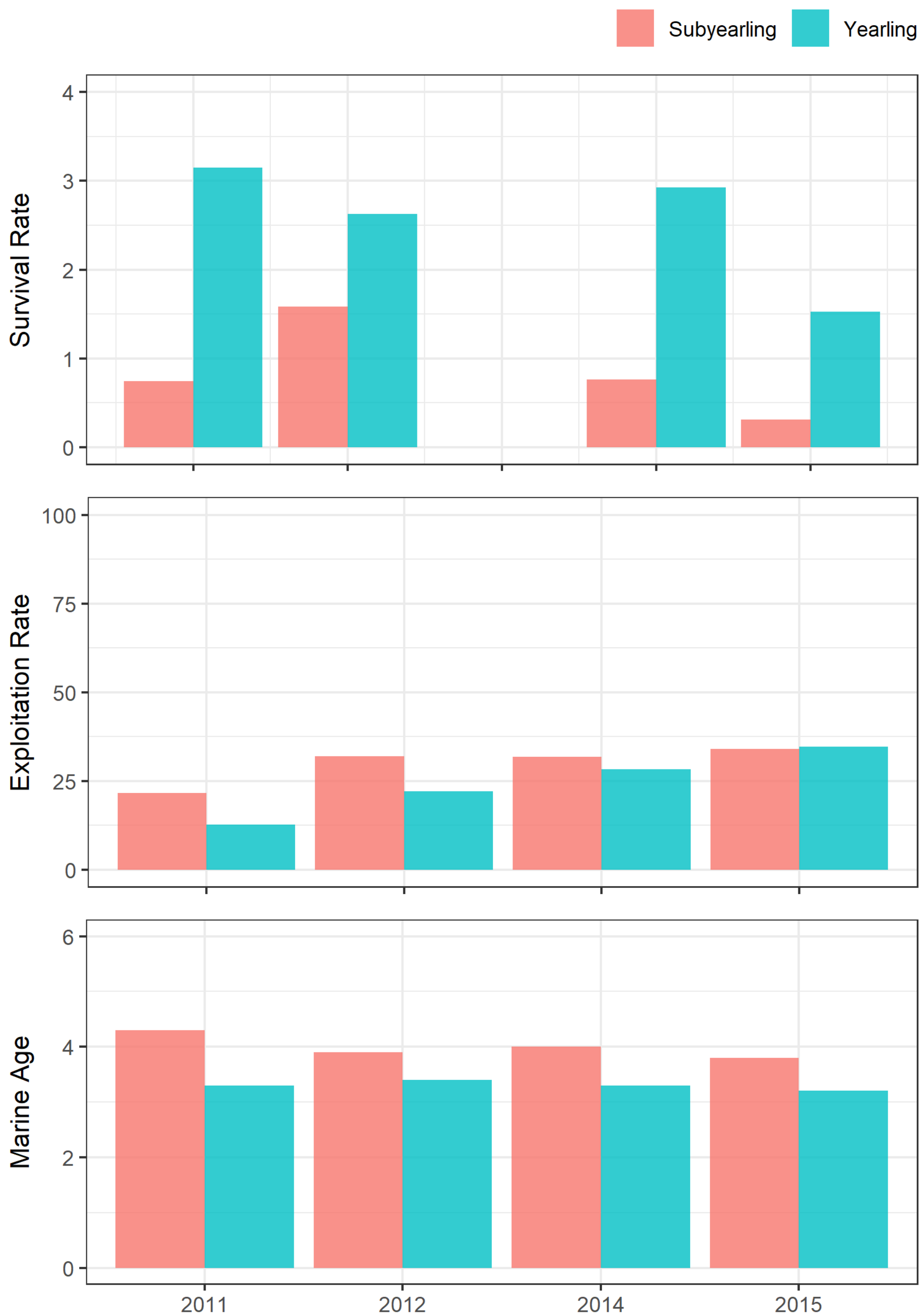

Figure 8: Survival rates (%), exploitation rates (%), and marine ages over time for Phillips River Chinook subyearling versus yearling smolt releases from the Gillard Pass Fishery Association hatchery.

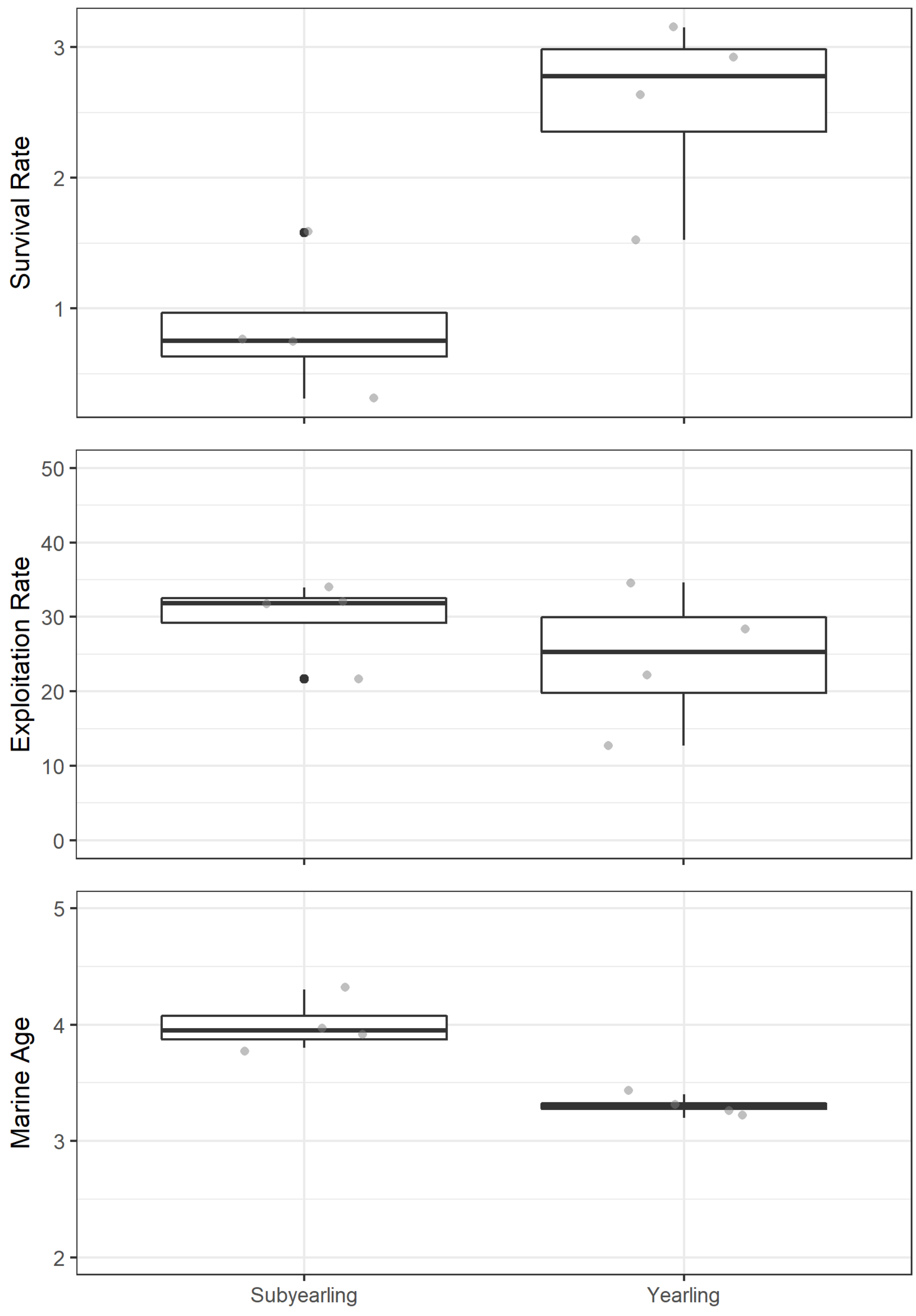

Figure 9: Survival rates (%), exploitation rates (%), and marine ages for Phillips River Chinook subyearling versus yearling smolt releases by the Gillard Pass Fishery Association hatchery in years 2011, 2012, and 2014. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey and outliers in black.

4. Puntledge River Summer Chinook

Puntledge River summer Chinook have been reared and released from Puntledge River Hatchery to meet both assessment and conservation objectives. Currently, 500,000 subyearling smolts are released annually into the Puntledge River. Survival rates of Puntledge River summer Chinook decreased in the 1980s from approximately 0.88% to 0.07% (Figure 10). Mean survival rates of releases between 2010-2015 were 0.26% (SD ± 0.11%).

In years 2002, 2003, and 2005, annual releases of between 100,000 and 1 million fed fry were made at four different release locations throughout the watershed for conservation purposes, while annual releases of 600,000-1.4 million subyearling smolts were made from the hatchery for hatchery assessment objectives (Figure 11). These releases were part of a captive brood stock program designed to conserve the unique summer Chinook run at Puntledge River that faced the risk of extinction. The program was designed to run for one full brood cycle (4 years). Below is a summary of the performance of fry and subyearling smolts during this program.

Mean survival rates of fed fry were significantly lower than those released as subyearling smolts (Kruskal-Wallis, $p = 0.003$) (

Table 9; Figure 12-Figure 13). The highest survival rate from a fry release was seen from the single release in Puntledge River in 2003 (

Table 9; Figure 12-Figure 13). Exploitation rates of summer Chinook fed fry were lower on average; however, the difference was not significant (Kruskal-Wallis, $p = 0.08$; Figure 12-Figure 13). Several of the fry releases had exploitation rates of ‘0’, meaning that there were no CWTs from these releases recovered in fisheries. This suggests that the numbers released were not large enough to adequately measure exploitation rates, given such low survival rates. Return ages were similar between the two life stages across years (Figure 12-Figure 13). It should be noted that these fish were unusually small for the application of CWTs and did demonstrate unusually low survival rates.

We examined several release covariates (life stage, release site, release weight, release day, ocean entry year) to determine which were best associated with the smolt-to-adult survival rate during these three years of dual releases. Given the annual variability in survival rates (Figure 12), ocean entry year was added as a random effect. Quadratic terms for release weight and date were also added to account for non-linear relationships. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each life stage in Figure 14.

The best model contained only release weight as a predictor for survival (Table 10), showing an increase in survival with increased weight at release (Figure 15). The intra-class correlation estimate is relatively low with the random year effect explaining 20% of the total variation in the survival response (Figure 16). Thus, the weight at release was an important determinant of survival in these three years. Residuals and normal quantile-quantile plots for the top model are provided in Figure 17. The higher survival rate for the 2003 subyearling release group is somewhat of an outlier, however given only three years of data, it was left in the model.

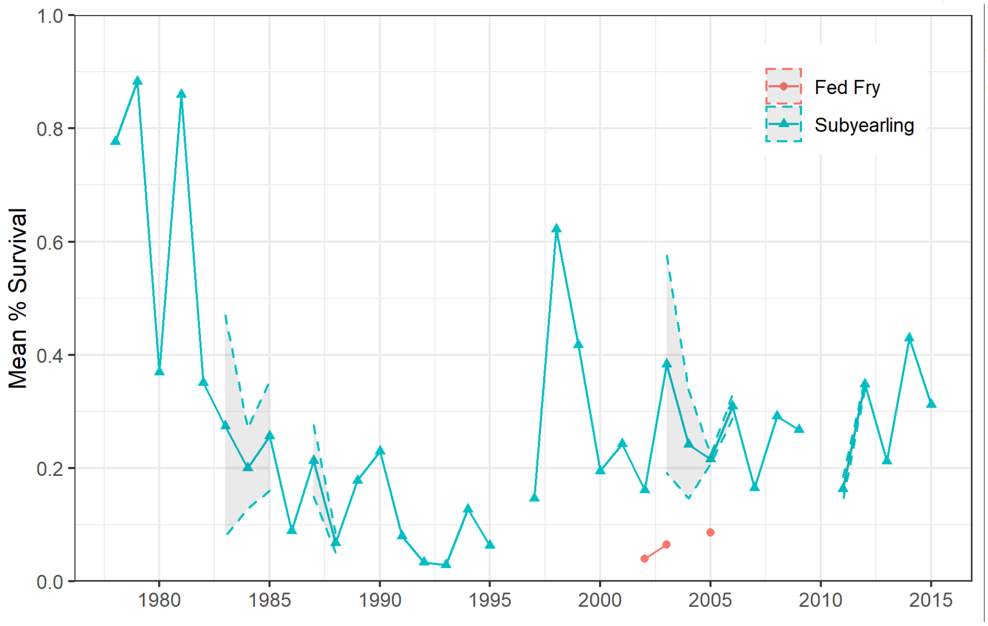

Figure 10: Mean percent survival of Puntledge River summer Chinook fed fry (red circles) and subyearling smolts (blue triangle) released from the upper watershed or Puntledge River Hatchery, respectively, by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

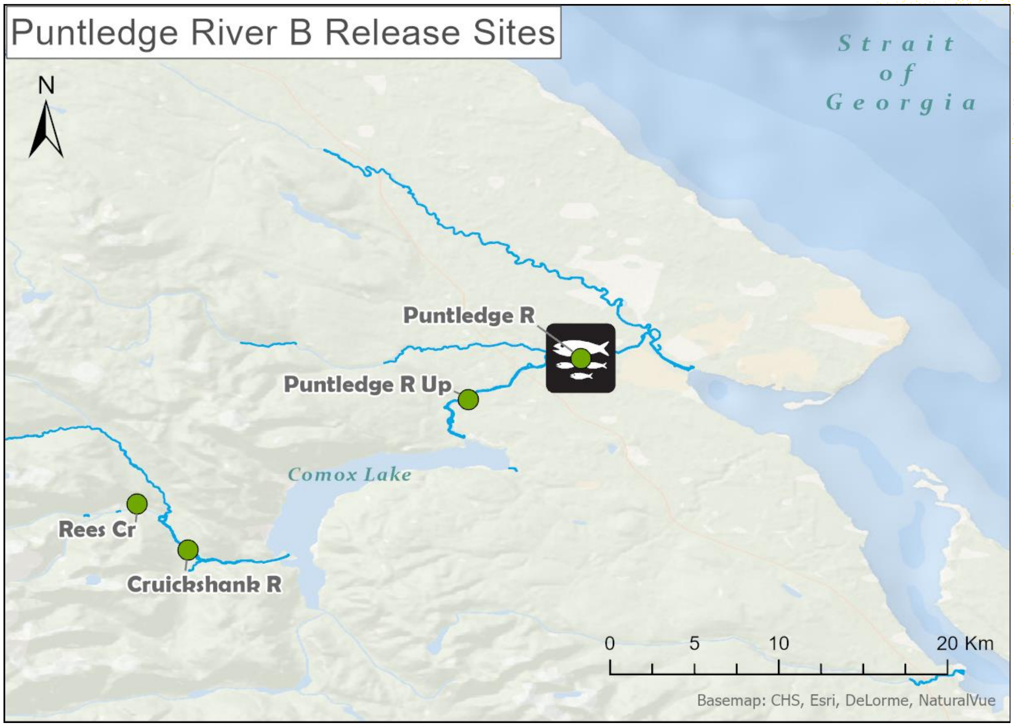

Figure 11: Release locations (green circles) for summer Chinook fry and subyearling smolts from the Puntledge River Hatchery (black and white fish symbol) in years 2002, 2003, and 2005.

Table 9: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Puntledge River summer Chinook fed fry and subyearling smolts released at different locations throughout the Puntledge River watershed in years 2002, 2003, and 2005. Standard deviation is given in parentheses for release events with > 1 release group.

OEY	STAGE	RELEASE SITE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2002	Fry	Cruickshank R	1.9	105	1	29,903	0.08	37.73	4.0
	Fry	Puntledge R Up	2.0	106	1	29,814	0.00	0.00	2.0
	Subyearling	Puntledge R	7.1	148	1	122,158	0.16	43.18	3.3
2003	Fry	Cruickshank R	2.2	126	1	30,369	0.02	36.57	3.8
	Fry	Puntledge R Up	2.2	126	1	30,192	0.06	0.00	2.9
	Fry	Puntledge R	2.5	148	1	60,610	0.12	22.53	3.2
	Subyearling	Puntledge R	6.9 (0.4)	148 (0)	2	60,400	0.40	23.62	3.1
2005	Fry	Rees Cr	3.6 (0.0)	108 (1)	2	40,366	0.08	0.00	2.1
	Fry	Puntledge R Up	3.6 (0.0)	110 (1)	2	40,246	0.09	0.00	2.7
	Subyearling	Puntledge R	6.7 (0.3)	152 (0)	2	80,375	0.21	6.81	2.4

Figure 12: Survival rates (%), exploitation rates (%), and return ages of Puntledge River summer Chinook fed fry vs subyearling smolts released across four different release locations over three years. Black bars show standard deviation where sufficient data permits.

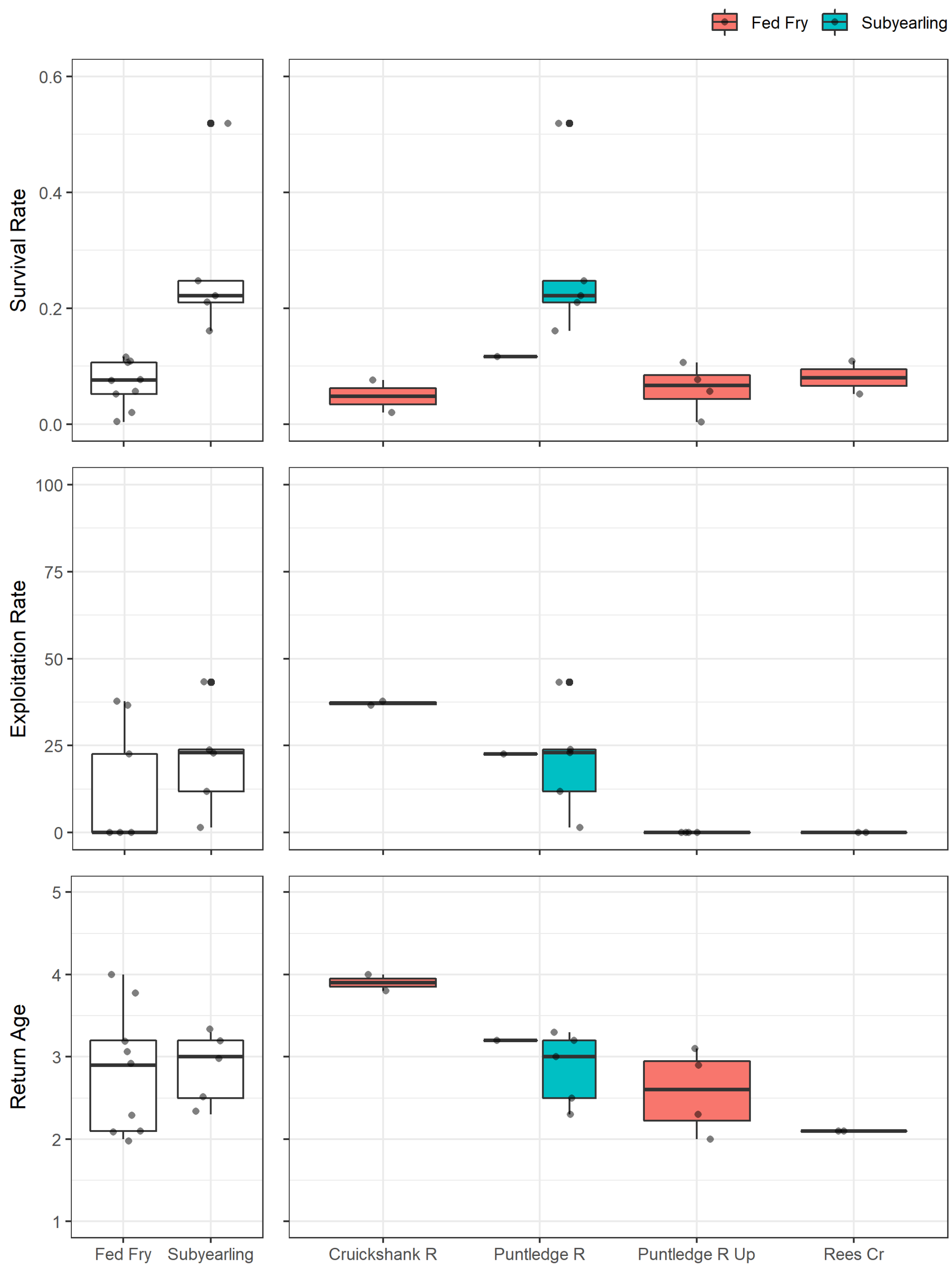

Figure 13: Survival rates (%), exploitation rates (%), and return ages for summer Chinook fed fry released from multiple locations throughout the watershed, and subyearling smolts released from the Puntledge River Hatchery in years 2002, 2003, and 2005. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey and outliers in black.

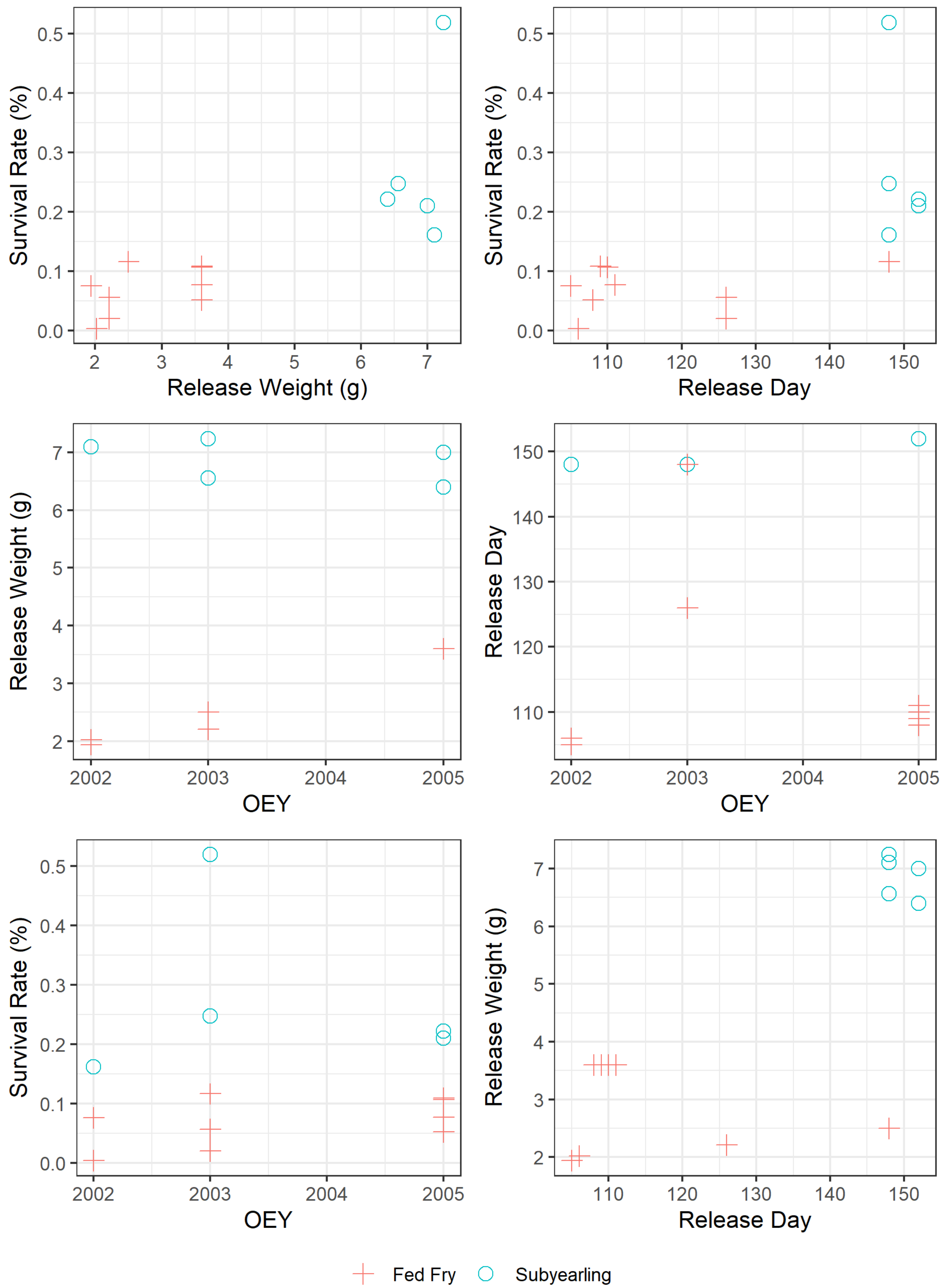

Figure 14: Data distributions of summer Chinook fed fry vs subyearling smolts released by Puntledge River Hatchery.

Table 10: Top three models showing fixed effects for predicting survival rates of Puntledge River summer Chinook salmon. The best model is bolded. ICC represents the intra-class correlation which describes the portion of the variation in the model attributed to the random ocean entry year effect.

INTERCEPT	SIZE	SIZE²	OEY	STAGE	DAY	DAY²	DF	LOGLIK	DELTA	ICC
-3.688	**0.018**	**-**	**-**	**-**	**-**	**-**	**4**	**30.78**	**0**	**0.20**
-3.636	-0.009	0.003	-	-	-	-	5	31.16	4.30	0.23
-3.689	0.018	-	-	+	-	-	5	30.78	5.05	0.24

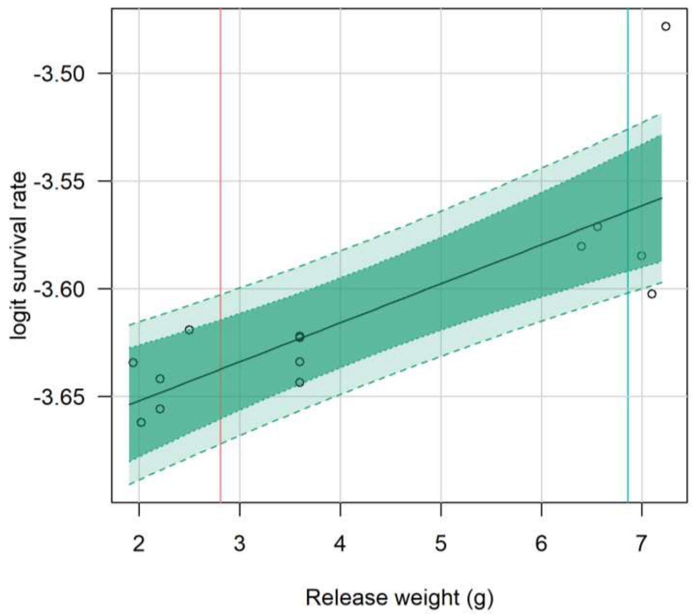

Figure 15: Mean logit survival and 95% CIs (dark green = fixed effects, light green = random effects) for the model fit to Chinook releases of different weights. The vertical solid lines indicates the median weight-at-release for fry (red) and subyearling smolts (blue).

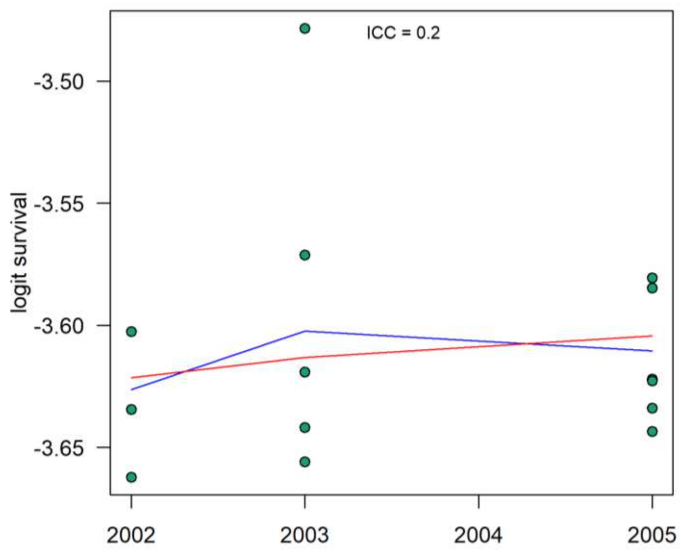

Figure 16: Estimated mean Puntledge River summer Chinook logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

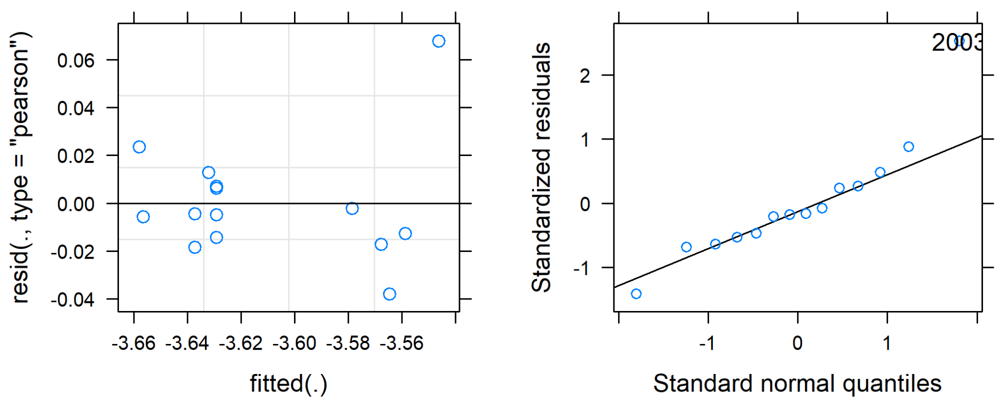

Figure 17: Residuals and quantile plot for the best Puntledge River summer Chinook model.

5. Quinsam River Fall Chinook

Quinsam River fall Chinook are currently reared and released to meet harvest and assessment objectives, with annual release targets of 2.7 million. Approximately 900,000 are also released into the Campbell River for rebuilding. Survival rates of hatchery reared Quinsam River Chinook decreased in the 1980s, going from approximately 3.32% survival in 1975 to 0.06% in 1990 (Figure 18) followed by some improvements in the late 1990s and mid 2010s. The mean survival rate of subyearling smolts released between 2010 and 2015 was 0.25% (SD ± 0.18%).

In the late 1990s, homing to the upper watershed was poor, with most returns going directly to the hatchery (Eric Fortkamp, personal communication). To address this, hatchery staff began releasing fed fry into the lake to facilitate imprinting on natural waters above the hatchery. This strategy was believed to be effective, though measuring its success was, and remains, challenging. These experimental fry releases were conducted in 2000-2007 and were started again in 2015. Note that a time of release trial was also conducted in 2015; however, we focus on the 'normal' releases for this analysis of life stages and have removed the early and late release outliers. In 2001, 2002, and 2007 the data show 'smolts' < 4 g that were released into the lake. After discussion with hatchery staff (Eric Fortkamp), it was decided that these should be treated as fed fry. Therefore, for this analysis anything < 4 g was designated as 'fed fry' and anything > 4 g were subyearling smolt (0+). Subyearling smolts were released from the hatchery around the same time as the fry were released into the lake (upper watershed).

Overall, no significant differences were found between mean survival rates, exploitation rates, or return ages of fed fry and subyearling releases (Table 11; Figure 19-Figure 20). For fed fry, mean survival rates were slightly lower than those of subyearling smolts, mean exploitation rates were higher, and mean return ages were also higher, however the difference were insignificant (t-test; $p = 0.2$; t-test; $p = 0.1$; Kruskal-Wallis, $p = 0.05$, respectively).

Several release covariates (life stage, release weight, ocean entry year) were examined to determine which were best associated with survival rate during this period. Given the annual variability in survival rates (Figure 19), ocean entry year was added as a random effect. Furthermore, a quadratic weight effect was added to account for possible non-linear relationships between weight at release and survival. Because most fry and subyearling smolts were released within a two-week window, the day of release was not included in this analyses. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each life stage in Figure 21.

The best model contained release weight and stage (Table 12; Figure 22). Weight and stage are likely confounded as smaller fish are fry and larger fish are subyearling smolts. As can be seen in Figure 22, the model attempts to predict survivals of larger fry and smaller subyearlings – conditions that are unrealistic. However, the relationship suggests an increase in weight at release was correlated with higher survival rates and that smolts generally survived better than fry. The intra-class correlation estimate indicates that the random year effect explained 59% of the total variation in the survival response and a model that incorporates the year effect provides a better fit to the data than one that only considers the fixed release strategy effects (i.e. life stage and weight) (Figure 23). Residuals and normal quantile-quantile plots for the top model are provided in Figure 24. Although there is evidence of heteroscedasity in the residuals, the difference between the observed and predicted values are normally distributed.

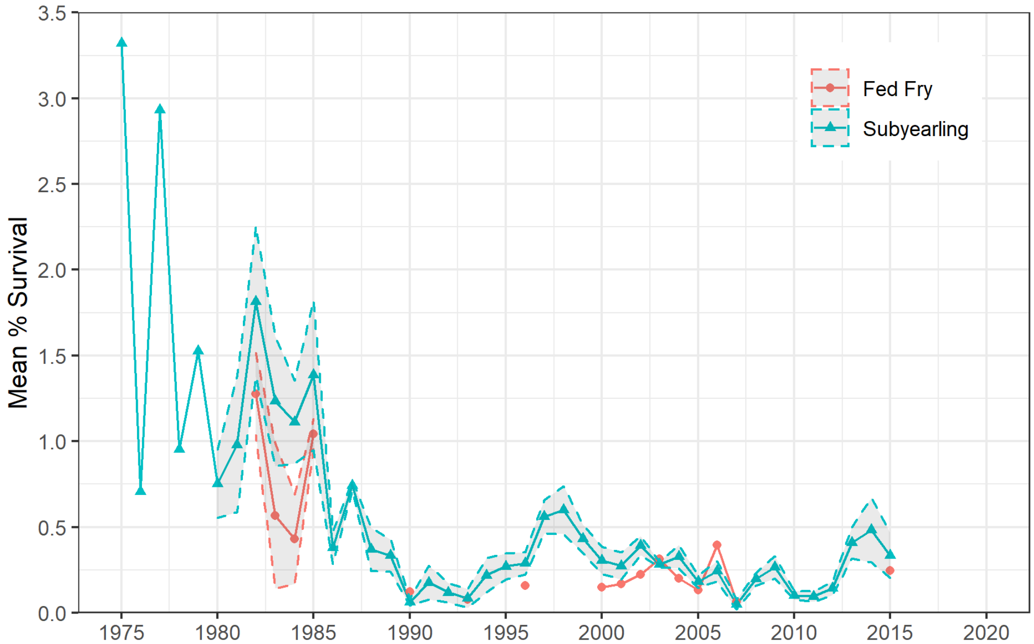

Figure 18: Mean percent survival of Quinsam River Chinook fed fry and smolts released from Quinsam Lake or Quinsam River, respectively, by ocean entry year. Dashed lines around the mean shaded grey represent the standard deviation.

Table 11: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%) and mean return ages of Chinook fed fry and smolt releases of Quinsam River stock by Quinsam River Hatchery in years 2001-2007, and 2015. Standard deviation is given in parentheses for release events with > 1 release group.

OEY	STAGE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2000	Fed Fry	2.4	126	1	29,102	0.15	23.70	4.6
	Subyearling	7.6 (0.8)	136 (2)	6	167,749	0.31	38.03	4.2
2001	Fed Fry	2.8	130	1	30,451	0.17	57.19	4.4
	Subyearling	7.7 (1.1)	131 (6)	8	228,528	0.28	42.19	4.1
2002	Fed Fry	2.9	123	1	32,793	0.22	41.79	4.3
	Subyearling	7.8 (0.6)	131 (4)	7	218,434	0.40	37.63	4.1
2003	Fed Fry	3.1	128	1	30,976	0.31	61.57	3.8
	Subyearling	7.8 (0.2)	132 (4)	7	210,446	0.28	42.19	4.0
2004	Fed Fry	2.5	125	1	31,263	0.20	46.90	4.5
	Subyearling	6.9 (0.5)	129 (4)	7	195,579	0.33	35.84	3.9
2005	Fed Fry	3.1	124	1	28,951	0.13	33.54	4.1
	Subyearling	5.2 (0.2)	134 (4)	7	209,757	0.18	24.05	4.0
2006	Fed Fry	2.9	130	1	27,172	0.39	60.41	4.2
	Subyearling	5.1 (0.4)	129 (4)	7	181,128	0.25	43.46	4.1
2007	Fed Fry	3.2	136	1	28,675	0.06	23.84	4.0
	Subyearling	4.9 (0.2)	134 (3)	7	199,466	0.05	43.04	4.0
2015	Fed Fry	3.4	133	1	43,599	0.25	54.94	4.0
	Subyearling	6.2 (0.6)	129 (3)	5	397,078	0.30	41.72	3.6

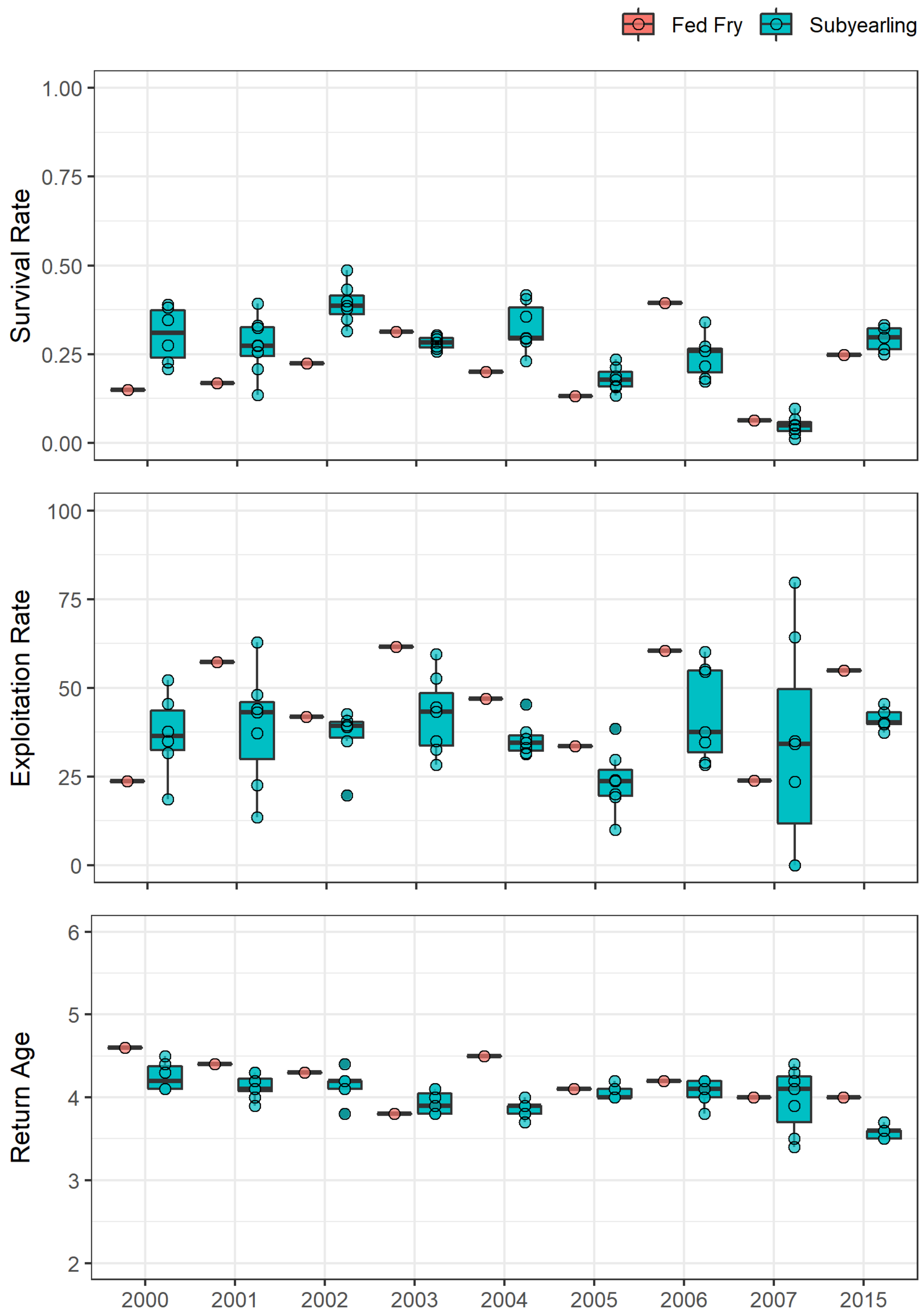

Figure 19: Survival rates (%), exploitation rates (%), and return ages of Quinsam River Chinook fed fry vs subyearling smolts for each ocean entry year when both life stages were released by Quinsam River Hatchery.

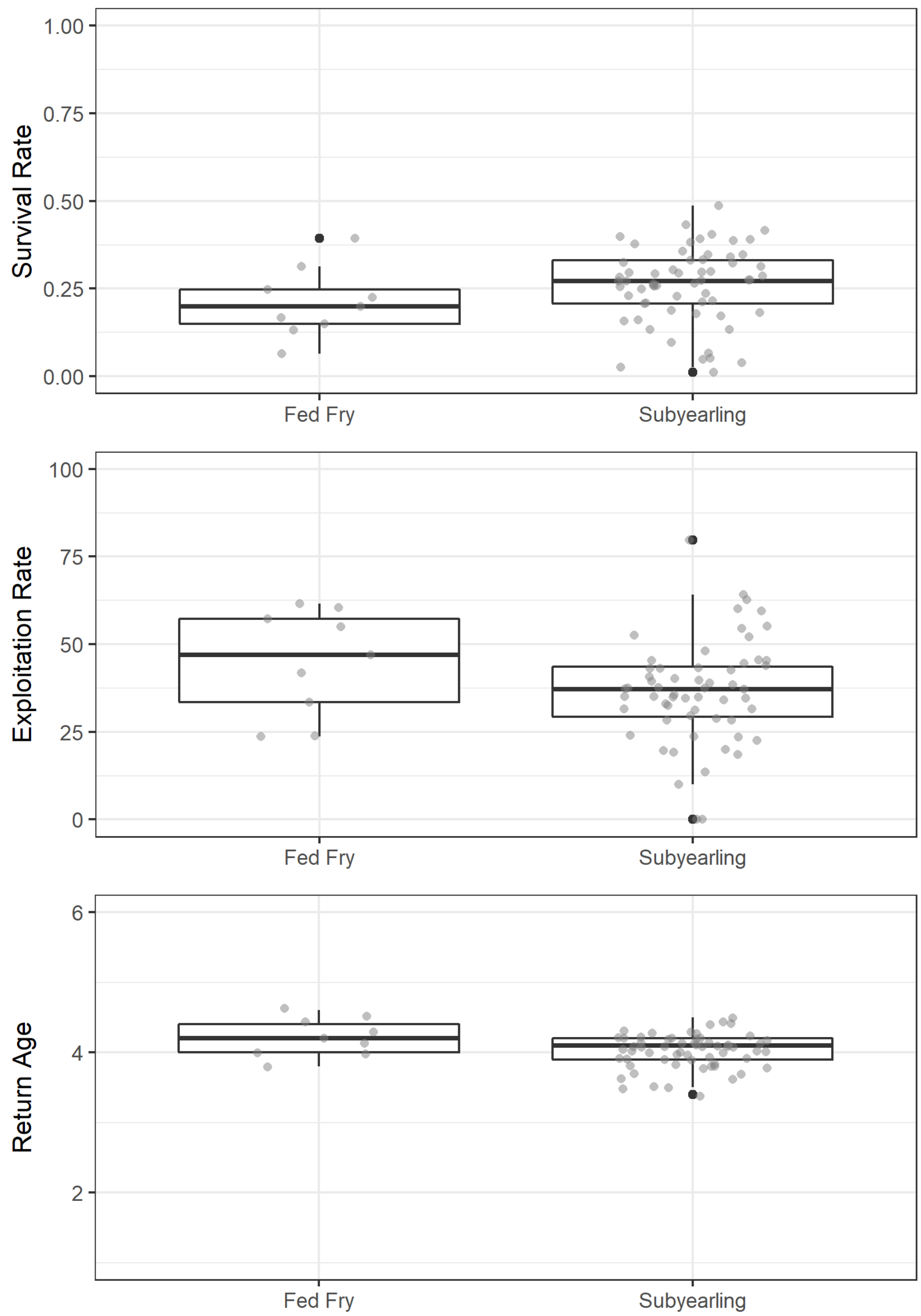

Figure 20: Survival rates (%), exploitation rates (%), and return ages for Quinsam River Chinook fed fry versus smolts released by Quinsam River Hatchery in years 2001-2007, and 2015. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey and outliers in black.

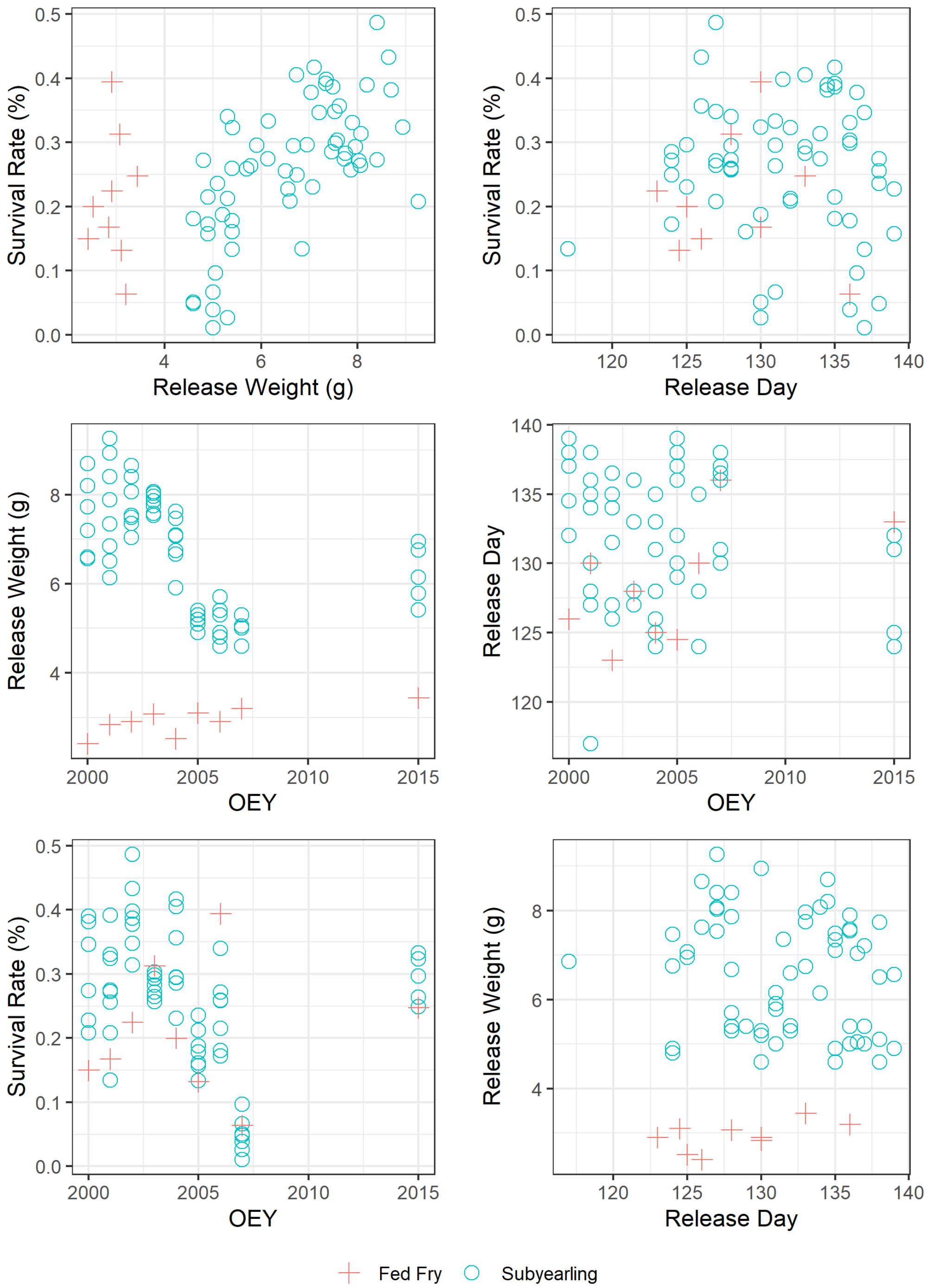

Figure 21: Data distributions of Chinook fed fry and smolts released by Quinsam River Hatchery.

Table 12: Top three models showing fixed effects for predicting survival rates of Quinsam River Chinook salmon. The best model is bolded. ICC represents the intra-class correlation which describes the portion of the variation in the model attributed to the random ocean entry year effect.

INTERCEPT	SIZE	$SIZE^2$	OEY	LIFE STAGE	DF	LOGLIK	DELTA	ICC
-3.707	0.049	-0.003	-	+	6	164.70	0	0.57
-3.625	**0.014**	**-**	**-**	**+**	**5**	**163.41**	**0.19**	**0.59**
-3.382	0.049	-0.003	<0.001	+	7	164.70	2.47	0.60

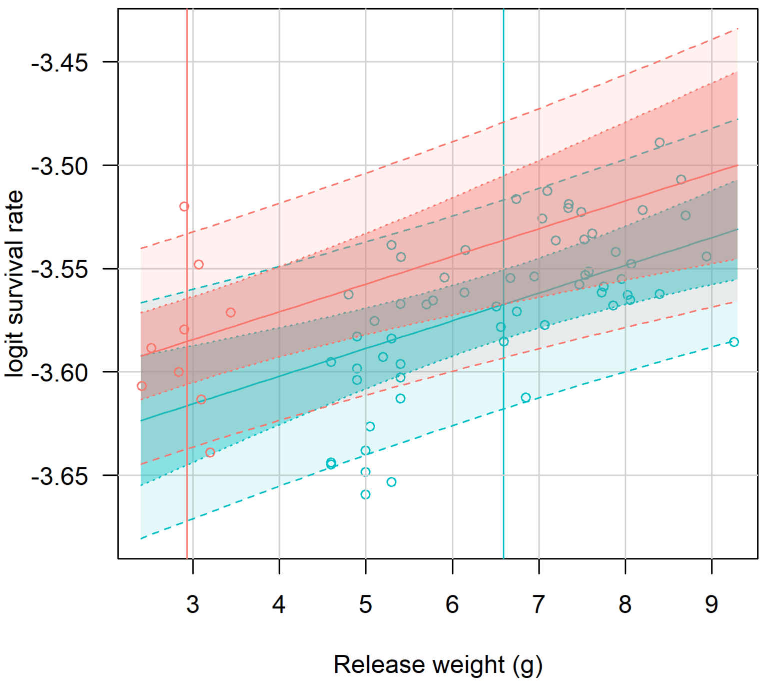

Figure 22: Mean logit survival of fry (red line) and smolt (blue line) releases and 95% CIs (darker = fixed effects, lighter = random effects) for the model fit to Chinook releases of different weights. The vertical solid lines indicate the median weight-at-release for fry (red) and subyearling smolts (blue).

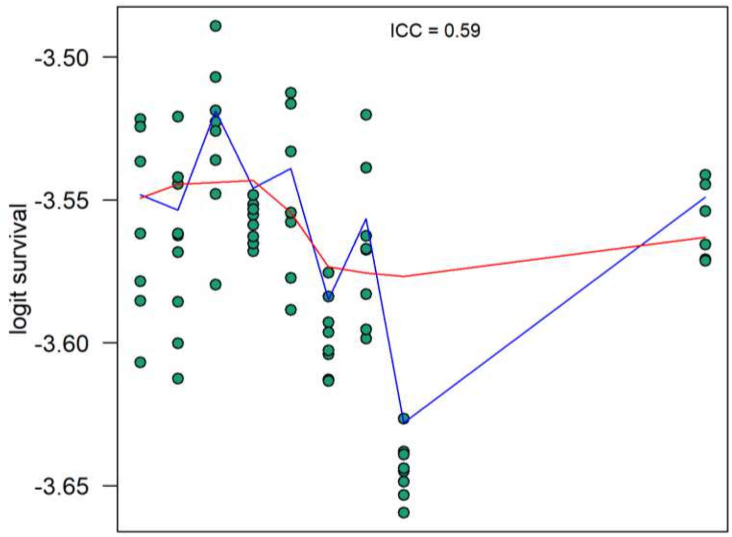

Figure 23: Estimated mean Quinsam River Chinook logit survival for different years accounting for both the linear trend over time and deviations due to random effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

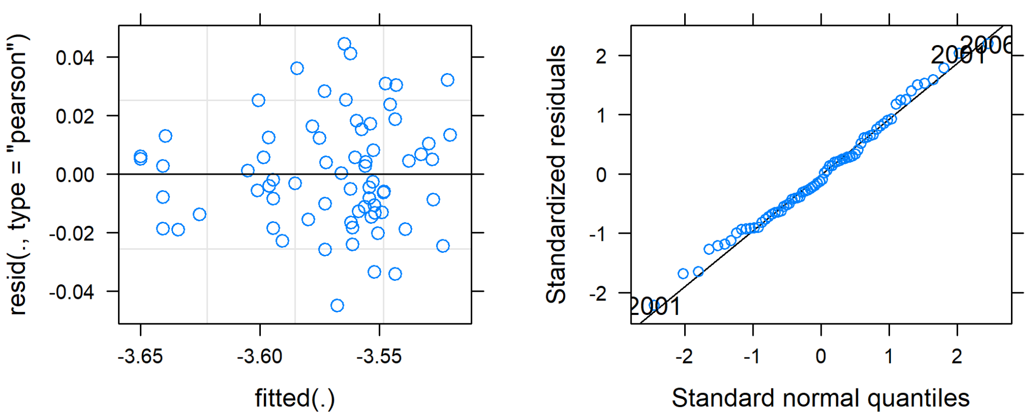

Figure 24: Residuals and quantile plot for the best Quinsam River Chinook model.

6. Robertson Creek Fall Chinook

Robertson Creek Hatchery produces fall-run Chinook salmon to meet assessment and harvest objectives with current annual release targets of 6.1 million fish. Unlike the survival patterns seen in the Strait of Georgia, survival rates for this stock have varied considerably over time with a roughly decadal oscillation (Figure 25). Periods of higher survival ranged from 1.7-3.9% and periods of low survival had values as low as 0.02%. The mean survival rate of releases between 2010 and 2015 was 0.82% (SD ± 0.59%).

A yearling trial was conducted on brood years 2002-2005, with 10,000-20,000 yearlings released along with 200,000 subyearling smolts in years 2004-2007. The objective was to see if they could increase survival and decrease the numbers of jacks and jimmies. The yearlings were released earlier in the calendar year between February 15 and May 1 at about 20 g, while subyearlings were released during a much shorter window between May 20 and 30 at 5 g.

There was a significant difference in the mean survival rates between the two life stages (Kruskal-Wallis, $p = 0.02$) (Table 13; Figure 26-Figure 27). Survival rates were higher for yearling releases than subyearling releases in three out of four years (Figure 26). There was no significant difference in the mean exploitation rate (Kruskal-Wallis, $p = 0.13$), although they were higher for subyearlings in three of four years (Figure 26).

Counter to the intention to decrease jacking rates, yearlings in fact yielded 9-14 times as many jacks as the subyearling release groups in two of the four years with 22.3% and 34.2% jacks returning from the 2002 and 2004 brood years (Figure 28). In the other two years, jacking rates were similar, but the mean return ages were higher for yearlings, with 29% and 20% age 5 returns from 2003 and 2005 brood years, respectively (15% and 4.3% for subyearlings from the same brood years). Overall, there was no significant difference in mean return ages between the two strategies (Kruskal-Wallis, $p = 0.80$). However, the mean marine ages of the yearling releases were significantly lower than those of the subyearling releases (Kruskal-Wallis, $p < 0.001$; Figure 26).

We examined several release covariates (life stage, release weight, release day, ocean entry year) to determine which were best associated with the smolt-to-adult survival rate in the four years of this trial. Quadratic terms for weight and day of release were also added to account for non-linear responses. Given the annual variability in survival rates (Figure 26), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each life stage in Figure 29.

The best model contained weight and the quadratic weight coefficient as covariates, suggesting that survival decreases with size for smaller sizes at release (i.e. subyearling smolts), but increases with size for larger sizes at release (i.e. yearling smolts) (Table 14; Figure 30). However, the effects of release weight, date, and life stage are likely confounded in this experiment. While the top model shows weight being the primary covariate, a combination of these covariates may in fact provide a more accurate prediction of survival rates. As can be seen in Figure 31, the model doesn't completely capture the degree of variation in survival. This is likely due to the fewer data points for yearling releases, confounding effects, and the higher survival of the 2005 and 2007 releases. The intra-class correlation estimate was relatively high, with 58% of the total variation in the survival response explained by the random year effect (Figure 31). Therefore, over a longer time series, accounting for the weight and date of release and life stage, as well as random variations associated with the year of ocean entry, may provide a better estimation of survival. Residuals and normal quantile-quantile plots for the top model are provided in Figure 32.

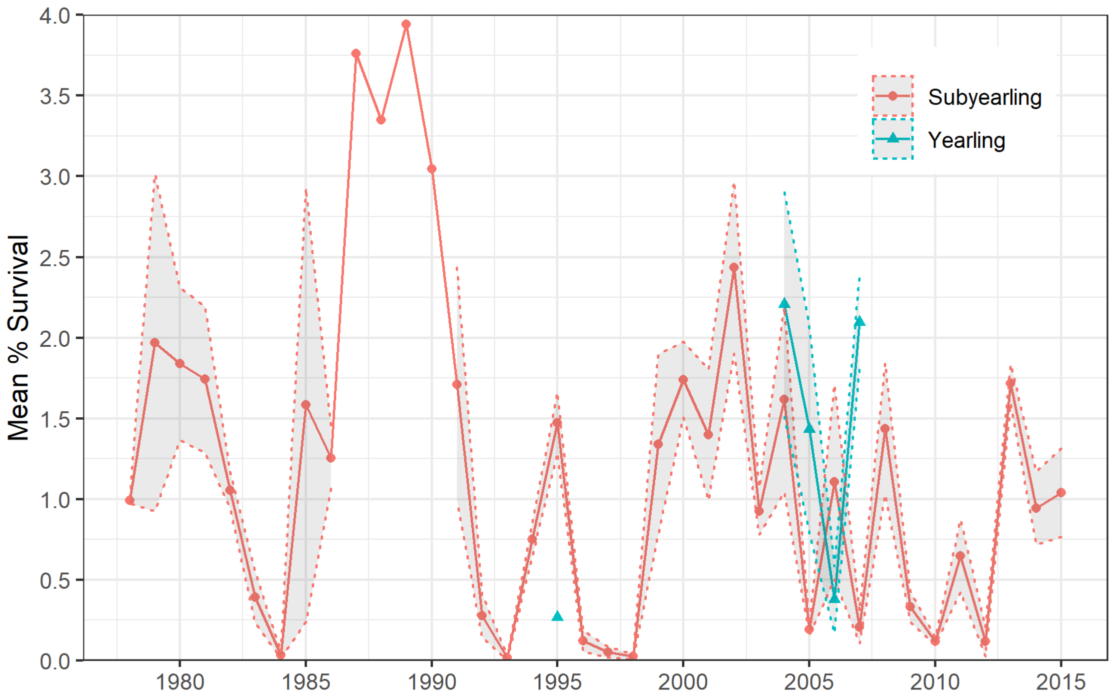

Figure 25: Mean percent survival of Robertson Creek Chinook subyearling (red circles) and yearling smolts (blue triangles) released from Robertson Creek Hatchery by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 13: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean marine ages of Robertson Creek Chinook subyearling and yearling releases by Robertson Creek Hatchery in years 2004 to 2007. Standard deviation is given in parentheses for release events with > 1 release group.

OEY	**Stage**	**Size** (g) (sd)	**Day** (sd)	**Release Groups**	**Tot CWT Releases**	**Survival** (%)	**Exploitation** (%)	**Age** (yrs)
2004	Subyearling	5.6 (1.0)	144 (1)	8	203,309	1.65	69.52	3.8
	Yearling	22.3 (0.0)	96 (20)	2	9,905	2.21	43.14	2.5
2005	Subyearling	6.1 (0.3)	140 (0)	7	200,803	0.19	59.25	3.9
	Yearling	18.7 (0.3)	73 (0)	2	9,764	1.50	72.49	3.1
2006	Subyearling	5.0 (0.3)	145 (2)	6	201,013	1.11	56.61	3.6
	Yearling	18.2 (1.7)	46 (20)	2	9,750	0.35	42.63	2.3
2007	Subyearling	4.9 (0.4)	150 (0)	6	201,524	0.21	47.98	3.8
	Yearling	25.9 (0.1)	121 (0)	2	19,831	2.09	34.11	3.0

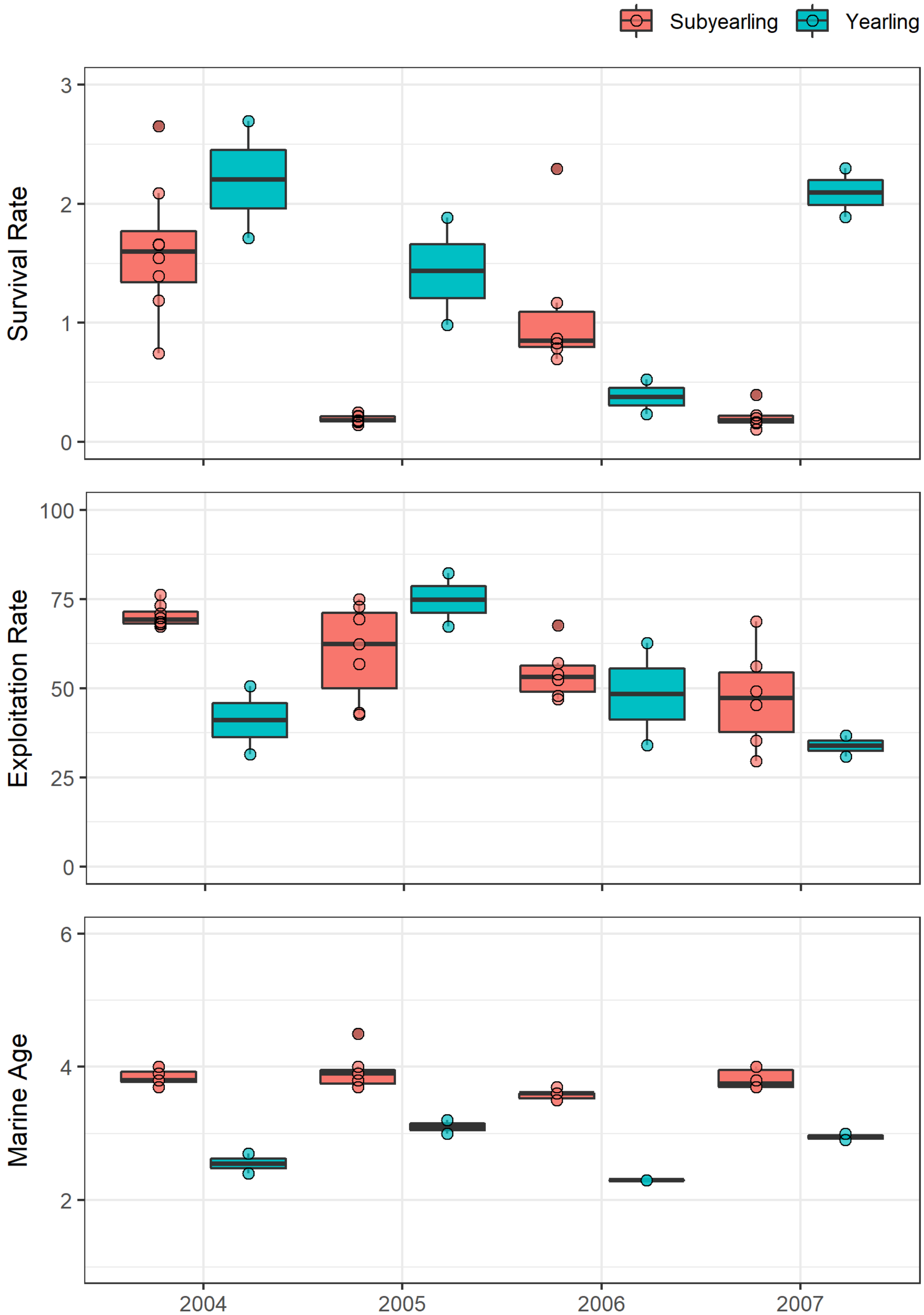

Figure 26: Survival rates (%), exploitation rates (%), and return ages of Robertson Creek Chinook subyearling and yearling smolts for each ocean entry year when both life stages were released by Robertson Creek Hatchery. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value.

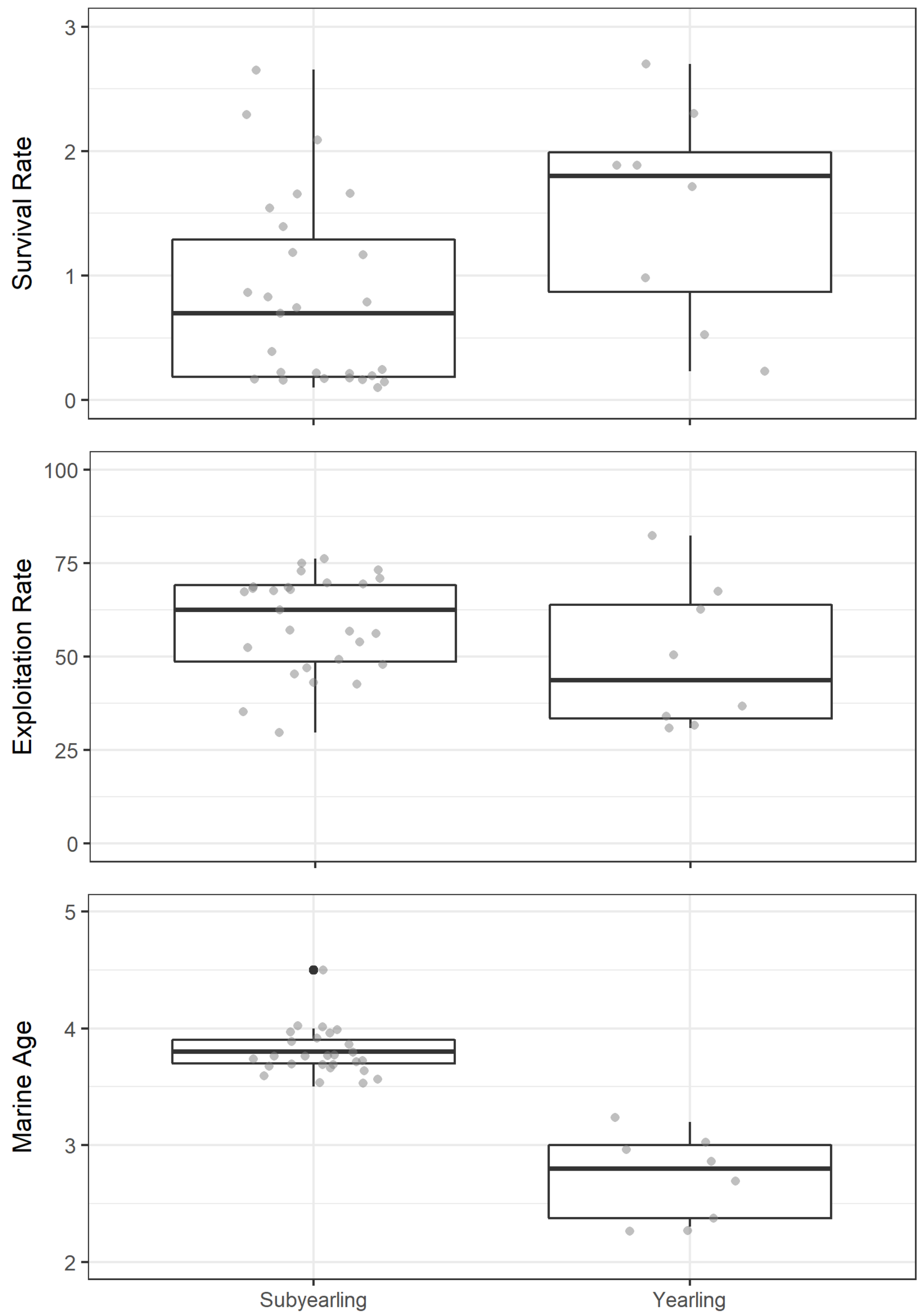

Figure 27: Survival rates (%), exploitation rates (%), and marine ages for Robertson Creek fall Chinook subyearling and yearling smolts released by Robertson Creek Hatchery in years 2004–2007. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey and outliers in black.

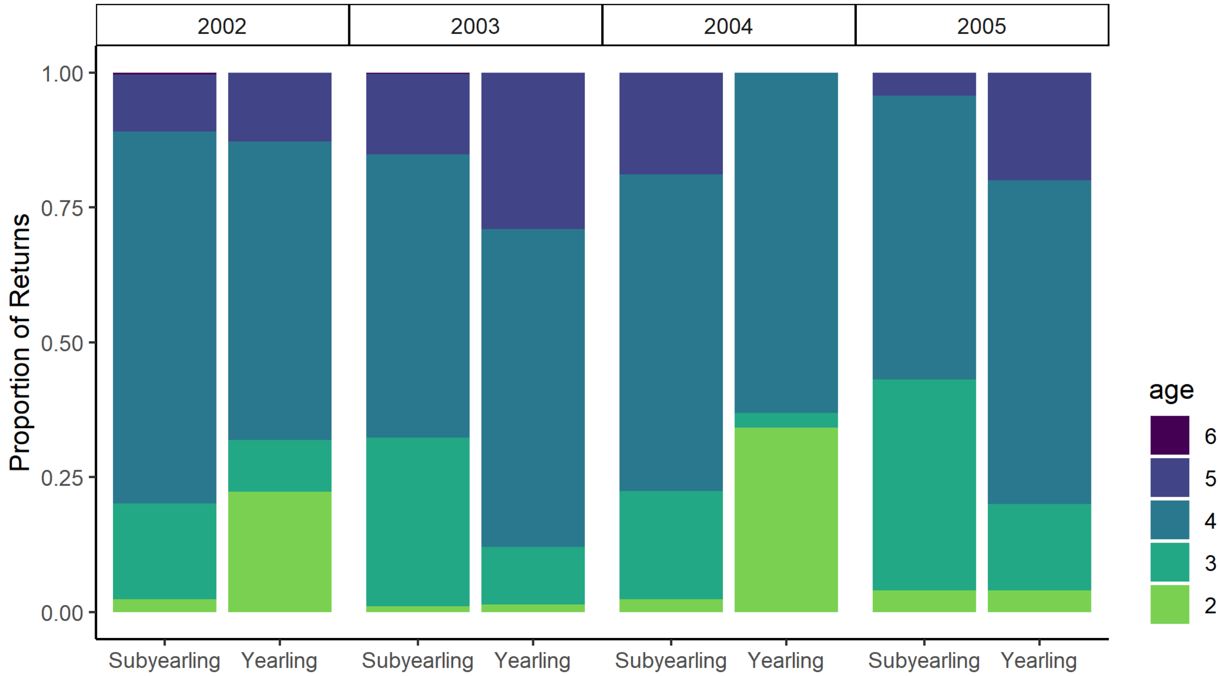

Figure 28: Proportion of returns (catch + escapement) of each age class from subyearling and yearling Robertson Creek Chinook releases by brood year.

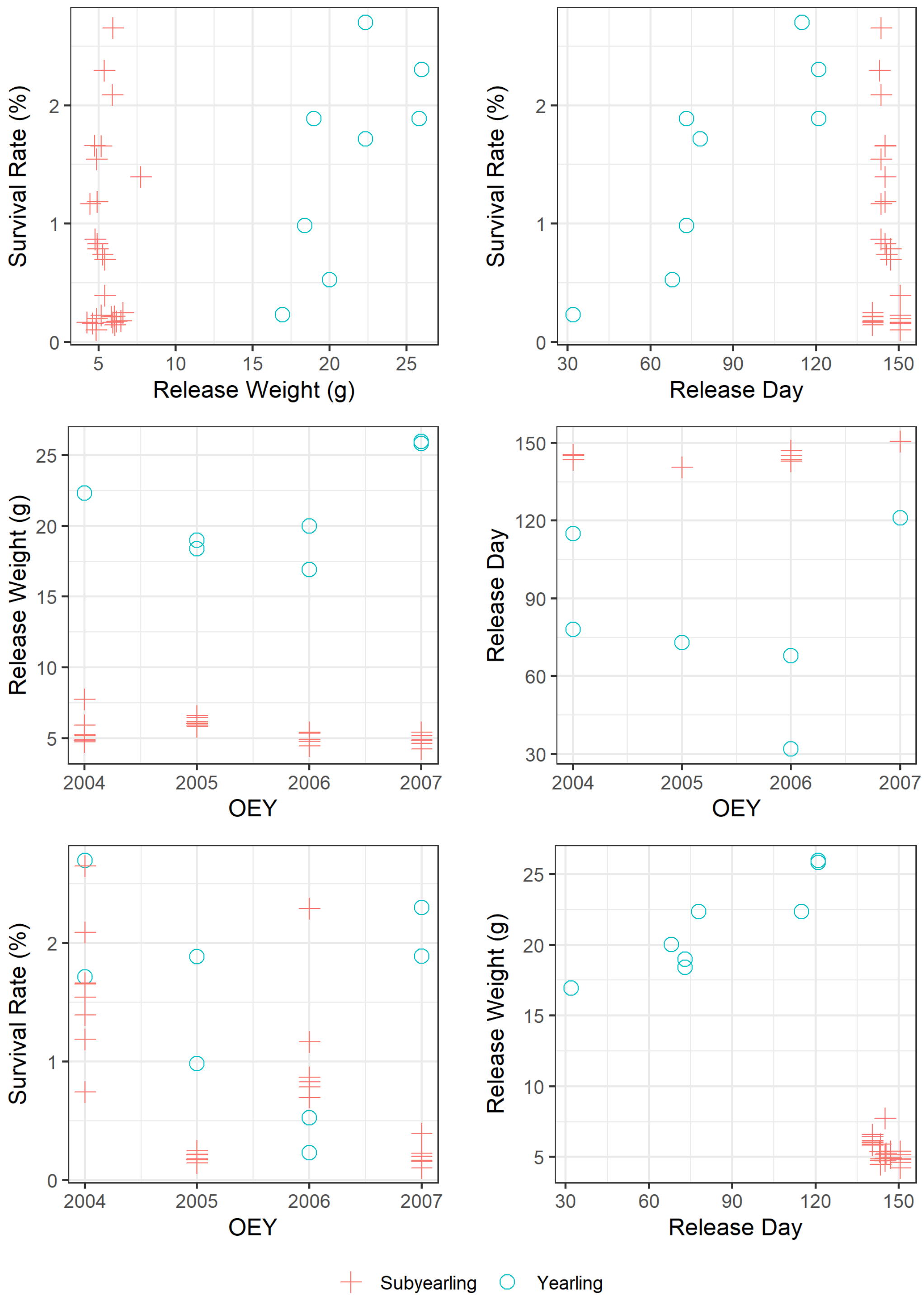

Figure 29: Data distributions of Robertson Creek Chinook smolts and yearlings released by Robertson Creek Hatchery.

Table 14: Top models (delta < 2) showing fixed effects for predicting survival rates of Robertson Creek Chinook salmon. The best model is bolded. ICC represents the intra-class correlation which describes the portion of the variation in the model attributed to the random ocean entry year effect.

INTERCEPT	SIZE	SIZE²	OEY	STAGE	DAY	DAY²	DF	LOGLIK	DELTA	ICC
220.538	-0.072	0.003	-0.112	-	-	-	6	17.29	0	0.39
-3.175	**-0.059**	**0.003**	**-**	**-**	**-**	**-**	**5**	**15.1**	**1.44**	**0.58**
-3.597	0.023	0	-	-	0.04	-	6	16.51	1.56	0.59
199.605	-0.004	0.001	-0.101	-	0.031	-	7	18.07	1.58	0.49

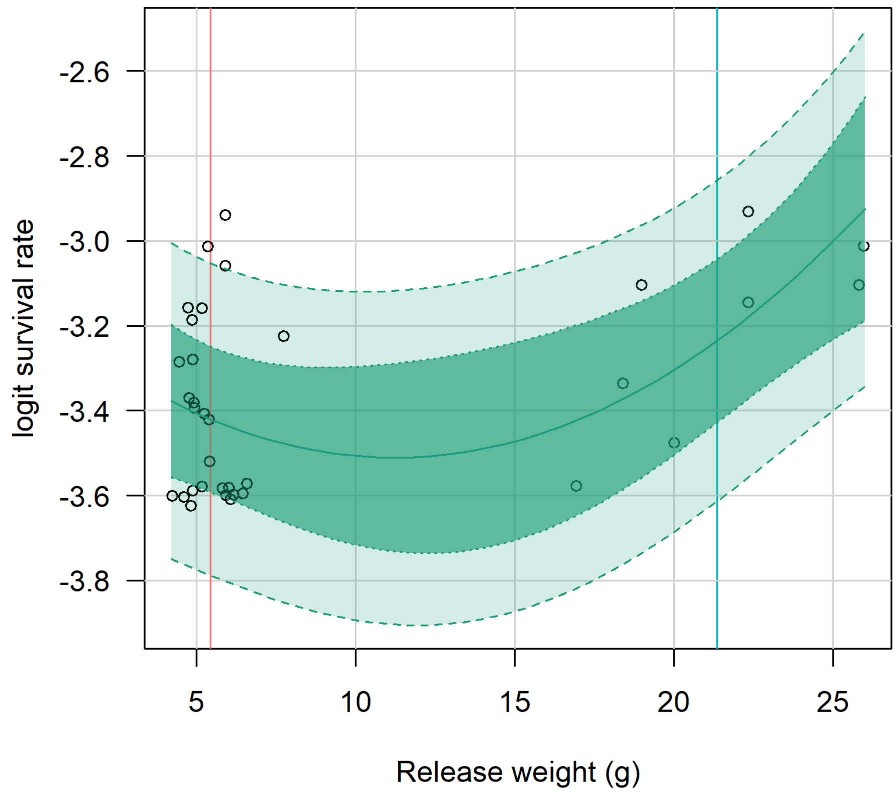

Figure 30: Mean logit survival and 95% CIs (dark = fixed effects, light = random effects) for the model fit to Chinook subyearling and yearling releases of different weights. Mean weights for each stage are shown by the vertical bars (subyearling = red, on the left; yearling = blue, on the right).

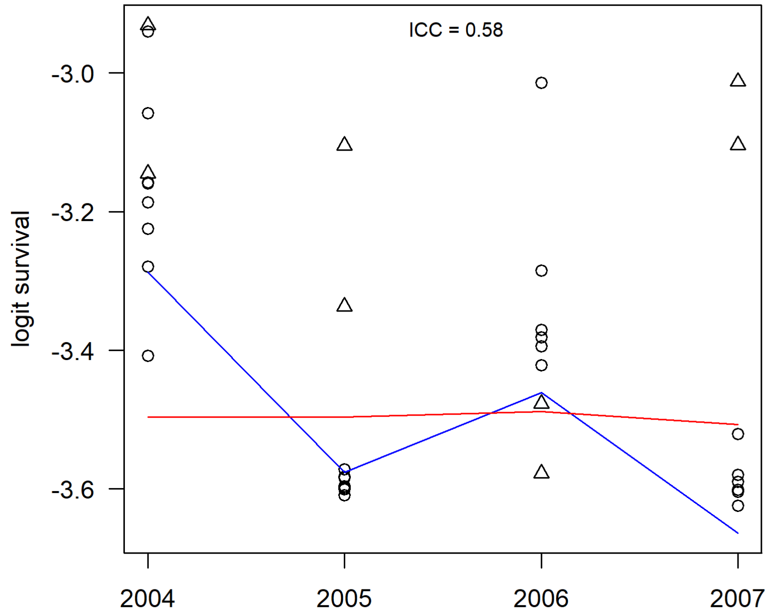

Figure 31: Estimated mean Robertson Creek Chinook logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects. The model is fit to all releases; however, smolt data are shown as circles and yearlings as triangles.

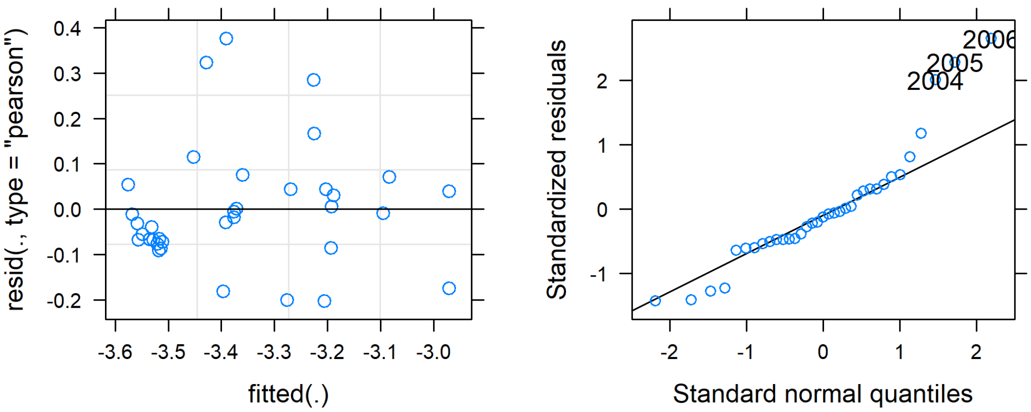

Figure 32: Residuals and quantile plot for the best Robertson Creek Chinook model.

7. Shuswap River Middle Summer Chinook

Shuswap River Middle summer Chinook are reared and released by Shuswap River Middle Hatchery to meet assessment objectives. Approximately 150,000 smolts are released annually, all marked with CWTs. Reliable survival estimates based on these CWT data were not available prior to the 2010 release year, therefore we do not know the historical survival rates of this stock. The mean survival rate of releases made between 2010 and 2015 was 0.69% (SD ± 0.51%).

Throughout the entire period of enhancement (1986-present), these Chinook have been released as subyearling smolts, also known as ocean-type Chinook. However, historical scale analyses revealed that this stock may have once also exhibited a yearling life history, also known as stream-type. While there is some uncertainty around the accuracy of these historical analyses, and the stream-type life history was not the dominant one, a yearling release experiment was initiated for Shuswap River Middle Chinook to see how their survivals compared to the traditional smolt production (Doug Lofthouse, personal communication).

The four-year trial began with the 2013 brood year, releasing approximately 20,000 yearling Chinook in addition to approximately 140,000 subyearlings (Table 15). At the time of this report, complete recovery data were only available for the 2015 releases. Preliminary data from this trial are presented below.

Although this experiment is ongoing, yearling releases will not be continued for this stock after the experimental period. An unknown pathogen has caused poor juvenile condition and low-level mortality in some brood years and this new health risk has made the rearing strategy unfeasible (Doug Lofthouse, personal communication).

Table 15: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean marine ages of Shuswap River Middle Chinook subyearling and yearling releases. Preliminary recovery data for the 2016 and 2017 releases are shown in green.

OEY	STAGE	SIZE (G)	DAY	RELEASE GROUPS	TOT CWTS RELEASED	SURVIVAL (%)	EXPLOITATION (%)	MARINE AGE (YRS)
2015	Subyearling	8.6	145	1	140,831	0.82	30.81	3.9
	Yearling	17.8	91	1	20,488	0.58	44.26	3.0
2016	Subyearling	8.2	145	1	143,497	0.29	8.45	3.7
	Yearling	19.1	96	1	16,777	0.64	25.52	3.3
2017	Subyearling	8.6	145	1	112,001	0.46	10.75	2.9
	Yearling	18.23	99	1	18,824	0.16	23.81	3.0
2018	Subyearling	7.86	136	1	172,368	-	-	-
	Yearling	19.0	93	1	19,604	-	-	-

TIME AND SIZE OF RELEASE EXPERIMENTS

The table below summarizes the results of the 11 time and size at release experiments with detailed analysis of each experiment following.

Table 16: Summary of outcomes of time and size at release experiments on survival rates, exploitation rates, and return ages. The experimental strategy is bolded. Where survival models were possible, the best release strategies from the top model are provided in the 'Survival' column. Green cells show experiments where a significant positive relationship was found between the bolded time/size at release and the production outcome. Red cells represent significant negative relationships, while grey cells represent no effect. Rows in orange had insufficient data for conducting statistical analyses.

SPECIES	STOCK	OEY	EXPERIMENT	SURVIVAL	EXPLOITATION	AGE
CN	Big Qualicum R	2011-2013, 2015-2017	normal vs **late/large**	none		
CN	Chilliwack R	1993-1995	early vs **late**	insufficient data		
CN	Cowichan R	1990-1995, 1998, 2001-2004, 2006, 2008-2009, 2011-2016	early and late, at two release locations	size, time, release site		
CN	Quinsam R	2015-2017, 2019	normal vs **late/large**	insufficient data		
CO	Big Qualicum R	2016-2018	normal vs **late/large**	insufficient data		
CO	Chilliwack R	1983, 1990-1991, 2000-2001	**early** vs mid vs **late**	insufficient data		
CO	Inch Cr	2006-2008	**early** vs normal	insufficient data		
CO	Inch Cr	2012-2014	**small** vs normal	insufficient data		
CO	Inch Cr	2015-2017	normal vs **late/large**	none		
CO	Quinsam R	2002-2012	**early** vs normal vs **late**	time, year		
CO	Quinsam R	2010-2012	normal vs **large**	insufficient data		
CO	Quinsam R	2016-2020	normal vs **late/large**	insufficient data		

8. Big Qualicum Fall Chinook

Big Qualicum River fall Chinook are currently reared and released to meet harvest and assessment objectives at Big Qualicum River Hatchery. Target annual releases are approximately 3.5 million subyearling smolts. Mean survival rates of this stock declined from 11.42% in the mid 1970s to 0.07% in the mid 1980s (Figure 33). The mean survival rate of releases made between 2010 and 2015 was 0.36% (SD ± 0.25%).

An experimental late/large release was conducted from 2010-2013 and from 2015-2017 to evaluate the effects of time and size at release on survival, marine distributions, and interactions with their wild counterparts. For the latter trial, complete recovery at the time of this report was only available for the 2015 releases. Approximately 100,000 Chinook smolts were held and released at different times each year between June and early August, while 450,000 'normal' Chinook smolts were released mid-late May. The initial late and large release for this trial was done in September 2010 with Chinook smolts > 50 g. No return data were available for this release group; therefore, the 2010 release was not included in this experimental analysis.

Annual survival rates of the late/large release groups were higher than those of the normal release group for three of the four years assessed, however the difference in mean survival rates was not significant (t-test; p = 0.27) (Table 17; Figure 34-Figure 35). The greatest difference was observed in the 2015 releases, when survival of the late/large group was more than double that of the regular release (Figure 34). Exploitation rates were also consistently higher for the late/large releases, however the mean exploitation rate was no different between treatments (t-test; p = 0.84; Figure 35). The mean return ages were similar between the normal and late/large releases with mean return ages of 3.4 and 3.3 years, respectively (t-test; p = 0.28; Table 17; Figure 34-Figure 35). Preliminary return data for the 2016 release group suggest high survival rates of the late/large release group similar to those seen for the 2015 group.

We examined several release covariates (time category, release weight, release day, and ocean entry year) to determine which were best associated with the smolt-to-adult survival rate during the late/large release trial. Quadratic terms for weight and day of release were also added to account for non-linear responses. Given the annual variability in survival rates (Figure 34), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each treatment group in Figure 36.

The top model was an intercept-only model, suggesting that the size/time of release has had little influence on survival so far (Table 18). The intra-class correlation estimate was high, with 63% of the total variation in the survival response explained by the random year effect (Figure 37). Therefore, accounting for random year will yield better estimations of survival than using release strategies. Residuals and normal quantile-quantile plots for the top model are provided in Figure 38 and suggest an adequate fit to the data, although the model may be limited by small sample size.

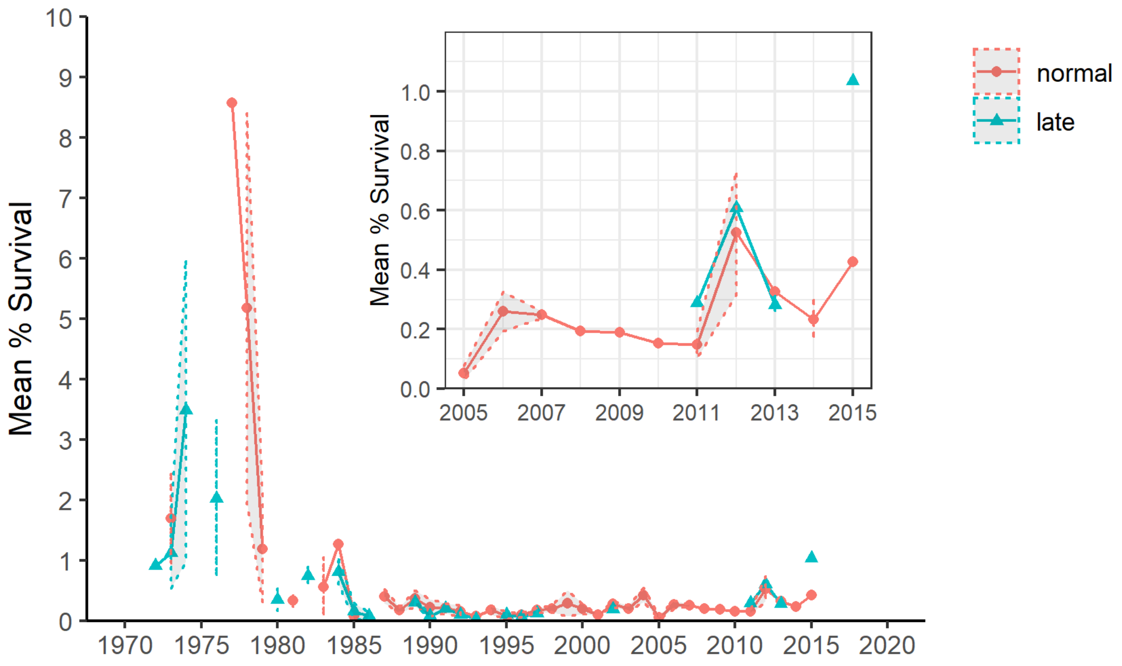

Figure 33: Mean percent survival of Big Qualicum River Chinook smolts released in two periods (normal and late) from Big Qualicum River Hatchery by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation. The inset provides a closer look at the experimental years of interest: 2011-2013, and 2015.

Table 17: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Big Qualicum River normal and late/large Chinook releases in 2011, 2012, 2013, and 2015 (years with complete recovery records). Preliminary return data (ages 2–4) for the 2016 release are shown in green. Standard deviation is given in parentheses for release events with > 1 release group.

OEY	TREATMENT	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2011	Normal	5.4 (0.6)	150 (0)	3	452,637	0.13	51.75	3.6
	Late	20.9	214	1	103,078	0.29	55.31	3.4
2012	normal	5.6 (0.6)	147 (3)	2	461,878	0.55	41.55	3.3
	Late	27.2	230	1	102,646	0.61	44.35	3.4
2013	normal	8.0	141	1	457,396	0.33	39.29	3.4
	Late	20.3 (0.2)	192 (0)	2	105,806	0.29	43.55	3.3
2015	normal	5.6	134	1	101,673	0.43	21.12	3.1
	Late	15.2	170	1	61,724	1.03	26.81	3.1
2016	normal	5.8	137	1	102,878	0.14	38.20	3.0
	Late	18.6	168	1	61,790	0.90	41.01	2.8
2017	normal	5.0	156	1	105,735	-	-	-
	Late	13.8	192	1	63,189	-	-	-

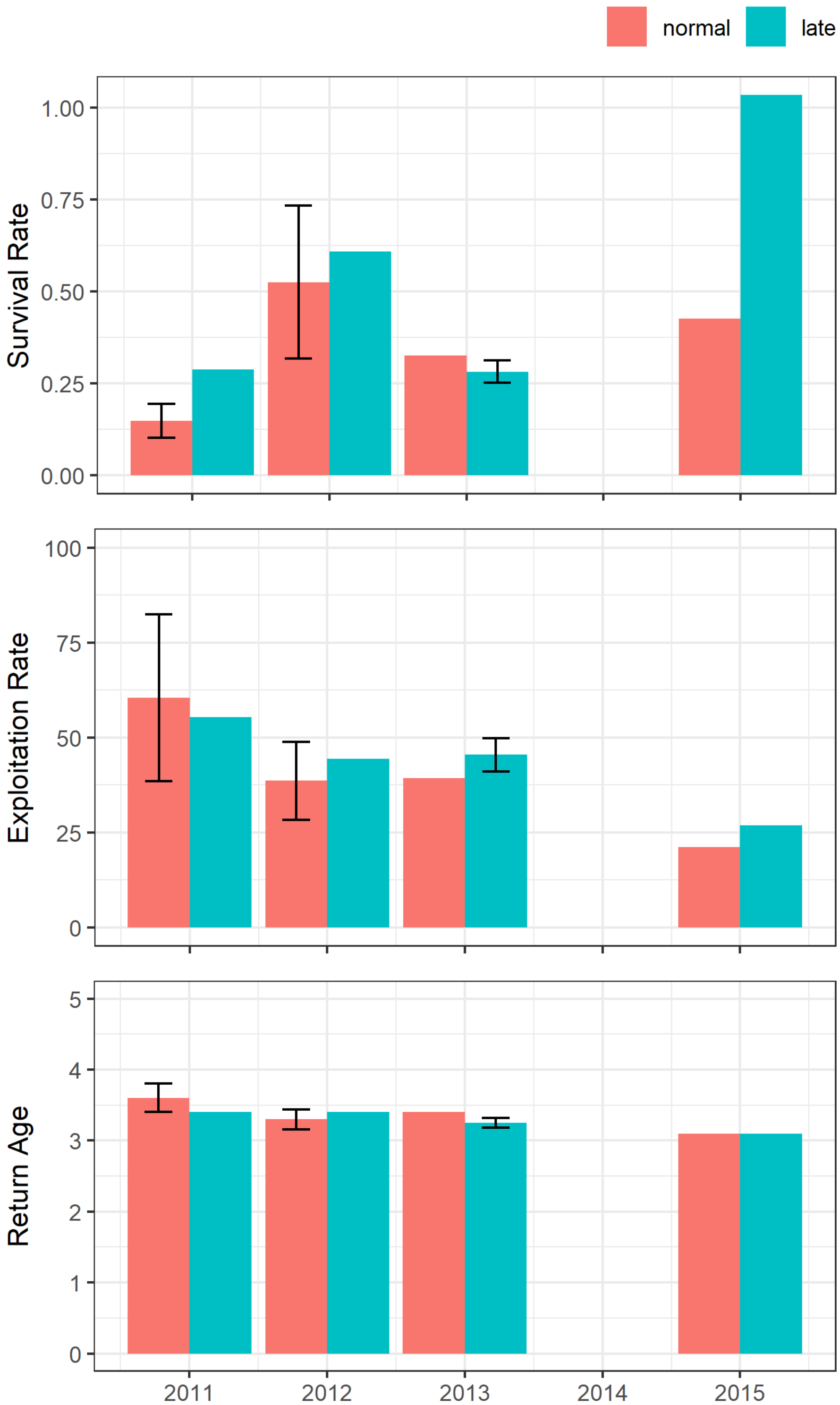

Figure 34: Mean survival rates (%), exploitation rates (%), and return ages of normal and late/large release groups from Big Qualicum River Hatchery for each ocean entry year. Only years with complete recovery records are shown.

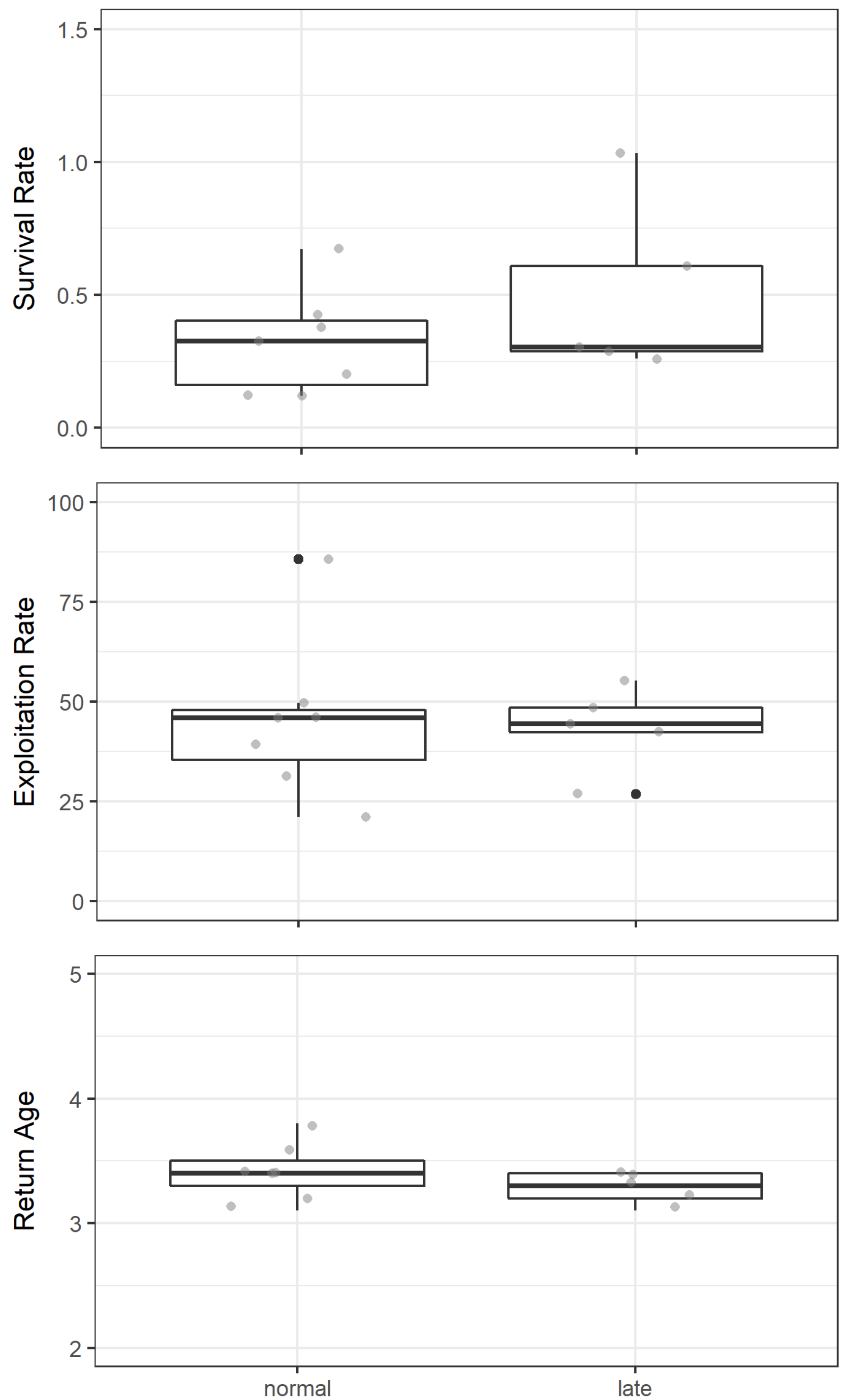

Figure 35: Survival rates (%), exploitation rates (%), and return ages for normal and late released Chinook smolts from Big Qualicum River Hatchery in 2011-2013 and 2015. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey and outliers in black.

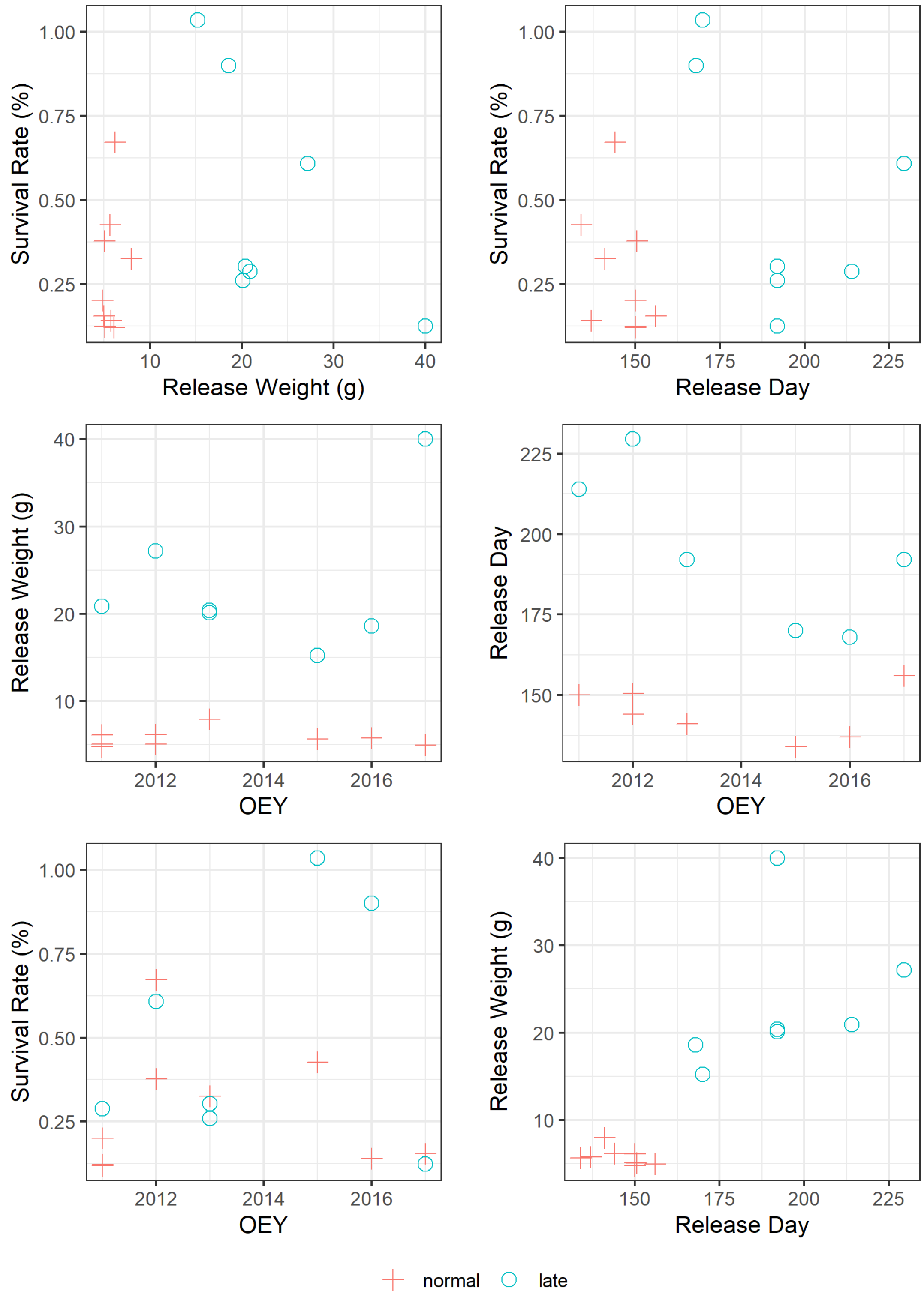

Figure 36: Data distributions of normal and late/large Big Qualicum River Chinook smolts released from Big Qualicum River Hatchery.

Table 18: Top models (delta < 2) showing fixed effects for predicting survival rates of Big Qualicum River Chinook salmon. The best model is bolded. ICC represents the intra-class correlation, which describes the portion of the variation in the model attributed to the random ocean entry year effect.

Intercept	Size	$Size^2$	OEY	Day	Day^2	Treatment	df	logLik	delta	ICC
-3.512	**-**	**-**	**-**	**-**	**-**	**-**	**3**	**14.48**	**0**	**0.63**
-76.824	-	-	0.036	-	-	-	4	16.16	1.34	0.49
-3.534	-	-	-	-	-	+	4	15.94	1.8	0.68

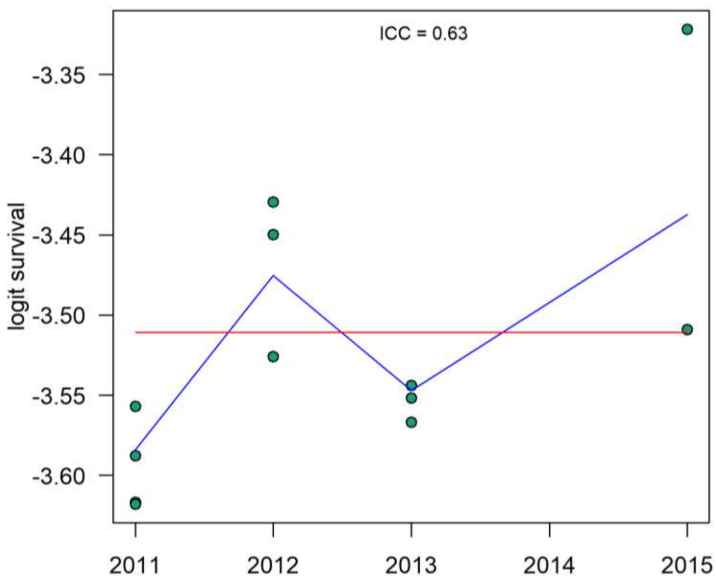

Figure 37: Estimated mean Big Qualicum Chinook logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

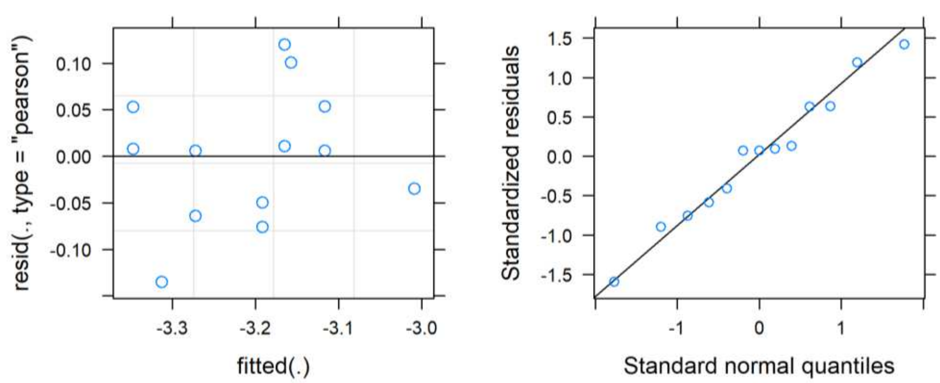

Figure 38: Residuals and quantile plots for the best Big Qualicum River Chinook model.

9. Chilliwack River Fall Chinook

While the focus of our review is on experiments conducted since 2000, Chilliwack River is one of the only hatcheries where we still see high survival rates for Chinook salmon. Unlike other stocks released into the Strait of Georgia, Chilliwack River Fall Chinook have shown highly variable survival rates on an annual basis, with alternating years of higher and lower survival (Figure 39). For releases made between 2010 and 2015, mean survival rates were 3.55% and ranged from 1.25-7.92%. Therefore, we reviewed experiments conducted at Chilliwack River to learn as much from their operations as possible. It should be noted that Chilliwack River fall Chinook are originally from the Harrison River stock and were transplanted in the early 1980s.

In years 1993-1995, the Chilliwack River Hatchery conducted a trial releasing 'early' smolts between May 13th and 15th and 'late' smolts two weeks later between May 27th and 31st. The objectives of this trial are unknown (Jeremy Mothus, personal communication). With only six release groups, there were insufficient data to conduct statistical analyses/modelling, however the data are summarized below.

Survival rates were higher for early releases in all three years (Table 19; Figure 40-Figure 41). Exploitation rates were slightly higher for late releases in two of the three years (Table 19; Figure 40). The mean return ages were higher for late releases in all three years and increased for both treatments over time (Table 19; Figure 40). It appears that the early release was representative of their 'normal' release strategy, and that this strategy was continued after the trial was completed. No similar study has been conducted in the last 20 years. Given the degree of environmental change since the early 90s, it is uncertain whether the trends observed during this study would hold true today.

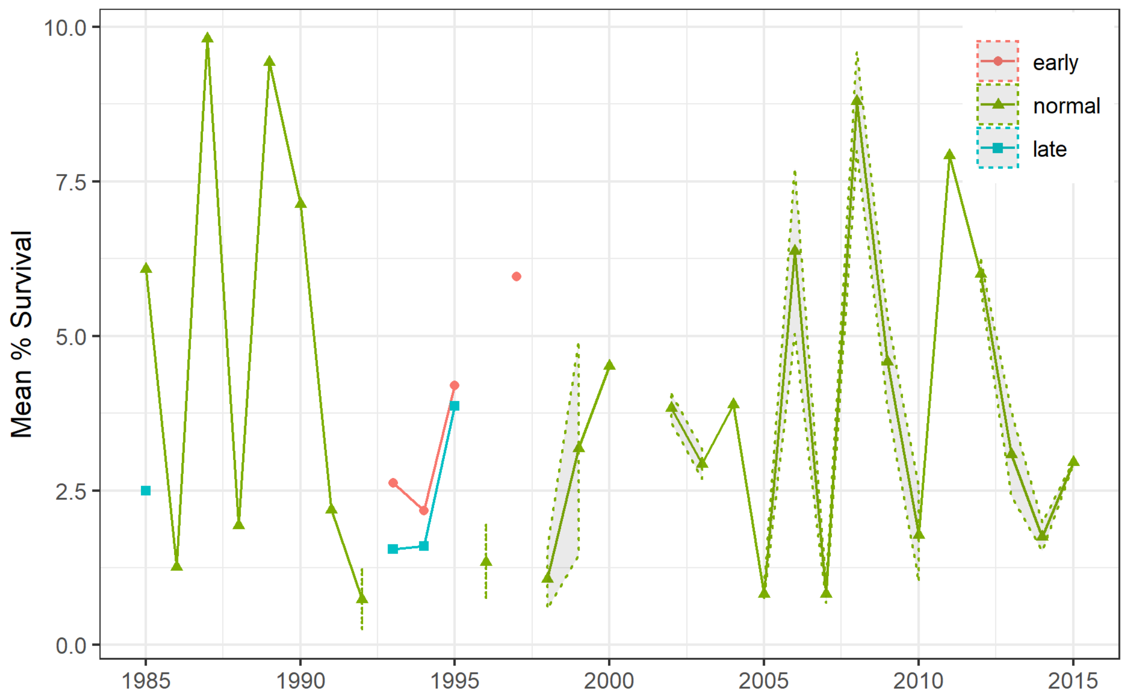

Figure 39: Mean percent survival of Chilliwack River fall Chinook smolts released in three time periods, early (red circles), normal (green triangles), and late (blue squares), from Chilliwack River Hatchery by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 19: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Chilliwack River Chinook early and late releases into Chilliwack River.

OEY	TREATMENT	SIZE (G)	DAY	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
1993	early	5.5	137	1	49,419	2.62	26.29	3.0
	late	5.7	149	1	48,230	1.55	28.20	3.1
1994	early	5.0	140	1	48,434	2.18	32.65	3.2
	late	6.3	154	1	48,993	1.60	37.75	3.3
1995	early	6.0	142	1	47,629	4.20	29.68	3.4
	late	5.8	154	1	49,178	3.87	23.34	3.5

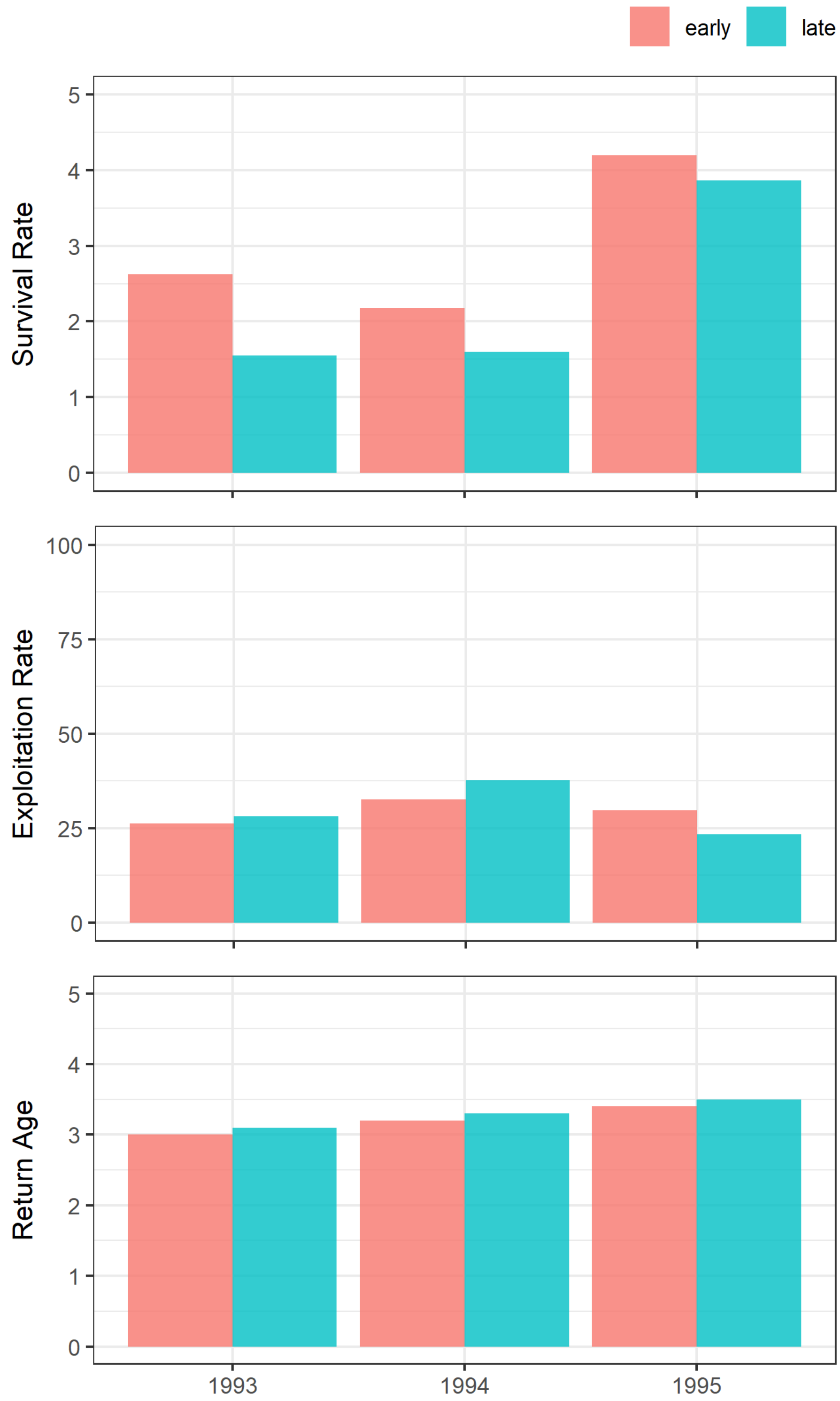

Figure 40: Survival rates (%), exploitation rates (%), and ages of returns over time for early vs late released subyearling Chinook smolts from Chilliwack River Hatchery.

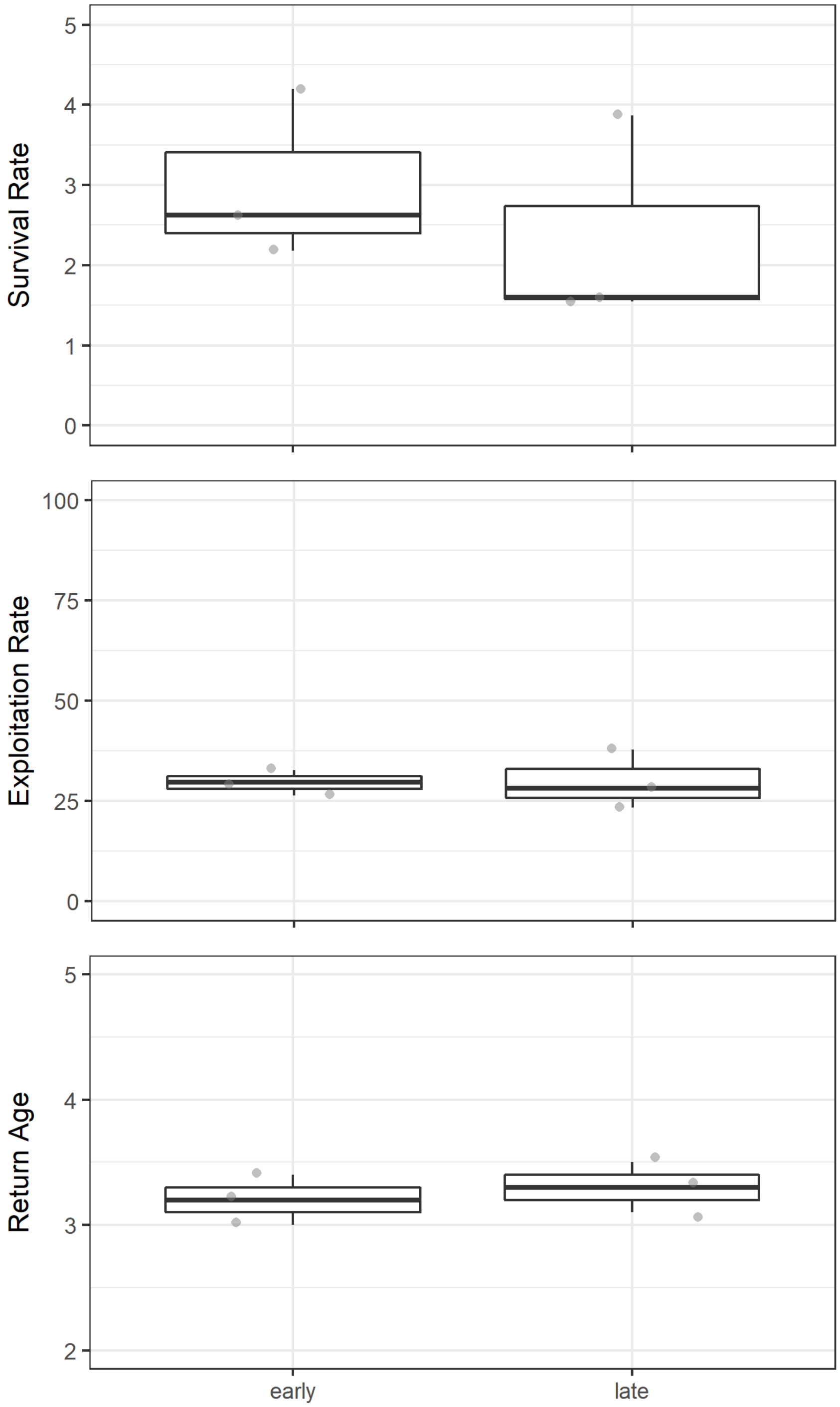

Figure 41: Survival rates (%), exploitation rates (%), and return ages for early and late released subyearling Chinook smolts from Chilliwack River Hatchery in 1993-1995. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey.

10. Cowichan River Chinook

The Cowichan River Hatchery is run by the Cowichan Tribes as part of SEP's Community Economic Development Program (CEDP). Cowichan River Chinook are reared and released to support re-building objectives, and to meet assessment objectives as a key Chinook indicator stock for the lower Strait of Georgia. Survival rates of hatchery-released subyearlings (excluding seapen releases) dropped precipitously in the 1980s from 4.41% in 1980 to 0.92% survival in 1986 and continued to decline into the early 2000s to lows of 0.06% (Figure 42). The mean survival rate of subyearling smolt releases between 2010 and 2015 was 0.44% (SD ± 0.24%).

For most years since 1989, Cowichan River Hatchery has been releasing Chinook smolts as one of two timed groups, either 'early' or 'late'. This release strategy was developed to mimic the natural life history of the stock, which was found to migrate to the ocean in two pulses. The early pulse consisted mostly of smaller fry (<60 mm) enroute to the estuary in March/April, while the later pulse consisted mostly of larger smolts (60-90 mm) migrating directly to the bay in May/June (Kevin Pellet, personal communication). Releases were also made at a number of different release sites, namely Cowichan River, Cowichan River Upper, Cowichan River Lower, and Cowichan Lake, and the Cowichan estuary (Figure 43). The objective was to improve the homing ability of hatchery fish by releasing them higher upriver to increase the duration of their freshwater migration. However, these upper river releases suffered from higher predation. Therefore, since 2017, most releases have been made mid-river (now known as 'Cowichan River' release site, formerly known as 'Cowichan River Lower'). The effects on homing have not yet been investigated.

There are a few data quality concerns that need to be considered when analysing these data:

- prior to 1990, the majority of release start dates only provide the year and month, making it impossible to determine the actual day of release (these years have not been included in the analyses below)
- there is some overlap in the timing of these groups making them difficult to define: 'early' releases range from March 7 to May 4, and 'late' releases from April 27 to May 29
- some releases have not been assigned to an early or late release category in the release comments, although there are two release dates (e.g. release years 2013-2016)
- same release locations were often given different names (e.g. Cowichan R and Cowichan R Up were the same site prior to 2017)
- release weights were identical (4 and 6 grams for two release groups) for three consecutive release years (2013-2015) which seems unlikely (possible data entry error)
- some years in the early 1990s have 'mid lake-pen' releases which we have not included in our assessment of release timing

These data discrepancies make it difficult to distinguish between treatments across all years. However, releases described in the comments as 'early', as well as the earlier of two release groups when no category is given, were treated as early releases in our analyses. The same was done for late releases, including the later of two release groups when no category was given. Note, however, that this time categorization is only used for data summarization and is not included in the model, where day of release is used instead. We focus specifically on these early and late release groups in Table 20 and Figure 44-Figure 45, however data for all Cowichan releases are shown in the subsequent data distribution plots and modelling. Survival rates prior to 1992 were anomalously high relative to the rest of the time series, therefore these data were removed. A single anomalously late and large release in the fall of 2010 was also removed. Preliminary return data for the 2016 releases are provided in Table 20 but are not included in any of the other figures or models.

Overall, mean survival rates were slightly higher for the late release group (Wilcoxon rank sum test; W = 199, $p = 0.046$, n = 49) (Figure 44-Figure 45). No difference was observed between exploitation rates of early and late release groups (t-test; $p = 0.60$). Exploitation rates were below average for both release groups between 1994 and 1999 but recovered in 2000 (Figure 44). The mean return age was slightly higher for late releases, however the difference was not significant (t-test; $p = 0.09$; Figure 44-Figure 45).

We examined several release covariates (release weight, release day, release location, and ocean entry year) to determine which were best associated with the smolt-to-adult survival rate. Quadratic terms for weight and day were also included to account for non-linear relationships. Given that some years had more than one release, ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each treatment group in Figure 46.

The weight at release, year of ocean entry, and release site were included in the top model as important predictors of survival (Table 21). The nature of the coefficients suggests an increase in survival as release weights are increased (Figure 47). The negative coefficient for ocean entry year shows that survival rates have decreased over time. And finally, post hoc analyses of the effects of release site show that survival rates were slightly lower for releases into Cowichan Lake than those released at the Cowichan R/Cowichan R Upper site (Figure 48). The intra-class correlation estimate shows that 46% of the total variation in the survival response could be explained by the random effect of the ocean entry year (Table 21) and that accounting for ocean entry year improved the model fit (Figure 49). Therefore, the size of fish released and the year in which they were released have been important determinants of survival. Residuals and normal quantile-quantile plots for the top model are provided in Figure 50 and show an adequate fit to the data.

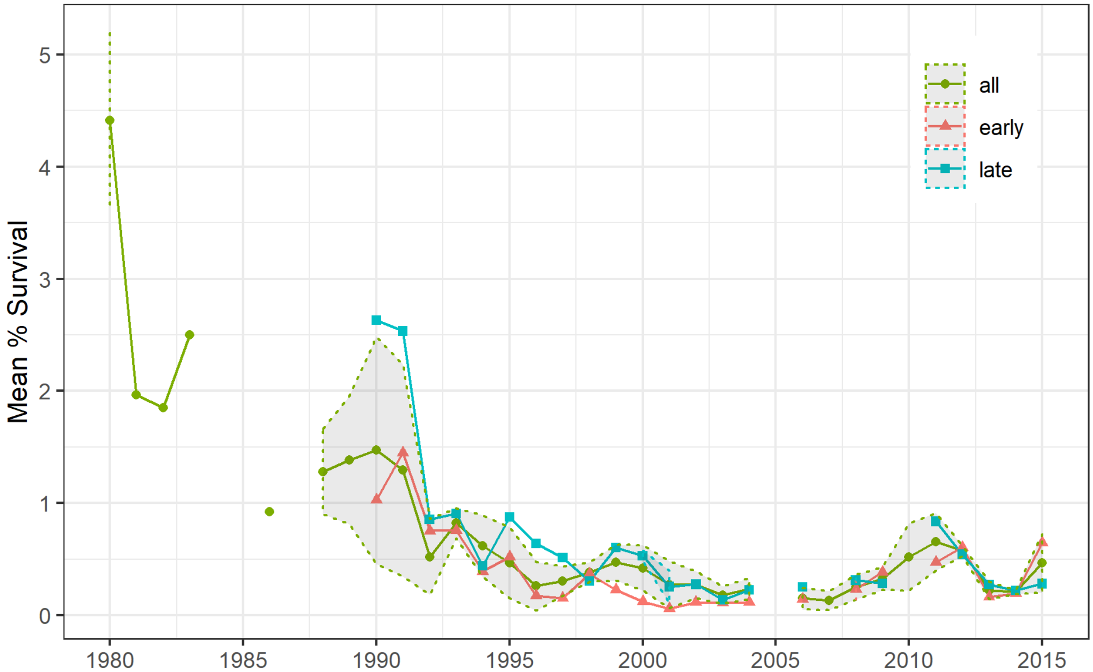

Figure 42: Mean percent survival of Cowichan River Chinook smolts released from the Cowichan River Hatchery by ocean entry year. Mean survivals are shown for all releases (green circles), early releases (red triangles), and late releases (blue squares). Dashed lines around 'all' releases and shaded grey represent the standard deviation.

Figure 43: Map of release locations (green circles) for Cowichan River Fall Chinook from Cowichan River Hatchery (black and white square fish symbol).

Table 20: Release parameters (OEY = ocean entry year, life stage, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Cowichan River early and late releases. Complete recovery data are only available up to the 2015 release. Preliminary data (ages 2-4) for the 2016 release are shown in green. No early releases were conducted after 2016. Continued on next page.

OEY	TREATMENT	SIZE	DAY	RELEASE GROUPS	TOT CWTS RELEASED	SURVIVAL	EXPLOITATION	AGE
1990	early	3.4	102	1	109,962	1.03	85.44	3.0
	late	6.5	142	1	111,354	2.63	79.96	3.1
1991	early	3.3	107	1	80,812	1.45	81.10	3.0
	late	6.4	142	1	80,247	2.53	77.52	3.0
1992	early	4.0	112	1	54,842	0.75	56.11	3.1
	late	5.5	141	1	54,748	0.85	63.22	3.1
1993	early	3.6	97	1	55,027	0.76	49.34	2.8
	late	5.9	138	1	51,694	0.91	43.78	2.9
1994	early	3.8	108	1	50,420	0.39	52.75	2.9
	late	6.1	138	1	50,045	0.44	57.45	3.0
1995	early	4.0	122	1	49,962	0.52	24.17	2.6
	late	6.3	136	1	49,610	0.88	38.09	2.8
1996	early	3.5	93	1	50,181	0.17	28.72	2.9
	late	6.3	128	1	50,401	0.64	16.21	2.5
1997	early	3.3	91	1	50,476	0.15	27.10	2.7
	late	6.3	118	1	50,867	0.52	42.14	2.8
1998	early	3.7	99	1	76,117	0.37	43.47	3.1
	late	6.5	133	1	74,630	0.31	44.24	3.0
1999	early	3.1	90	1	50,321	0.23	39.09	3.3
	late	6.6	130	1	49,788	0.60	40.18	2.9
2000	early	3.2	67	1	99,729	0.12	64.93	3.2
	late	6.8 (0.2)	122 (4)	2	99,772	0.53	52.20	3.0
2001	early	3.2	78	1	100,026	0.06	61.87	2.8
	late	6.4 (0.2)	122 (1)	2	100,151	0.25	67.34	3.3
2002	early	3.5	101	1	100,399	0.12	47.01	3.0
	late	5.6	136	1	50,130	0.28	77.01	3.3
2003	early	4.5	101	1	100,277	0.11	77.62	2.9
	late	5.7	146	1	74,942	0.14	46.28	3.0
2004	early	3.8	96	1	100,396	0.12	44.70	2.8
	late	5.3	141	1	75,018	0.22	55.61	2.9
2006	early	3.4	115	1	100,120	0.14	54.28	2.8
	late	6.1	135	1	100,063	0.25	46.71	2.6
2008	early	6.0 (0)	116 (0)	2	204,134	0.22	62.70	2.7
	late	7.5 (0)	150 (0)	2	204,715	0.31	61.74	2.9
2009	early	5.2	124	1	249,740	0.39	45.83	3.1
	late	5.6	139	1	416,840	0.28	54.62	3.4
2011	early	6.0	119	1	145,688	0.47	41.03	2.8
	late	7.1	138	1	292,155	0.84	53.47	2.9
2012	early	4.5	121	1	146,915	0.61	38.18	2.8

OEY	TREATMENT	SIZE	DAY	RELEASE GROUPS	TOT CWTS RELEASED	SURVIVAL	EXPLOITATION	AGE
	late	6.7	136	1	403,997	0.54	55.27	3.0
2013	early	4.0	106	1	149,781	0.16	74.46	3.4
	late	6.0	136	1	448,155	0.27	52.57	3.6
2014	early	4.0	113	1	98,233	0.20	56.08	2.9
	late	6.0	137	1	123,574	0.22	55.23	3.0
2015	early	4.0	112	1	348,485	0.65	34.78	2.6
	late	6.0	140	1	465,438	0.28	66.63	3.2
2016	early	3.8	110	2	196,782	0.54	43.63	2.5
	late	4.6	139	2	394,856	0.37	43.59	2.6
2017	late	3.6	144	1	449,567	-	-	-
2018	late	3.8	143	1	49,993	-	-	-

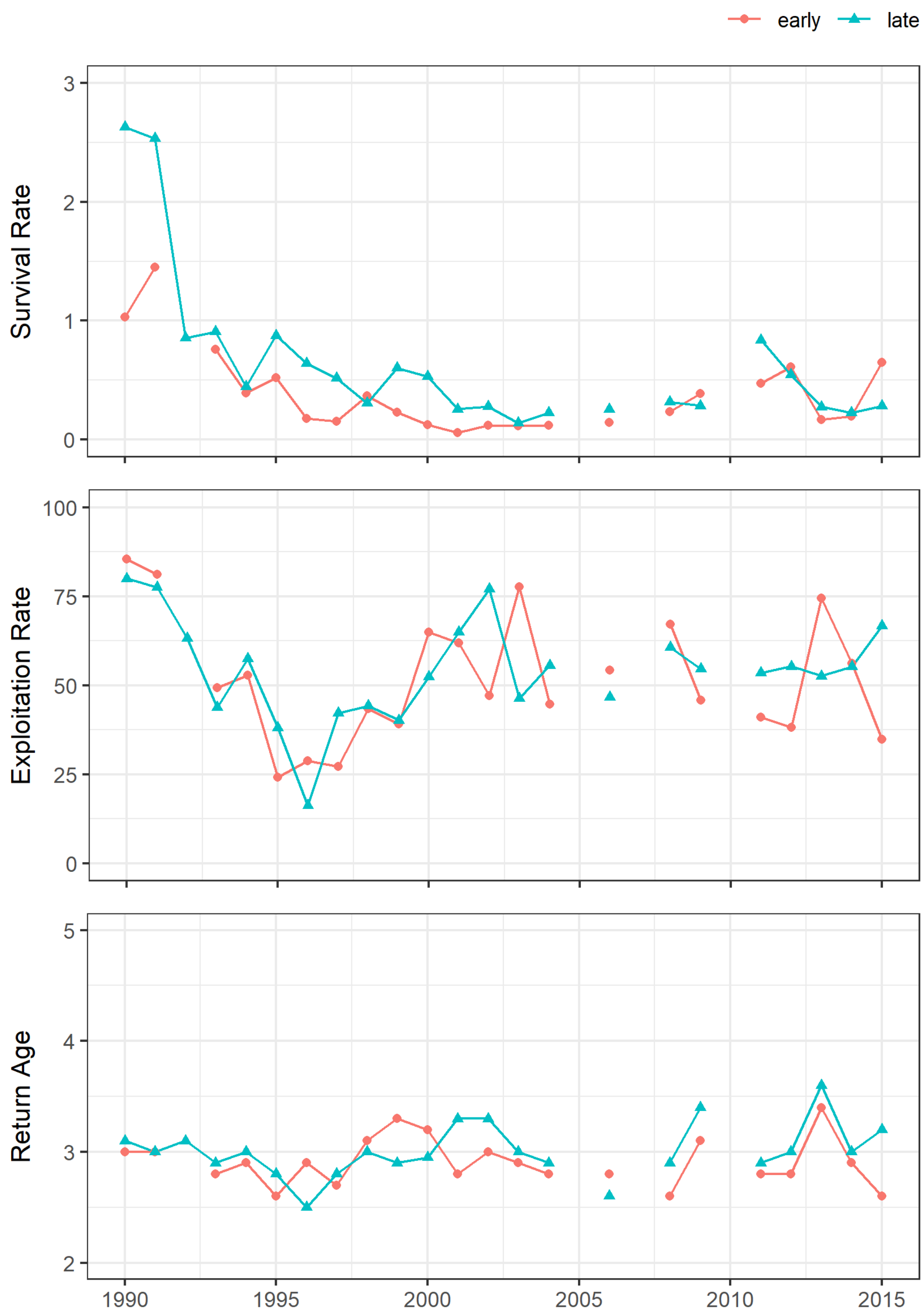

Figure 44: Survival rates (%), exploitation rates (%), and return ages over time of early and late release groups from Cowichan River Hatchery presented for both the Cowichan River and Cowichan River Upper release locations together. Only years with complete recovery records are shown.

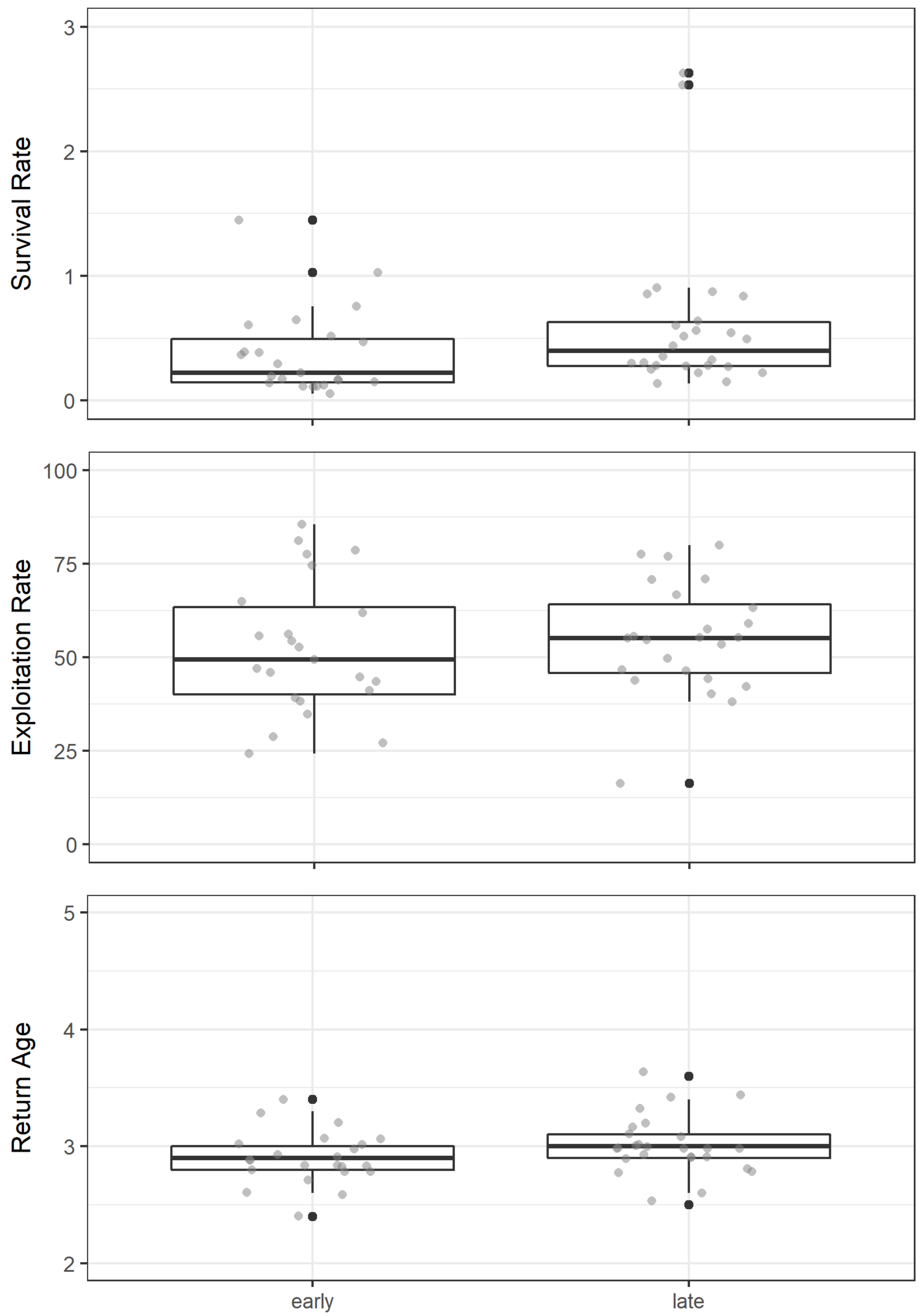

Figure 45: Survival rates (%), exploitation rates (%), and return ages for early vs late released Chinook smolts released from Cowichan River Hatchery, 1990-2015. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey with outlier points in black.

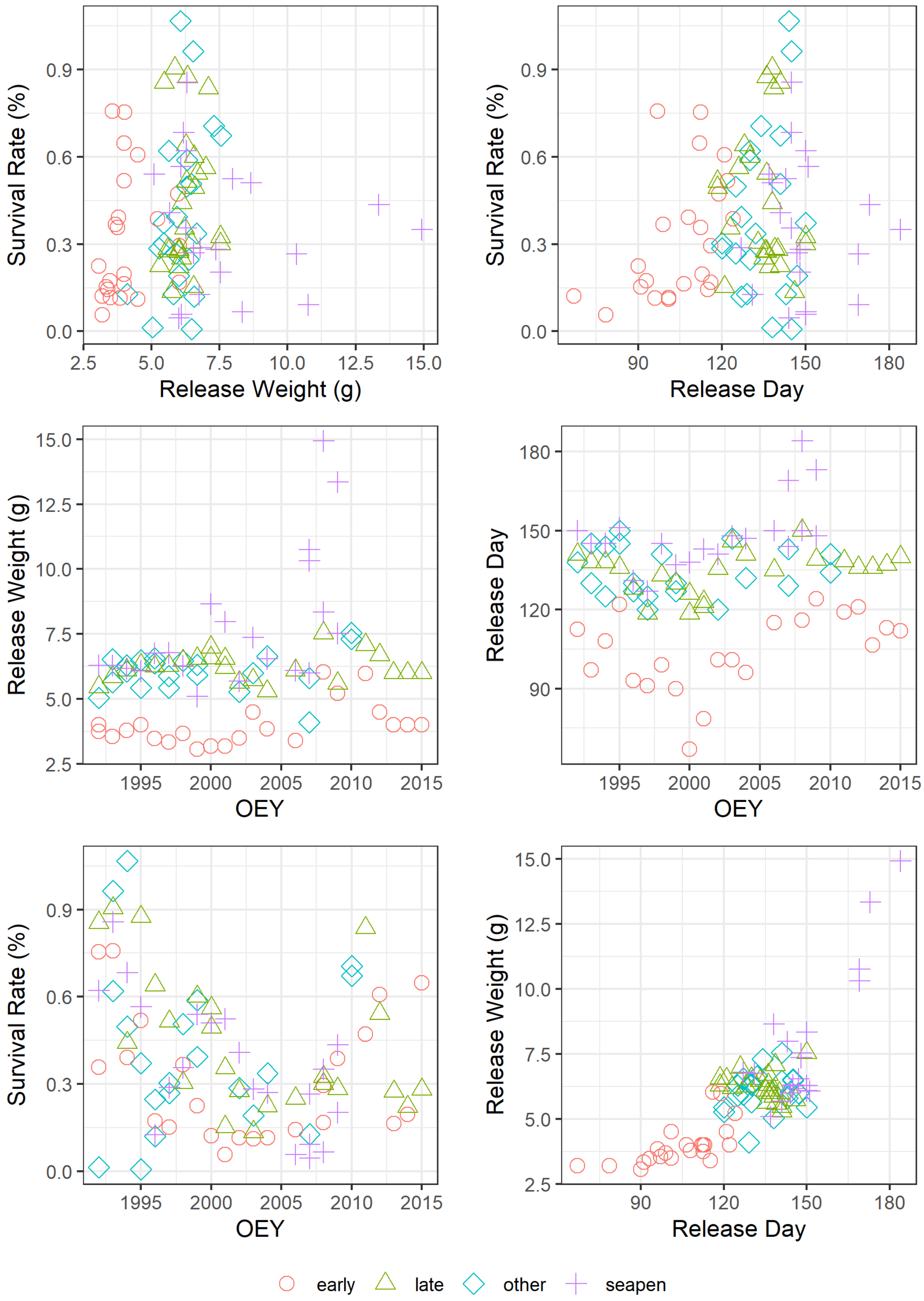

Figure 46: Data distributions of Cowichan River Chinook smolts releases. 'Other' releases are those released from the hatchery or into Cowichan Lake that were not identified as being 'early' or 'late'.

Table 21: Top three models showing fixed effects for predicting survival rates of Cowichan River Chinook salmon. The best model is bolded. ICC represents the intra-class correlation which describes the portion of the variation in the model attributed to the random ocean entry year effect.

INTERCEPT	SIZE	SIZE²	DAY	DAY2	OEY	REL SITE	DF	LOGLIK	DELTA	ICC
6.156	0.034	-0.001	-	-	-0.005	+	10	122.66	0	0.48
7.108	**0.014**	**-**	**-**	**-**	**-0.005**	**+**	**9**	**121.04**	**0.68**	**0.46**
6.556	0.006	0.001	0	0	-0.005	+	12	124.95	0.71	0.48

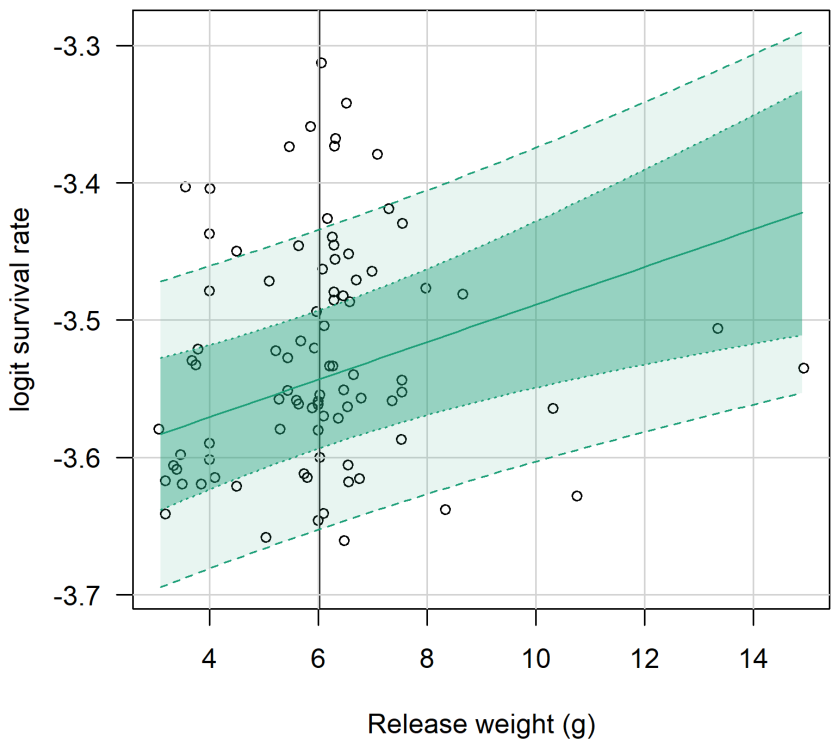

Figure 47: Mean logit survival and 95% CIs (dark green = fixed effects, light green = random effects) for the model fit to Cowichan River Chinook releases of different weights. The vertical solid line indicates the median weight of release.

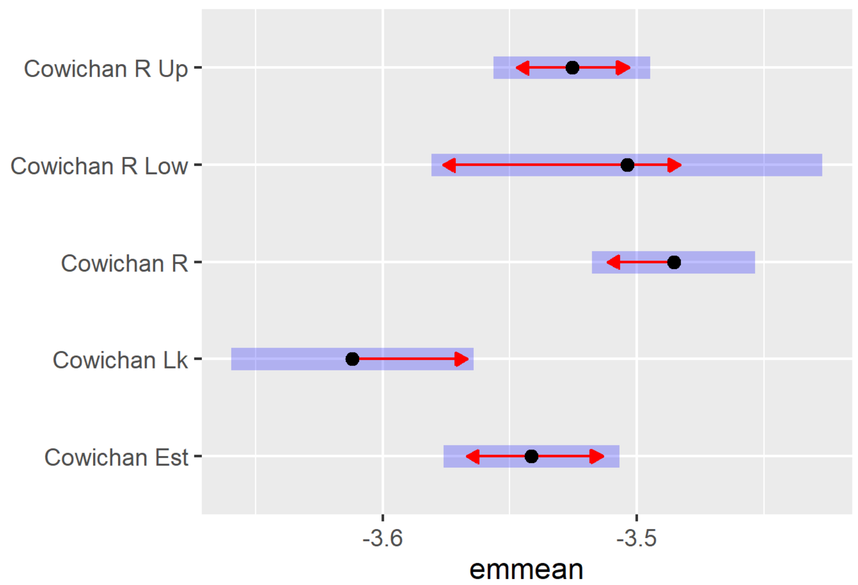

Figure 48: Tukey pairwise comparison between estimated marginal mean survival rates (emmean) of Cowichan River Chinook releases from different sites. Blue bars represent the confidence intervals for the emmean and red arrows show comparisons between them. Arrows that cross are not significantly different from one another.

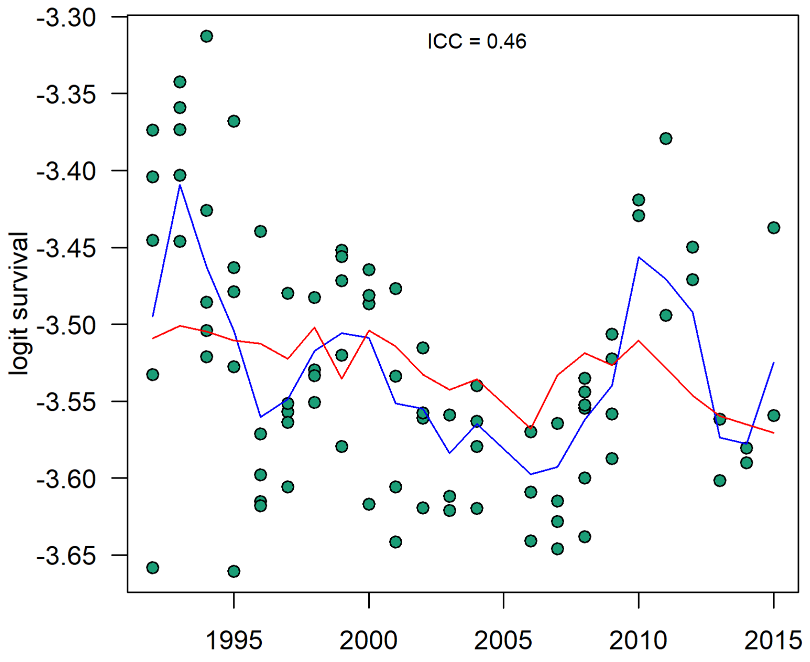

Figure 49: Estimated mean Cowichan River Chinook logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

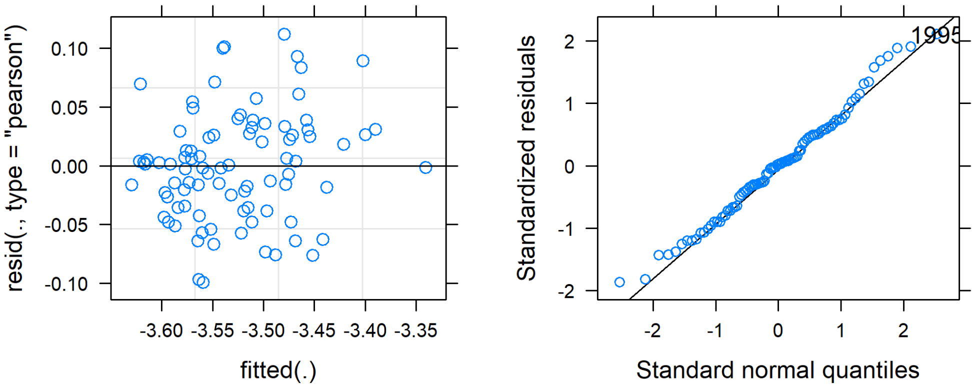

Figure 50: Residuals and quantile plot for the best Cowichan River Chinook model.

11. Quinsam River Chinook

Quinsam River fall Chinook are currently reared and released to meet harvest and assessment objectives (see Section 5). Release timing has varied over the history of enhancement, with 'normal' release events over the past 30 years occurring in May. However, releases in the late 1970s and early 1980s were much later than they have been over the past 30 years, typically occurring in June, with a few 'early' releases prior to May throughout the history of releases (Figure 51).

In years 2015-2017, Quinsam River Hatchery tried the release of approximately 130,000 later and larger Chinook smolts in addition to the regular 1.8 million smolt releases each year. The objective of this trial was to evaluate the effects of time and size at release on survival, marine distribution and interactions with wild counterparts in the nearshore environment. The 'late/large' release groups ranged from 10.5-14.2 g and were released between June 17th and 29th during the three year trial, whereas 'normal' releases ranged from 5.3-7.0 g and were released between May 1st and 16th (Table 22). An early release was also made in 2015 of 6.0 g smolts on March 30th. Because we do not have full recoveries for this experiment, no modelling was performed. However, the data are summarized below.

Full return data from the 2015 release and preliminary return data for ages 2-4 from the 2016 release suggest that later, larger Chinook smolts survived better than normal releases (Table 22). Exploitation rates and return ages are also slightly higher. However, the effectiveness of this trial should be evaluated once the 2020 return data are available.

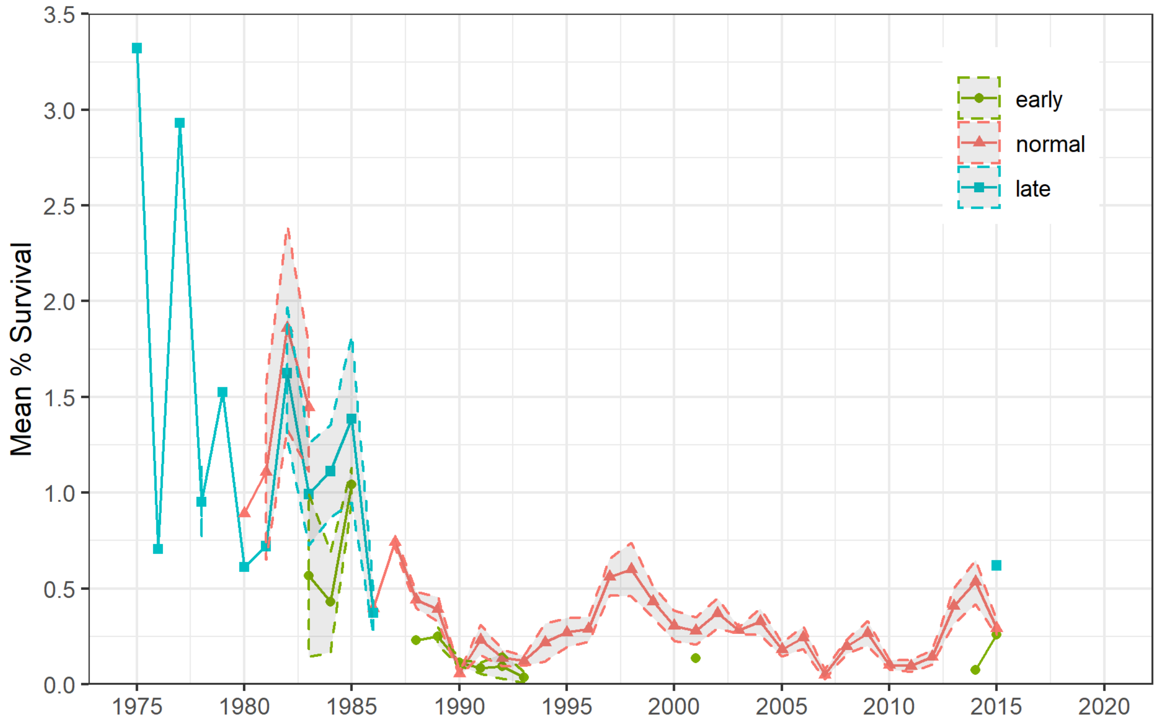

Figure 51: Mean percent survival of Quinsam River Chinook smolts released at different periods (early = pre-May, normal = May, and late = post-May) from Quinsam River Hatchery by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 22: Release parameters (OEY = ocean entry year, treatment category, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Quinsam River timed Chinook releases in 2015-2017. Note complete return data are currently only available for the 2015 OEY. Preliminary return data for age 2-4 Chinook from the 2016 release are provided in green.

OEY	TREATMENT	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2015	early	6.0	89	1	73,410	0.26	38.95	3.7
	normal	6.2 (0.6)	129 (3)	5	397,078	0.30	41.72	3.6
	late	10.5	168	1	84,487	0.62	49.19	3.7
2016	normal	6.0 (0.4)	132 (6)	7	497,161	0.22	62.29	3.3
	late	14.2	181	1	102,806	0.37	73.03	3.6
2017	normal	6.4 (0.4)	126 (3)	8	507,369	-	-	-
	late	13.3	174	1	90,995	-	-	-

12. Big Qualicum Coho

Big Qualicum River Coho are reared to meet assessment and harvest objectives. They are an indicator stock for monitoring survival and exploitation rates of Coho in the Strait of Georgia. Production in the early 2000s (and prior) often exceeded 1.2 million Coho releases per year, however in 2007, releases were reduced by half to ~ 600,000, and then again in 2015 to ~ 300,000, with target releases of 400,000 today. Survival rates were exceptionally high during the 1970s (31.17% in 1974), but declined dramatically in the 1980s (0.44% in 1986) (Figure 52). The mean survival rate of yearling releases between 2010 and 2015 was 1.78% (SD ± 1.15%).

For the 2016-2018 releases, Big Qualicum River Hatchery tried releasing later and larger Coho yearlings than conventionally had been released. Due to a mortality event, the 2018 releases could not be included in this trial. The late/large groups were 1.3 or 2.1 times heavier and released 44-49 days later than the normal release groups in 2016 and 2017 respectively (Table 23). Because this experiment involves only four release events, no modelling could be performed; however, the data are summarized below.

The survival of the late release group was higher in both years, and considerably higher for those Coho released in 2017 (Table 23; Figure 52). Exploitation rates were similar between treatments and years but slightly higher for the normal release in 2016. The proportion of jacks was much higher for the 2016 normal releases but was the same for both treatments released in 2017. Given the large increases in survival observed over two years, this release strategy warrants further trials.

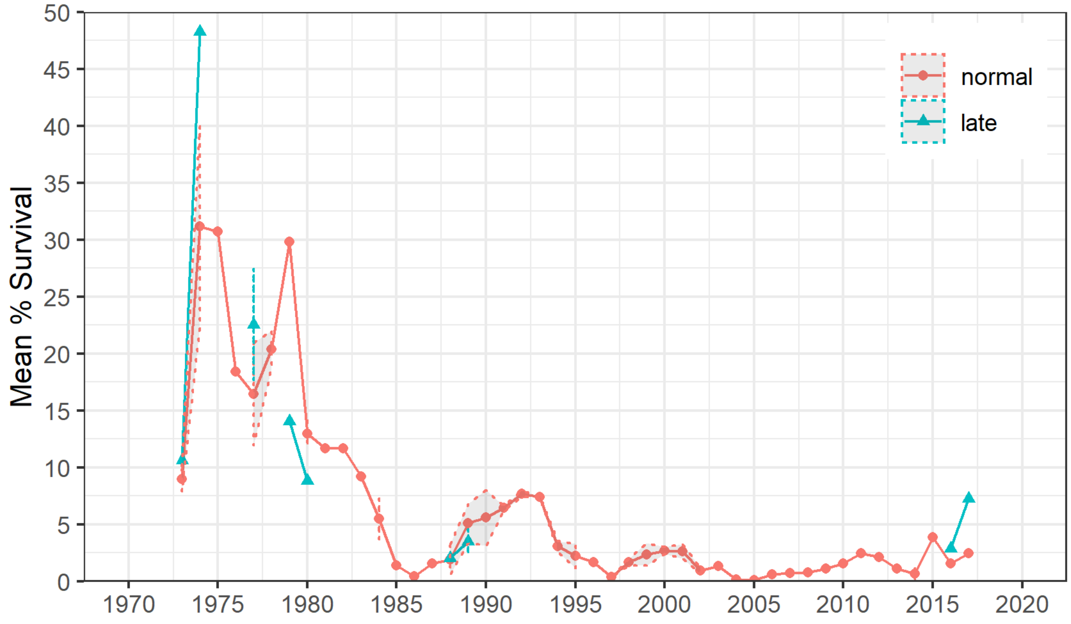

Figure 52: Mean percent survival of Big Qualicum River Coho yearlings released in two periods (normal and late) from Big Qualicum River Hatchery by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 23: Release parameters (years, life stages, sizes (g), days), the number of unique release groups and total CWTs released, mean survival, exploitation, and jacking rates (%) of Big Qualicum River normal and late/large Coho releases in 2016 and 2017.

OEY	TREATMENT	SIZE (G)	DAY	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	JACKS (%)
2016	normal	23.1	123	1	101,884	1.54	21.31	26.22
	late	30.2	172	1	42,144	2.88	16.22	7.04
2017	normal	14.4	128	1	100,795	2.47	16.12	13.45
	late	30.9	172	1	74,180	7.26	16.31	13.96

13. Chilliwack River Coho

Chilliwack River Coho are currently reared at Chilliwack River Hatchery with release targets of 800,000 yearlings to meet harvest objectives. Fish were tagged with CWTs up until the 2002 brood year, after which they continued to be AD clipped but not coded-wire tagged. Parentage-based tagging was initiated in the 2016 brood year, and as of 2019, fish are also thermal marked and some are PIT tagged. Unlike Big Qualicum River Coho, Chilliwack River Coho survival rates decreased significantly in the 1990s (rather than the 1980s) from a high of 19.66% survival of the 1987 release to a low of 1.51% of the 1997 release (Figure 53). This survival pattern is similar to that observed for Inch Creek Coho (see section 14, 15 & 16. Inch Creek Coho).

Although the purpose of this review is to examine experimental releases post-2000, the relatively high returns of Chinook at Chilliwack River Hatchery led us to include all experimentation at this facility, including those on Coho. In years 1983, 1990-1991, and 2000-2001, Chilliwack River Coho were released over multiple periods ranging from April 30 to June 6 (Table 24). No information could be found on the objectives or outcomes of these older trials (Jeremy Mothus, personal communication). It should be noted that the release dates for the different treatments were often only a week apart, or were entered as the same date and only classified as ‘early’, ‘mid’, or ‘late’ in the release comments. Given the lack of reliable release dates, no modelling of survival was done, but data are summarized below.

Except for in the 1980s, survival rates were higher for early than late releases (Table 24, Figure 54-Figure 55). However, mid-timed releases, in the years conducted, had the highest survivals. Prior to 2000, the mean exploitation rate measured from these trials was 63%. However, DFO implemented Coho salmon non-retention in all southern BC recreational and commercial fisheries in 1998, thus in the 2000 and 2001 trials, the mean exploitation rate was only 21% (Table 24, Figure 54). Later releases consistently yielded the lowest proportion of jacks in their returns (Table 24, Figure 54-Figure 55).

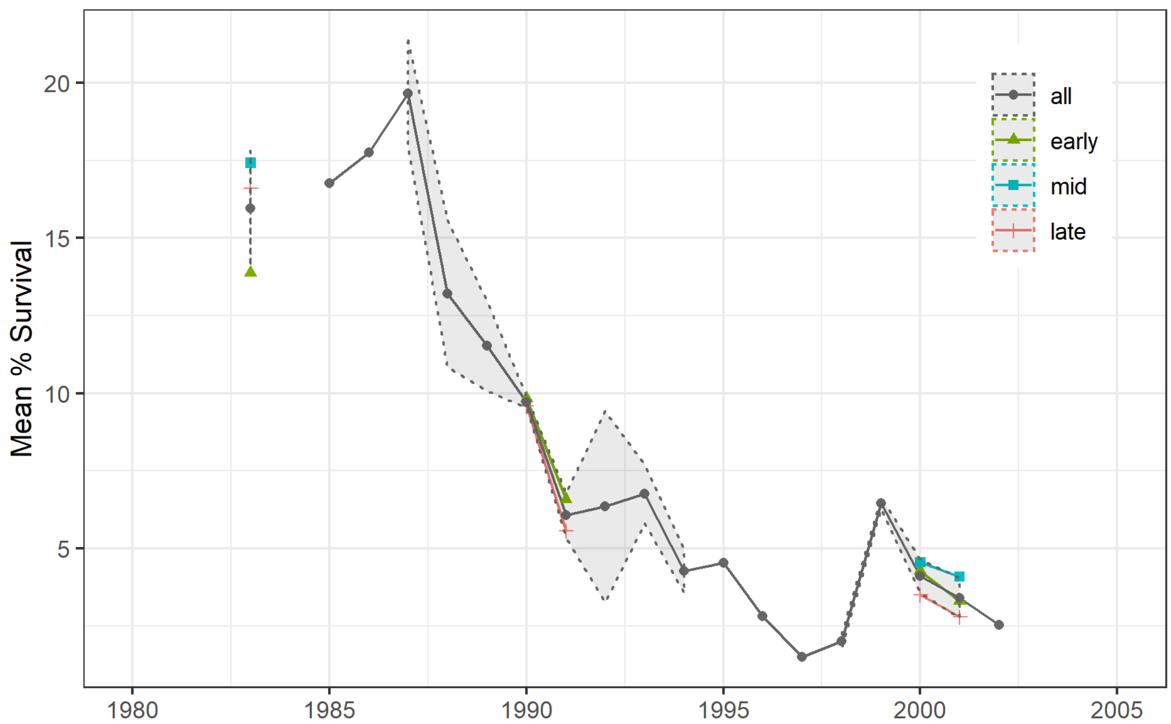

Figure 53: Mean percent survival of Chilliwack River Coho yearlings released from Chilliwack River Hatchery by ocean entry year. Grey lines and circles show the mean for all releases, with early (green triangles), mid (blue squares), and late (red crosses) releases illustrated on top. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 24: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean proportion of jacks (%) in the returns of Chilliwack River Coho released during release timing trials.

OEY	TREATMENT	SIZE (G)	DAY	RELEASE GROUPS	CWTS RELEASED	SURVIVAL (%)	EXPLOITATION (%)	JACKS (%)
1983	early	19.9	122	1	8,568	13.87	54.59	11.37
	mid	22.7	140	1	9,854	17.42	57.21	11.42
	late	23.5	156	1	10,080	16.60	58.00	4.67
1990	early	19.9	127	1	19,895	9.83	69.60	6.98
	late	19.3	134	1	19,906	9.58	66.87	4.93
1991	early	19.0	127	1	19,908	6.58	62.60	7.34
	late	18.7	134	1	19,592	5.56	71.45	5.05
2000	early	20.7	-	1	13,850	4.28	9.02	6.09
	mid	18.7	-	1	13,855	4.55	26.95	6.93
	late	18.5	-	1	9,271	3.50	26.02	4.27
2001	early	21.4	-	1	14,221	3.31	22.61	5.83
	mid	21.6	-	1	14,229	4.09	21.64	7.16
	late	20.5	-	1	14,345	2.80	18.31	4.30

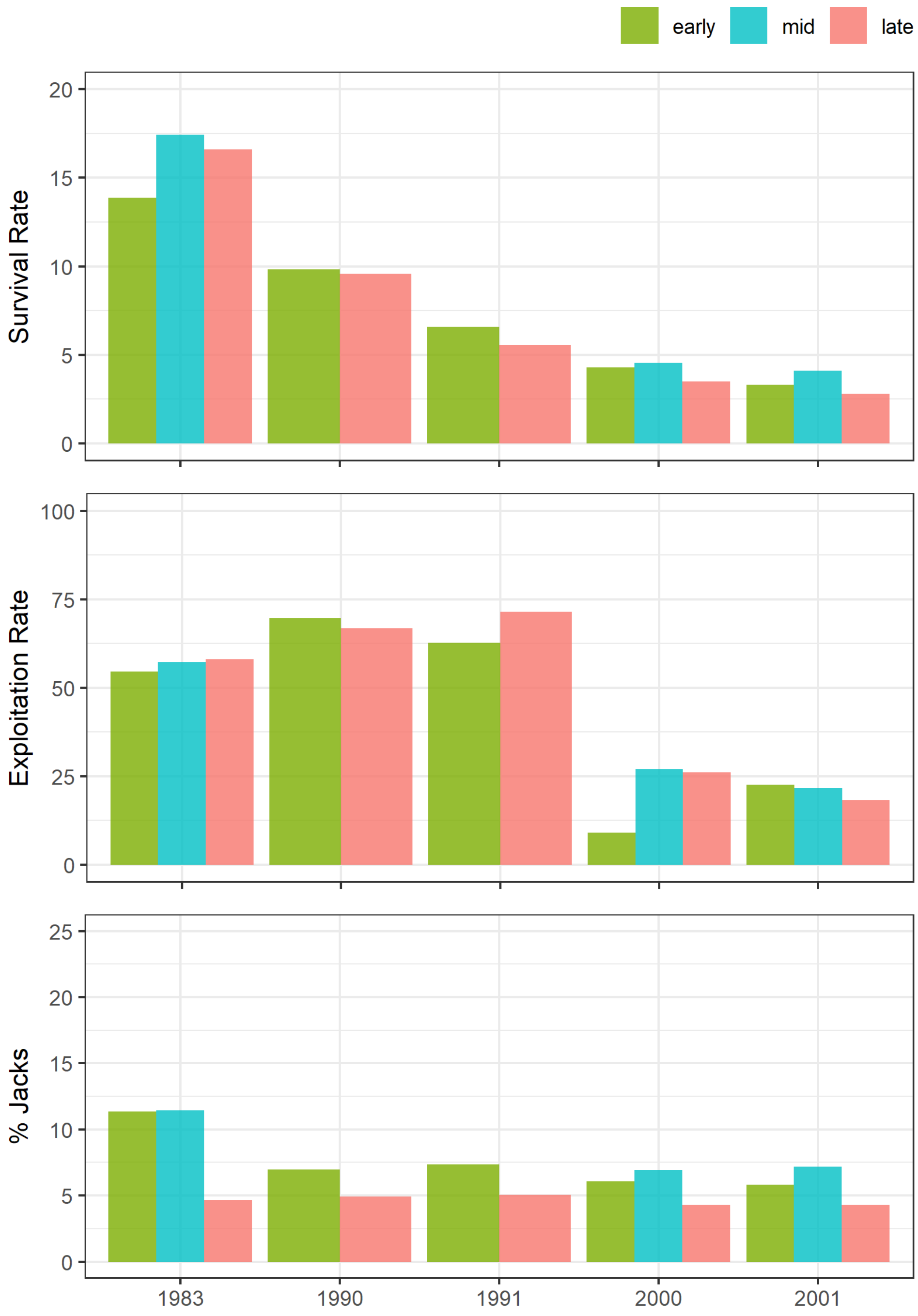

Figure 54: Survival rates (%), exploitation rates (%), and proportion of jacks (%) for early, mid, and late released Chilliwack River Coho yearlings from Chilliwack River Hatchery over time.

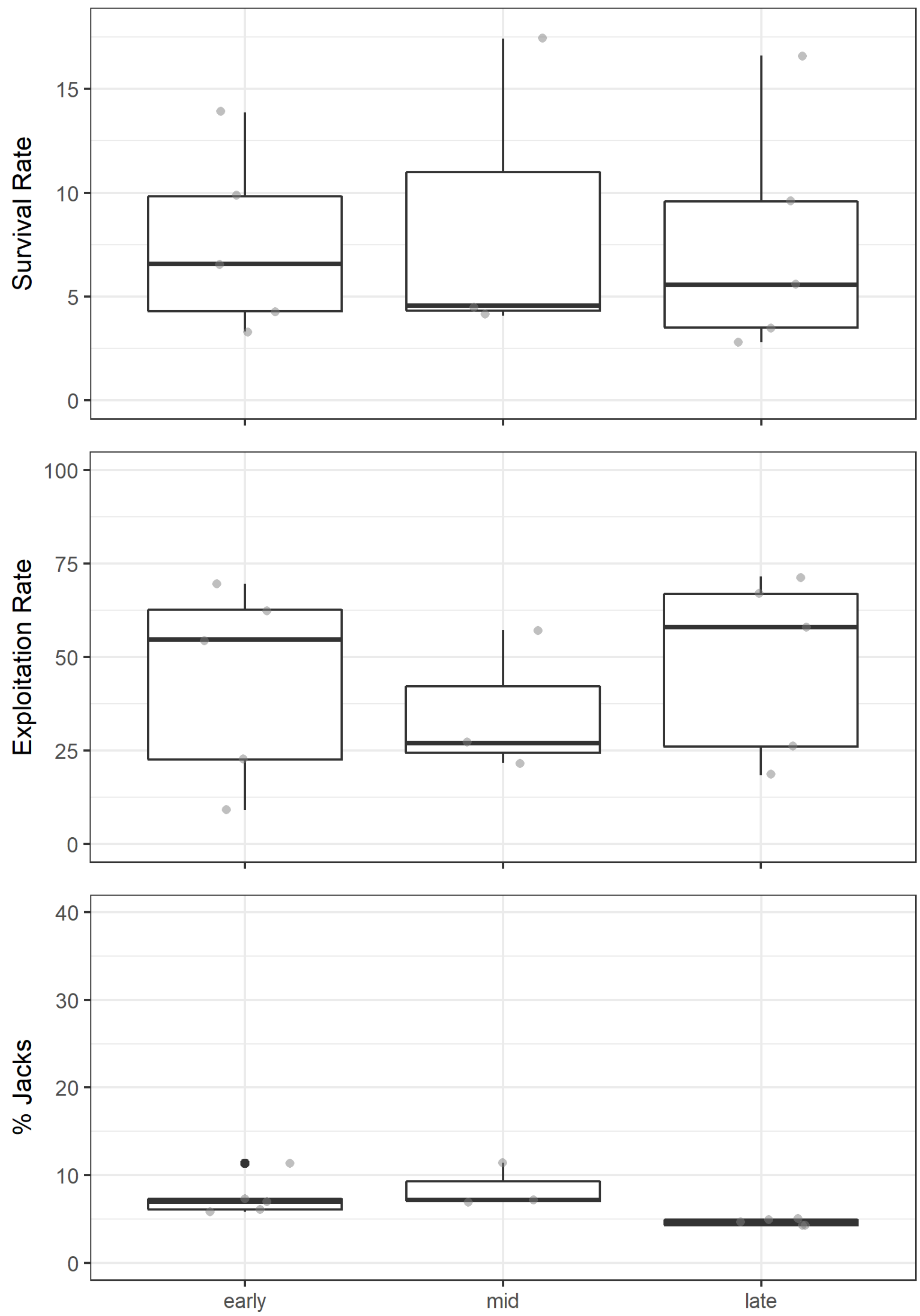

Figure 55: Survival rates (%), exploitation rates (%), and proportion of jacks (%) for early, mid, and late released Coho smolts from Chilliwack River Hatchery in 1983, 1990-1991, and 2000-2001. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey and outliers in black.

14, 15 & 16. Inch Creek Coho

Inch Creek Coho are an indicator stock for lower Fraser River Coho salmon, with target annual releases of 150,000 yearling Coho to meet harvest objectives. Similar to trends for Chilliwack River Coho, survival rates of this stock decreased dramatically throughout the 1990s from highs of 21.19% in 1987 to 0.66% in 1997 (Figure 56). The mean survival rate of releases between 2010 and 2015 was 3.14% (SD ± 1.07%).

Early vs Normal Time of Release

Two time of release trials have been conducted at Inch Creek Hatchery. First, in years 2006-2009, an experimental 'early' release of Coho yearlings was trialed. The goal was to assess how release timing might affect returns and to see whether release strategies should be adjusted. Approximately 20,000 yearlings were released between April 20 and April 27 each year, while 40,000 regular releases went out between May 9 and 14 (Table 25). Fish in both release groups were of a similar weight at release.

Survival rates of the early treatment were consistently and significantly lower than that of the normal Coho releases (Kruskal-Wallis; $p = 0.027$; Table 25; Figure 57-Figure 58). Exploitation rates of the early releases were higher, but not significantly (Kruskal-Wallis; $p = 0.22$; Table 25; Figure 57-Figure 58). Jacking rates were similar between the groups (Kruskal-Wallis; $p = 0.81$), although returns from the early release in 2009 had a higher proportion of jacks (Table 25; Figure 57). Depending on the production objective, early releases may or may not be effective. Further experimentation would be required.

The data were insufficient for modelling the effects of release strategies on survival in this experiment.

Normal vs Small Release

A size experiment was also conducted at Inch Creek using releases from 2012-2014. Each year, approximately 50,000 'normal' or 20 g yearling smolts were released at the same time as 50,000 'small' or 15 g yearling smolts (Table 25). The goal here was similar to that of the other experiments: to better understand how release strategies affect survival rates, but also to serve as a comparison for other facilities experimenting with size at release (e.g. Quinsam River Coho in 2010-2012).

Survival rates and exploitation rates of the small releases were not statistically different from those of the normal release group (t-test; $p = 0.45$ and $p = 0.23$, respectively; Figure 57-Figure 58). The mean proportion of jacks was higher for normal releases compared to small releases (12.1% versus 7.2%), however the difference was not significant (t-test; $p = 0.42$).

The data were insufficient for modelling the effects of release strategies on survival in this experiment.

Late/Large Release

The second time of release trial compared normal releases to later and larger releases of Coho in years 2015-2017. This was done as part of a regional assessment of a late/large release strategy for Coho involving Quinsam River, Big Qualicum River, Chilliwack River, and Inch Creek Hatcheries. The aims of the overarching study were to determine whether the late/large release strategy could improve marine survival rates, increase the proportion of catch in the Strait of Georgia, and reduce competition with wild salmon. At Inch Creek, approximately 40,000 large yearlings (mean weight = 35.0 g) were released between June 16-18 each year, while the 100,000 normal releases (mean weight = 20.4 g) were released during the period of May 9-15 (Table 25).

Overall, the mean survival and exploitation rates of the late/large treatment were not significantly different from those of the normal releases (t-test; $p = 0.9$ and $p = 0.2$ respectively; Table 25; Figure 57-Figure 58). However, both survival and exploitation rates were higher in 2015. Mean jacking rates were also not statistically different for the two release groups; however, the mean was slightly lower for the late/large release group (6% vs 11%; Table 25; Figure 57-Figure 58).

We examined several release covariates (time category, release weight, release day, and ocean entry year) to determine which were best associated with the smolt-to-adult survival rate during the late/large release trial. Quadratic terms for weight and day were also included to account for non-linear relationships. Given the annual variability in survival rates (Figure 57), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each treatment group in Figure 59.

The top model was an intercept-only model, suggesting that the size and time of release had little influence on survival during the three years of this trial (Table 26). The intra-class correlation estimate was relatively high, with 87% of the total variation in the survival response explained by the random year effect (Figure 60). Thus, during this trial, conditions other than those at the hatchery had a greater effect on survival. Residuals and normal quantile-quantile plots for the top model are provided in Figure 61. The residuals suggest that the error variances are not equal, however this is a very limited dataset. Additional years of data could improve model performance.

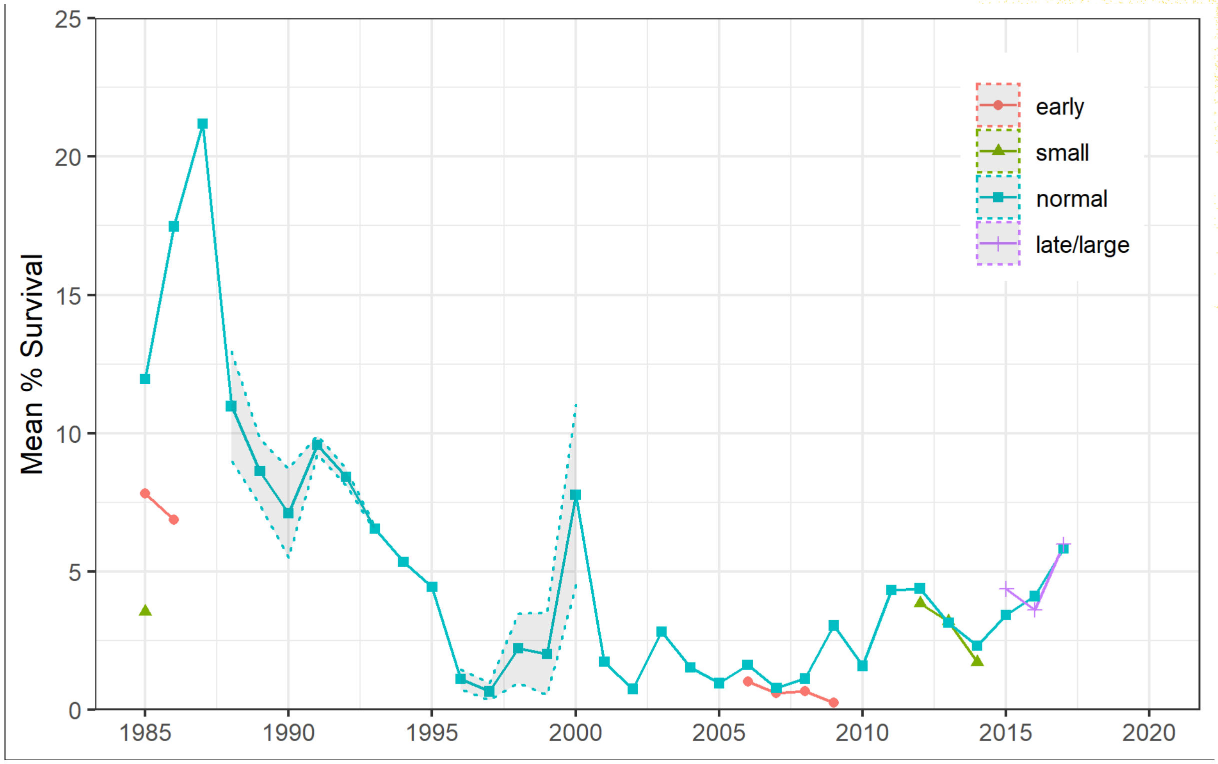

Figure 56: Mean percent survival of Inch Creek Coho yearlings released from Inch Creek Hatchery by ocean entry year. 'Normal' releases are shown (blue squares/lines) with experimental early (red dots/lines), small (green triangles/lines), and late/large (purple crosses/lines). Dashed lines around the mean and shaded grey represent the standard deviation.

Table 25: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%) and proportion of jacks (%) for an early vs normal release timing experiment, a small vs normal size experiment, and a normal vs late/large release experiment at Inch Creek Hatchery.

OEY	TREATMENT	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	JACKS (%)
2006	early	22.3	110	1	20,276	1.01	38.47	9.16
	normal	22.0 (0.7)	129 (0)	2	39,724	1.62	30.01	6.54
2007	early	19.8	110	1	21,050	0.60	20.48	3.26
	normal	20.0	132	1	39,035	0.78	13.24	0.00
2008	early	19.4	111	1	20,092	0.68	57.29	3.79
	normal	20.1	135	1	40,117	1.12	22.06	5.42
2009	early	20.4	117	1	20,078	0.26	19.32	13.56
	normal	20.0	135	1	40,306	3.04	10.58	4.05
2012	small	15.4	132	1	49,308	3.85	22.12	4.96
	normal	20.4	132	1	49,343	4.38	21.84	10.2
2013	small	15.5	131	1	49,958	3.20	23.27	2.68
	normal	20.9	131	1	50,070	3.15	18.85	4.87
2014	small	15.6 (0.0)	134 (0)	2	49,999	1.73	21.36	10.56
	normal	20.1	134	1	50,142	2.32	17.47	21.29
2015	normal	20.3 (1.1)	129 (2)	3	100,132	3.37	13.60	14.23
	late/large	32.6	169	1	49,811	4.37	36.93	2.48
2016	normal	20.8	132	1	100,513	4.10	44.93	8.30
	late/large	38	169	1	39,957	3.61	40.24	11.19
2017	normal	20.1 (0.1)	135 (0)	3	108,081	5.82	28.23	8.81
	late/large	34.5	167	1	39,725	5.99	25.08	4.30

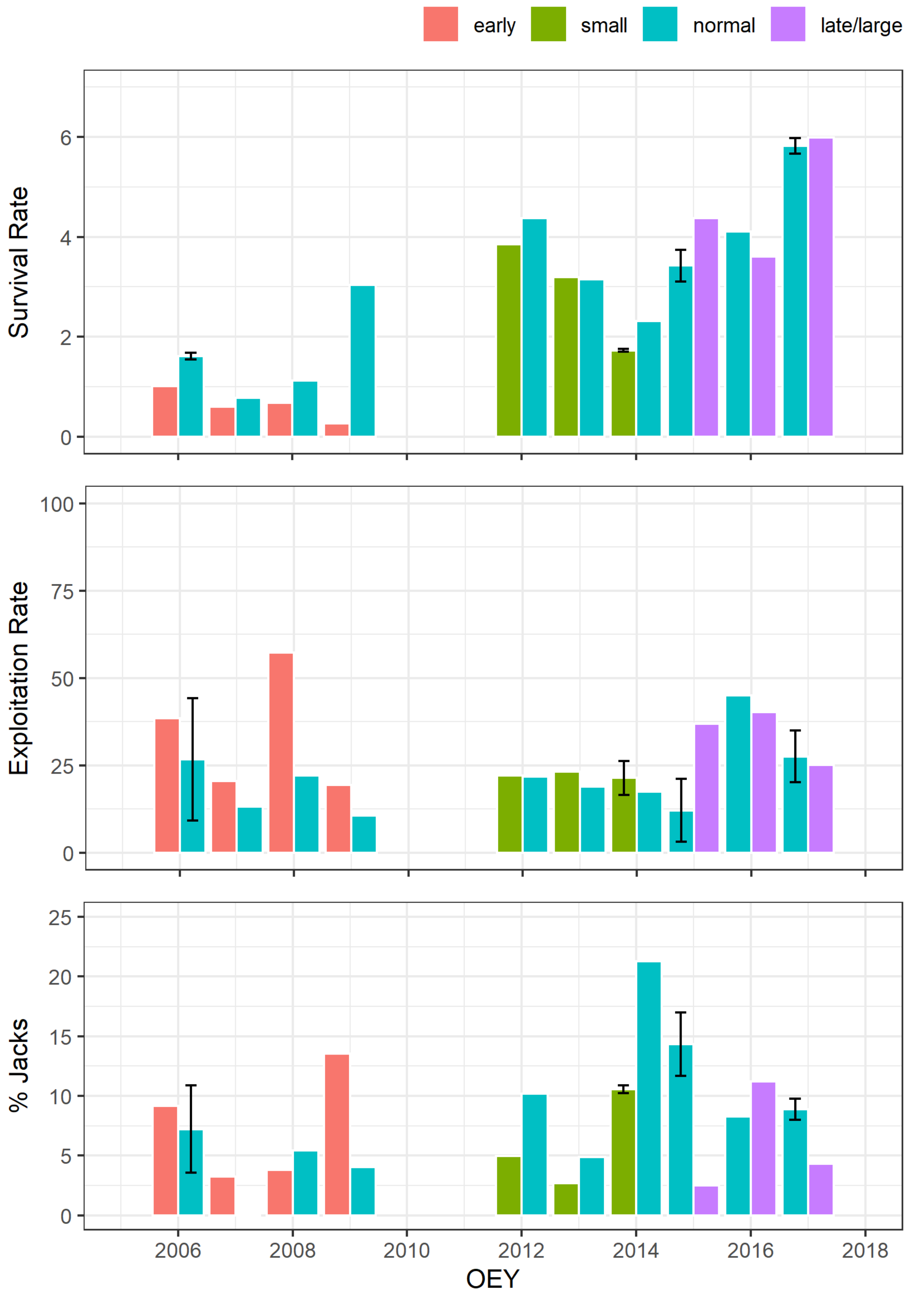

Figure 57: Survival rates (%), exploitation rates (%), and proportion of jacks (%) over time for Inch Creek Coho yearlings released in three trials: early vs normal releases in 2006-2009, small vs normal releases in 2012-2014, and normal vs late releases in 2015-2017 at Inch Creek Hatchery.

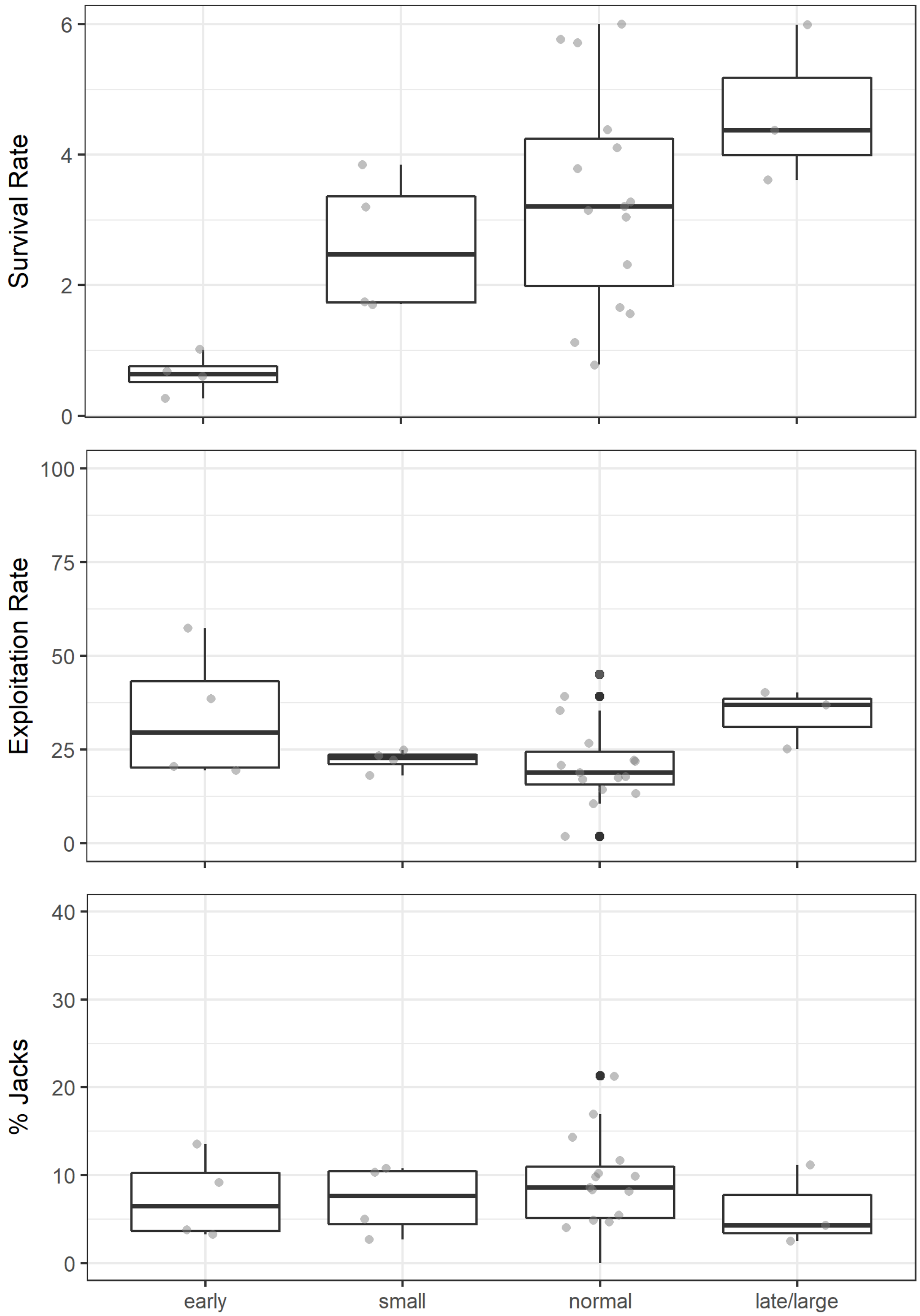

Figure 58: Survival rates (%), exploitation rates (%), and proportion of jacks (%) for early, small, normal, and late/large Inch Creek Coho releases from Inch Creek Hatchery in years 2006-2009 (early and normal), 2012-2014 (small and normal) and 2015-2017 (late/large and normal). Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey.

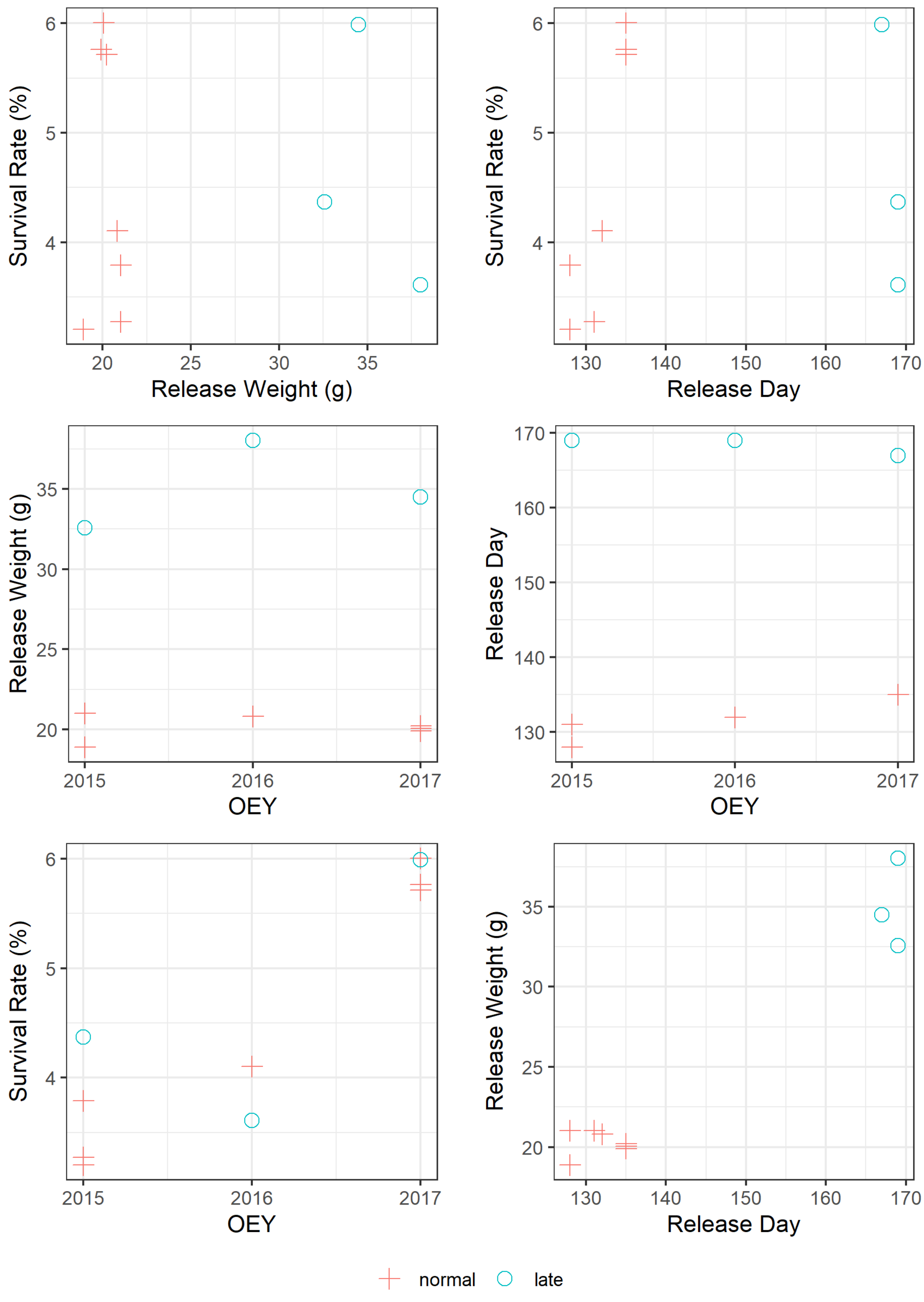

Figure 59: Data distributions of normal vs late/large Inch Creek Coho yearlings released from Inch Creek Hatchery.

Table 26: Top three models showing fixed effects for predicting survival rates of Inch Creek Coho salmon. The best model is bolded. ICC represents the intra-class correlation which describes the portion of the variation in the model attributed to the random ocean entry year effect.

INTERCEPT	SIZE	SIZE²	OEY	DAY	DAY²	TREATMENT	DF	LOGLIK	DELTA	ICC
-509.854	-	-	0.251	-	-	-	4	7.27	0	0.64
-3.088	**-**	**-**	**-**	**-**	**-**	**-**	**3**	**4.27**	**0.02**	**0.87**
-3.112	-	-	-	-	-	+	4	4.75	5.05	0.87

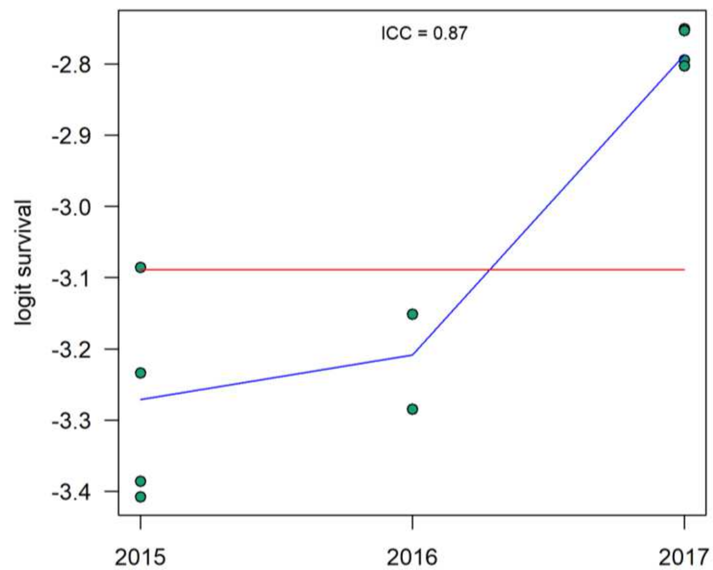

Figure 60: Estimated mean Inch Creek Coho logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

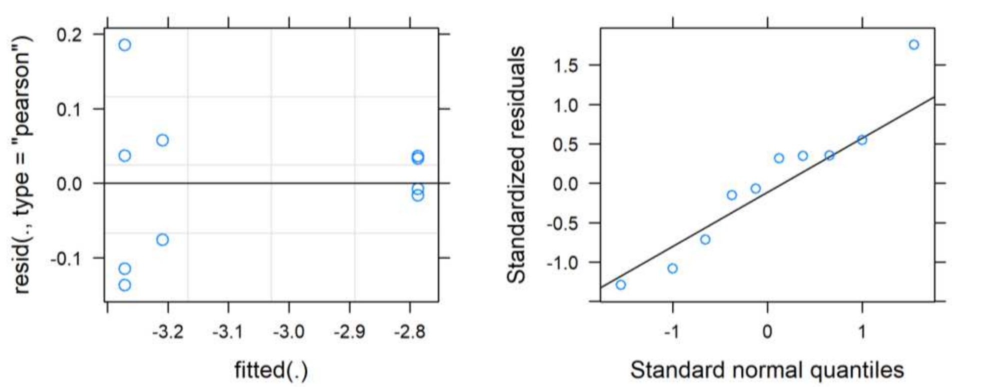

Figure 61: Residuals and quantile plot for the best Inch Creek late/large Coho model.

17, 18 & 19. Quinsam River Coho

Quinsam River Coho are an indicator stock for Northern Strait of Georgia with target annual releases of 400,000 into the Quinsam River to meet assessment and harvest objectives. Fed fry are also released across several different locations for stewardship and rebuilding purposes. Similar to trends seen at other facilities releasing Coho into the Strait of Georgia, survival rates of Quinsam River Coho rapidly declined from highs of 12.68% in 1988 to 1.09% in 1998 (Figure *62*). Survival rates have remained low since the decline, with a mean rate of 1.78% (SD ± 0.95%) between 2010 and 2015. Release strategies have varied over time, with a mix of early, mid, and late releases trialed in the first few years of operations. Some of the earliest experiments on size and time of release were done at Quinsam River Hatchery in the 1980s. Those experiments suggested that 20 g Coho yearlings released between June 4th and 6th would see the best returns (Bilton et al. 1984, Morley et al. 1988). Late releases were therefore continued into the early 2000s, when low survival rates of the late release group led hatchery managers to re-visit the time and size at release experiments. Environmental conditions, fishing pressures, and survival rates have changed over time. Therefore, the relationships between size and time of release and various production outcomes are likely to have changed as well. The following describes the more recent, post-decline size and time of release experiments at Quinsam River Hatchery.

Time of Release (2002-2015)

In years 2002-2015, Quinsam River Hatchery ran an ongoing experiment to assess the effectiveness of different release times. A mix of early (April 20-May 5), mid (May 5-19), and late (May 16-May 27) groups were released each year with all three groups released consistently from 2004-2012 (Table 27). Weight was kept relatively constant across release groups. The objective of this experiment was to update existing knowledge on the optimal time of release for Coho at this facility.

No significant difference was found in the overall mean survival rate, exploitation rate, or proportion of jacks in the returns between the early, mid, and late release groups (ANOVA; survival: $F(2) = 2.20$, $p = 0.12$; exploitation: $F(2) = 1.16$, $p = 0.32$; jacks: $F(2) = 0.25$, $p = 0.78$; Table 27, Figure 63-Figure 64). The mean survival rate was highest for the mid release group, while the mean exploitation rate was highest for the early release group. The mean proportion of jacks did not show any trends with time of release.

There were sufficient data from the time of release experiment to examine the relationships between the release covariates (time category/treatment, release day, and ocean entry year) and the smolt-to-adult survival rate. Size at release was not included as there was little variation between groups (Figure 65). For the model, only years with all three release groups were included (2004-2012). A quadratic term for day of release was also added to account for non-linear responses. Given the annual variability in survival rates (Figure 63), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years are shown for all treatment groups (including those not modelled) in Figure 65.

The best model contained the ocean entry year, day of release and the quadratic coefficient for day of release (Table 30). This reflects the gradual increase in survival rates over time, as well as the higher survival of the mid release group (Figure 66-Figure *67*). The intra-class correlation estimate was 44%, meaning that the random effects of the year of ocean entry could explain 44% of the total variation in the survival over time (Figure 67). Therefore, accounting for size at release and temporal trends could improve predictions of survival. Residuals and normal quantile-quantile plots for the top model are provided in Figure 68. The residuals are somewhat uneven in their distribution, suggesting that there may be some explanatory power missing from the model that is being captured by the random error term (e.g. environmental conditions).

Size at Release (2010-2012)

From 2010-2012, a subset of Coho yearlings were released on the same day during the mid (normal) release period in one of two different weight groups: 'normal' (mean ± SD: 26.4 g ± 1.6 g) and 'large' (mean ± SD: 31.5 g ± 1.4 g) (Table 28).

No significant differences were found between the mean survival rates (t-test; p = 1.0), exploitation rates (t-test; p = 0.58), or proportion of jacks in the returns (t-test; p = 0.53) of the normal and large release groups. While there was no difference between treatments during the three years of the experiment, the mean survival of the mid/large release group was higher than the mean of the mid release group over the entire time series (2002-2015) (Figure 64). Therefore, size at release may have some effect on survival, but the relationship appears to vary over time.

Late/Large Experiment (2016-2018)

In years 2016-2018, a late/large release of Coho was tried at the Quinsam River Hatchery. Each year, 38,000 yearlings were released late between June 18 and June 29 in addition to the 135,000 normal yearling releases between May 8 and May 10. The late releases were also > 10 g heavier than their normal counterparts. Age-3 return data are not yet available for the 2018 release, however preliminary return data are given in green in Table 29.

When looking at the complete return data for the 2016 and 2017 ocean entry years, mean survival rates of the late/large release group were significantly higher than for the normal release group (Kruskal Wallis; p = 0.01) (Table 29; Figure 63-Figure 64). Mean exploitation rates were also significantly higher on the late/large release group (Kruskal Wallis; p = 0.04), with lower jacking rates (Kruskal Wallis; p = 0.02) (Table 29; Figure 63). Thus, this strategy has the potential to increase survival and exploitation rates while also decreasing the occurrence of jacking. Further analyses should be done once all recovery data has been collected.

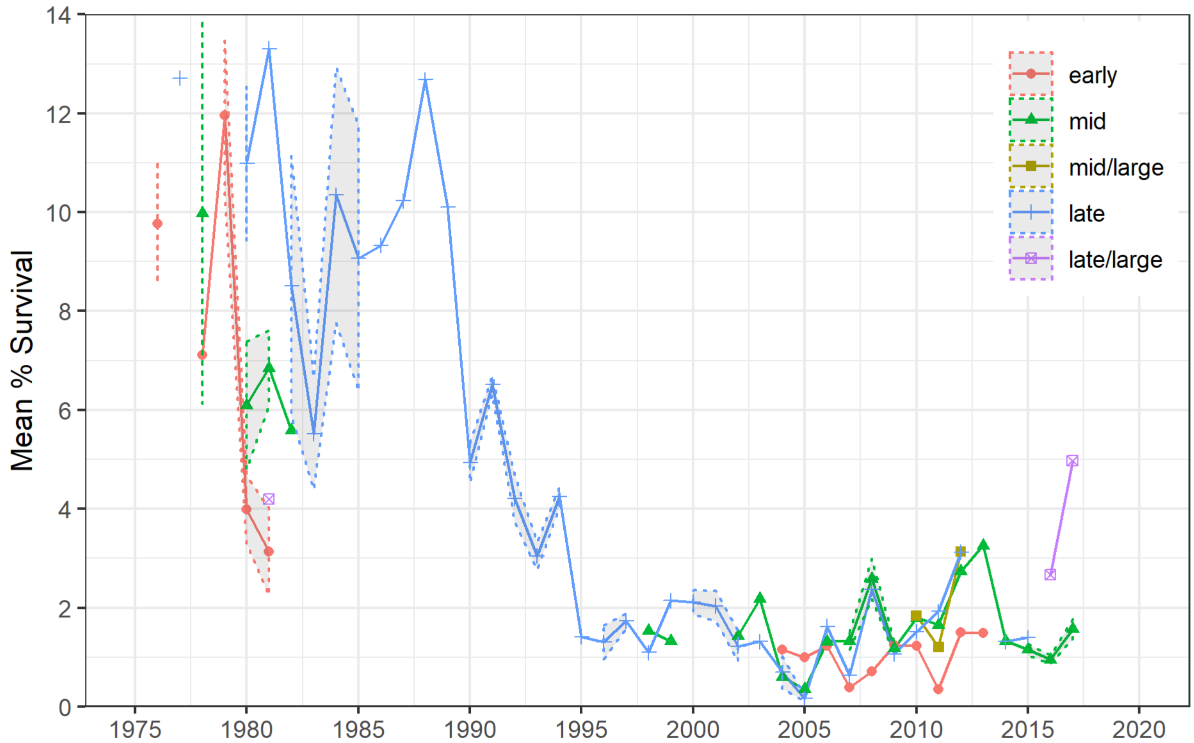

Figure 62: Mean percent survival of Quinsam River Coho yearlings released from Quinsam River Hatchery by ocean entry year. The different release strategies, including early (red dots), middle (green triangles), middle/large (yellow squares), late (blue crosses) and late/large (purple boxes) releases are shown over time. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 27: Release parameters (OEY = ocean entry year, time group, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%) and proportion of jacks (%) for the Quinsam River Coho release timing experiment from 2002-2015.

OEY	TREATMENT	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	JACKS (%)
			136	1	21,163	1.43	23.49	14.58
			148 (0)	2	21,502	1.22	14.44	10.66
			131	1	10,861	2.17	30.01	2.74
			145	1	32,053	1.32	19.81	3.83
			126	1	10,869	1.15	8.60	30.53
			140	1	10,849	0.60	0.00	25.23
			148 (1)	4	43,367	0.70	33.33	24.89
			125	1	5,454	0.99	47.95	14.84
			137	1	10,906	0.35	16.72	33.83
			142 (3)	2	21,638	0.17	0.00	31.85
			115	1	10,930	1.23	46.29	32.13
			130	1	10,925	1.32	29.86	14.92
			137	1	10,910	1.62	40.89	12.15
			115	1	11,492	0.38	0.00	23.00
			132 (4)	2	23,027	1.32	12.20	17.57
			143	1	9,929	0.63	0.00	20.95
	early	22.6	115	1	11,059	0.72	22.57	2.54
2008	mid	27.8 (2.7)	129 (0)	2	22,217	2.59	17.23	5.78
	late	25.7	143	1	10,994	2.37	23.56	5.01
	early	24.2	112	1	11,289	1.24	9.45	20.70
2009	mid	25.8 (1.2)	126 (0)	2	22,368	1.18	5.62	27.78
	late	25.3	140	1	10,943	1.06	15.27	27.57
	early	27.3	111	1	10,874	1.23	33.30	15.20
2010	mid	28.0	126	1	10,399	2002	mid	23.0
	late	27.6	140	1	10,747	1.52	late	23.5 (0.8)
	early	26.2	111	1	11,041	2003	mid	21.4
2011	mid	26.2	130	1	11,485	1.65	late	22.6
	late	27.1	144	1	10,618	2004	early	24.3
	early	26.7	116	1	10,756	1.51	mid	24.3
2012	mid	24.9	130	1	10,690	2.74	late	23.7 (1.3)
	late	26.9	144	1	10,190	2005	early	22.8
2013	early	24.4	115	1	18,811	1.49	mid	25.2
	mid	25.1	129	1	18,339	3.26	late	25.1 (0.5)
2014	mid	24.6	129	1	19,191	2006	early	23.3
	late	24.0	142	1	18,879	1.31	mid	22.8
2015	mid	23.6 (0.2)	127 (0)	2	104,285	1.12	late	25.1
	late	24.1	141	1	33,674	2007	early	26.7
							mid	25.6 (0.6)
							late	24.6

Table 28: Release parameters (OEY = ocean entry year, time group, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%) and proportion of jacks (%) for the Quinsam River Coho size at release experiment (2010-2012).

OEY	TREATMENT	SIZE (G)	DAY	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	JACKS (%)
2010	normal	28	126	1	10,399	1.8	21.56	23.99
	large	31	126	1	11,374	1.84	17.98	21.49
2011	normal	26.2	130	1	11,485	1.65	40.72	20.19
	large	33.1	130	1	11,003	1.2	21.75	20.31
2012	normal	24.9	130	1	10,690	2.74	39.74	17.73
	large	30.4	130	1	10,820	3.13	43.76	13.95

Table 29: Release parameters (OEY = ocean entry year, time group, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%) and proportion of jacks (%) for Quinsam River normal and late/large Coho releases (2016-2018). Preliminary data for 2018 returns are shown in green.

OEY	TREATMENT	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	JACKS (%)
2016	normal	24.8 (0.5)	131 (1)	4	132,741	0.95	22.97	17.68
	late/large	35.9 (0.1)	181 (0)	2	38,061	2.67	36.44	4.58
2017	normal	21.9 (0.8)	128 (0)	4	137,315	1.62	19.54	32.22
	late/large	39.0	174	1	38,319	4.98	27.12	13.99
2018	normal	25.6 (0.6)	129 (0)	4	135,190	1.12	11.60	88.67
	late/large	35.5 (0.5)	169 (0)	2	37,088	1.08	35.84	64.41

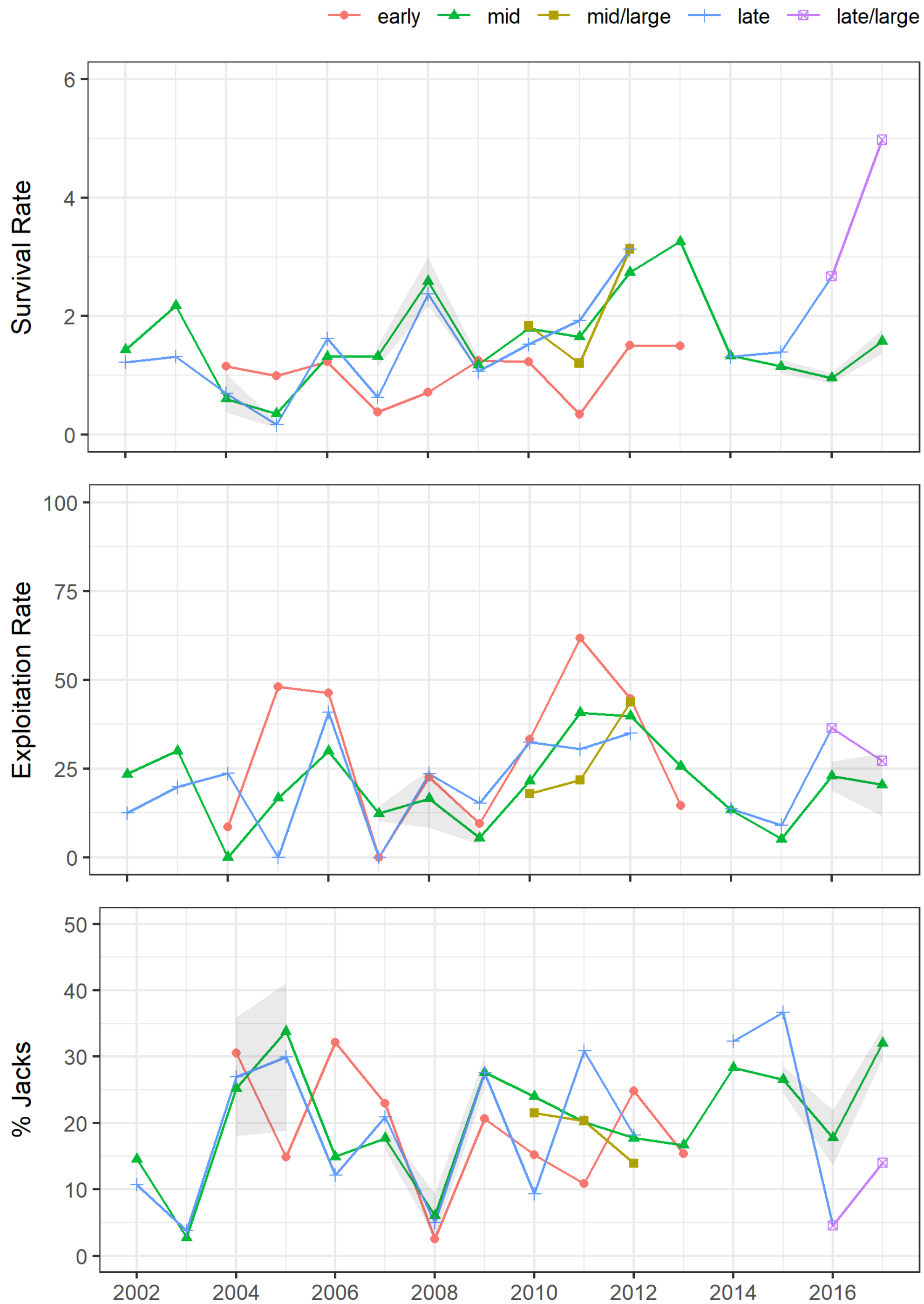

Figure 63: Survival rates (%), exploitation rates (%), and proportion of jacks (%) over time for differently timed Quinsam River Coho releases from Quinsam River Hatchery. Shaded areas around the mean represent one standard deviation.

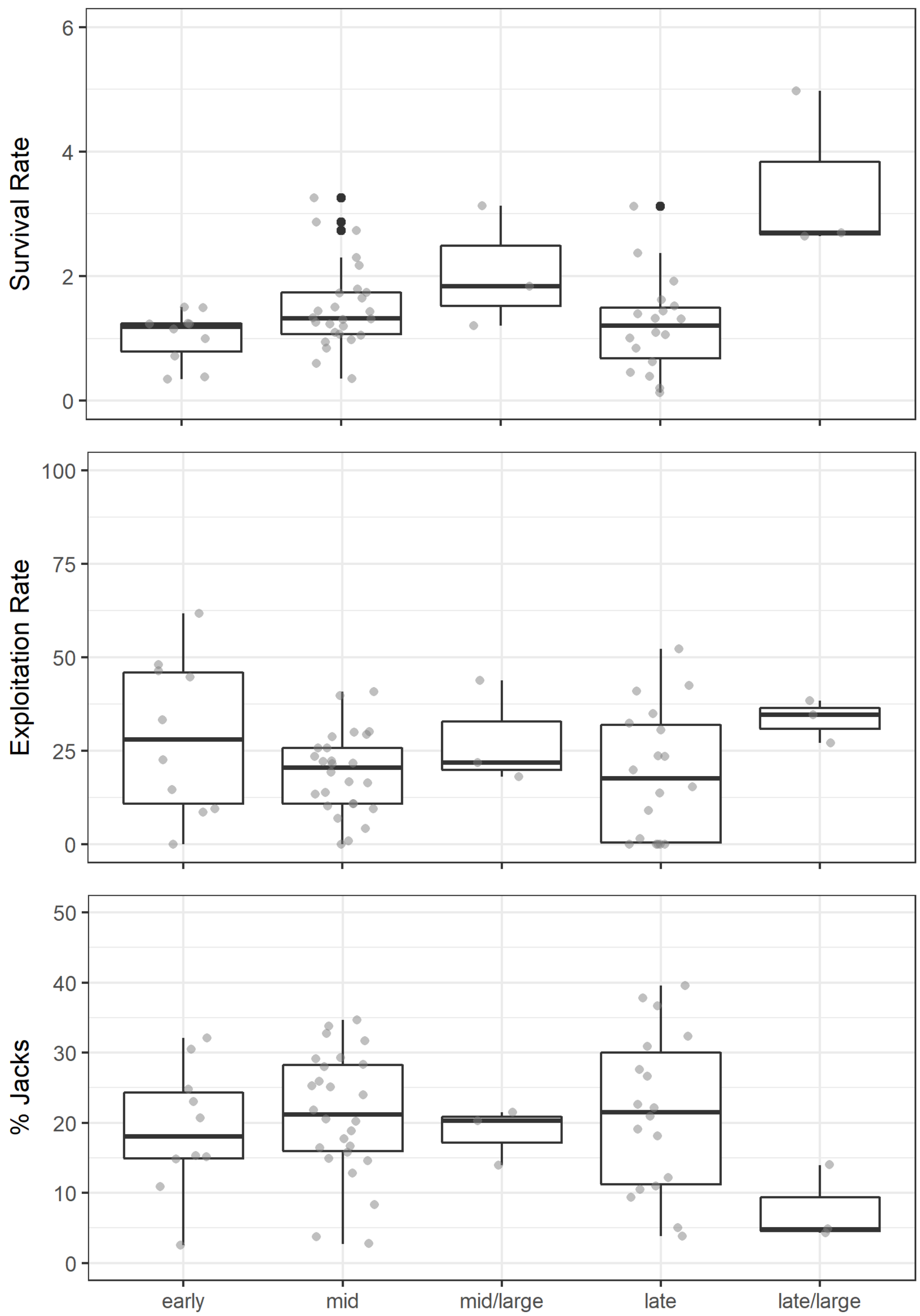

Figure 64: Survival rates (%), exploitation rates (%), and proportion of jacks (%) for different times and sizes at release for Quinsam River Coho yearlings released from Quinsam River Hatchery between 2002 and 2017. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Data points are shown in grey and outliers in black.

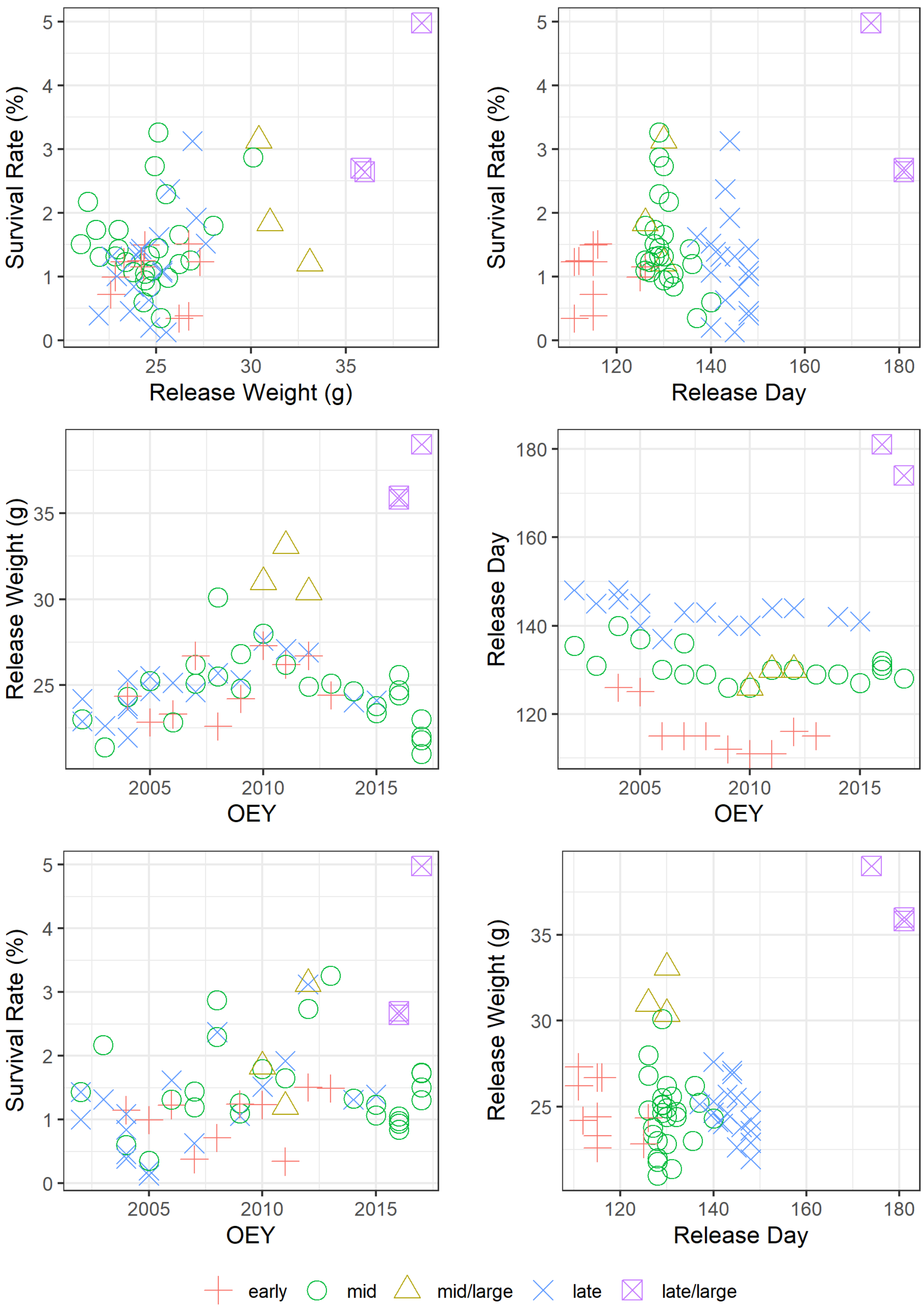

Figure 65: Data distributions of different times and sizes of Quinsam River Coho releases.

Table 30: Top three models showing fixed effects for predicting survival rates of Quinsam River Coho salmon during the 2002-2015 release timing experiment. The best model is bolded. ICC represents the intra-class correlation which describes the proportion of the variation in the model attributed to the random year effect.

INTERCEPT	OEY	DAY	DAY2	TREATMENT	DF	LOGLIK	DELTA	ICC
-325.285	**0.16**	**-0.015**	**-0.002**	**-**	**6**	**-26.9**	**0**	**0.44**
-4.242	-	-0.017	-0.002	-	5	-29.85	2.93	0.59
-406.567	0.201	0.029	-0.003	+	8	-25.48	3.8	0.54

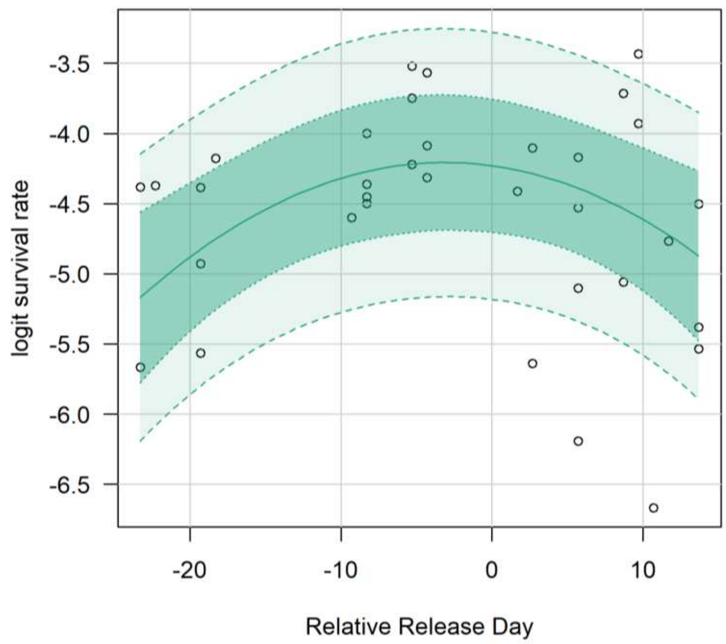

Figure 66: Mean logit survival and 95% CIs (dark green = fixed effects, light green = random effects) for the model fit to Quinsam River Coho releases at different times relative to the mean.

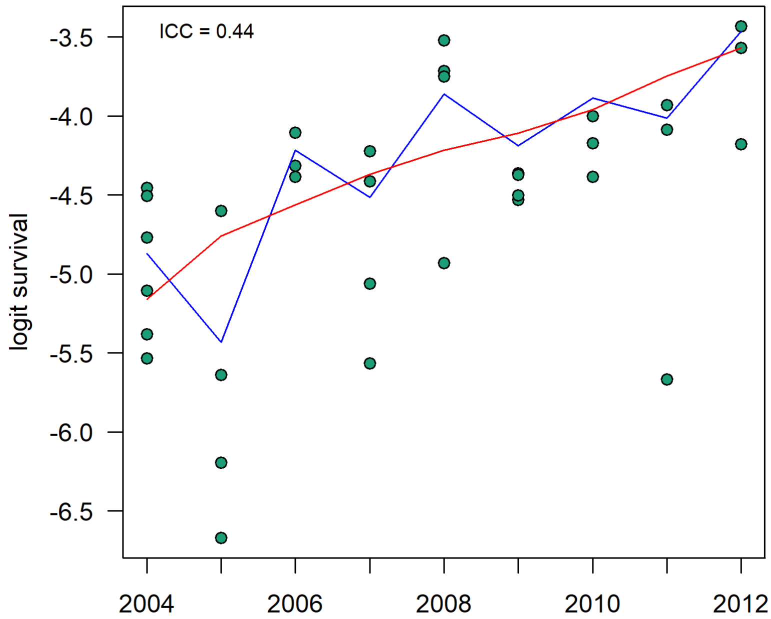

Figure 67: Estimated mean Quinsam River Coho logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects during the release timing experiment (2004-2012). The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

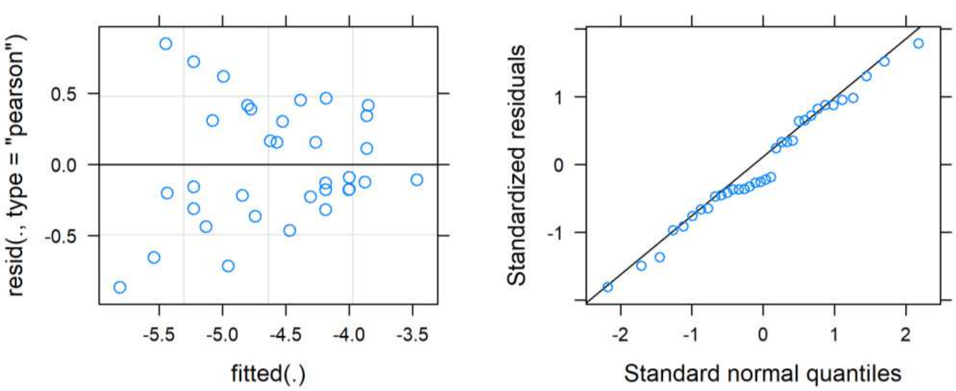

Figure 68: Residuals and quantile plot for the best Quinsam River Coho survival model during the release timing experiment (2004-2012).

SEAPENS

The following tables (Table 31Table 32) serve as summaries of experimental outcomes from seapen releases at six locations with detailed information and analyses on each experiment in the following sections.

Table 31: Summary of relationships found between seapen releases and survival rates, exploitation rates, and return ages relative to a corresponding hatchery release. Where survival models were possible, the best release strategies from the top model are provided in the 'Survival' column. Green cells represent significantly higher outcomes for the seapen release group, red cells represent significantly lower outcomes, and grey cells represent no difference between release groups. Rows in orange have insufficient data for conducting statistical analyses.

SPECIES	STOCK	OEY	EXPERIMENT	SURVIVAL	EXPLOITATION	AGE
CN	Chilliwack R	2014-2017	Sandy Cove seapen	insufficient data		
CN	Cowichan R	1992-2004, 2006-2009	Cowichan estuary seapen	size, year, release site		
CN	Puntledge	2000, 2002-2003, 2006-2009	Comox Bay seapen	none		
CN	Quinsam R	2000-2018	Seapens throughout Discovery Passage	size, time		
CN	Robertson Cr	2002-2004, 2014-2018	Harbour Quay seapen (02-04), Alberni Inlet Seapen (14-18)	release type		
CN	Wannock R	2010-2011, 2014-2015, 2018-2019	Wannock Estuary seapen	insufficient data	NA	

Table 32: Overall mean (standard deviation) survival rates, exploitation rates, and return ages for facilities releasing Chinook salmon from both the hatchery and seapens over a set number of years.

STOCK	SURVIVAL (%)		EXPLOITATION (%)		AGE (YRS)		YEARS
	Hatchery	Seapen	Hatchery	Seapen	Hatchery	Seapen	
Chilliwack R (Capilano)	0.62 (0.37)	1.14 (0.48)	77.65 (4.30)	78.41 (3.67)	2.97 (0.10)	2.95 (0.05)	2
Cowichan R	0.24 (0.12)	0.30 (0.16)	56.81 (14.85)	68.34 (15.83)	2.97 (0.24)	3.13 (0.23)	9
Puntledge R (Summer)	0.24 (0.11)	0.37 (0.21)	24.42 (10.46)	33.41 (11.61)	3.12 (0.18)	3.20 (0.27)	8
Quinsam R	0.26 (0.14)	0.26 (0.16)	39.60 (15.87)	55.6 (18.24)	3.92 (0.35)	3.75 (0.31)	19
Robertson Cr	1.43 (0.68)	2.01 (0.84)	64.68 (6.21)	73.79 (5.11)	3.72 (0.19)	3.72 (0.18)	5
Wannock R	0.18 (0.06)	0.19 (0.11)	NA	NA	4.07 (0.19)	4.10 (0.20)	4

20. Capilano (Chilliwack) River Chinook

Historically, there were no Chinook stocks on the Capilano River, however a hybridized Chinook stock was introduced by the hatchery in 1972. The objective behind this production was to produce Chinook salmon for harvest. This stock was the result of multiple transfers from other facilities, primarily 'Qualicum reds' and 'Harrison whites'. Survival rates rose rapidly over the first three years of enhancement up to 5.28% in the mid 1970s, however dropped back down to a low of 0.04% by the mid 1980s and have remained low since (Figure 69). The application of CWTs ceased in 2001 but started up again in 2013. At that time, Capilano River Hatchery began rearing and releasing tagged Chilliwack River Chinook exclusively and releasing them from both the hatchery and seapens in Sandy Cove in West Vancouver. Approximately 460,000 subyearling Chinook smolts are released from the hatchery each year, with an additional 100,000 smolts transferred to the seapens prior to release for one to three weeks. Each group receives 60,000 CWTs. The objective behind the seapen rearing is to facilitate the transition from fresh to saltwater and provide more fish for harvest by encouraging homing to a specific area where fisheries are concentrated.

With only two years of complete recovery data, no statistical analyses were conducted, however the data are summarized below.

For both 2014 and 2015 releases, survival rates were higher from those Chinook released from the seapens than those released directly from the hatchery (

Table 33; Figure 70). However, preliminary survival rates of hatchery releases in 2016 were higher than those from the seapens, and were the highest survival rates seen since the early 1980s. Exploitation rates and return ages were similar for the two release groups. Preliminary data from 2016 and 2017 releases show mixed results, with higher survival and exploitation rates from hatchery releases in 2016, yet higher rates from seapen releases in 2017.

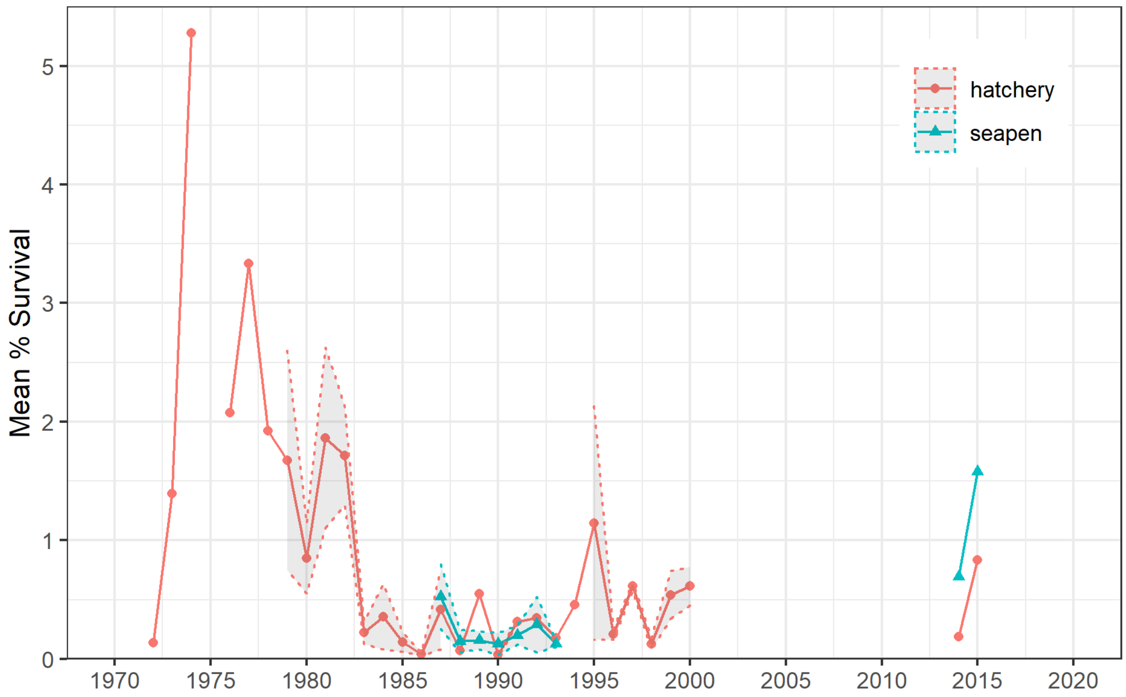

Figure 69: Mean percent survival of Chilliwack River Chinook subyearling smolts reared at Capilano River Hatchery and released either from the hatchery (red circles) or Sandy Cove seapens (blue triangles) by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 33: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Chilliwack River Chinook released from Capilano Hatchery and Sandy Cove seapens. Where greater than one group was released, standard deviation is given in parentheses. Preliminary return data for entry years 2016 and 2017 are given in green.

OEY	RELEASE TYPE	SIZE	DAY	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL	EXPLOITATION	AGE
2014	hatchery	6.7	142	1	59,988	0.19	72.00	3.1
	seapen	7.9	142	1	59,802	0.70	75.06	3.0
2015	hatchery	7.6 (0.8)	142	2	56,816	0.84	80.66	2.9
	seapen	9.9	139	1	57,261	1.58	81.76	2.9
2016	hatchery	6.6	148	1	27,595	1.40	77.83	3.0
	seapen	4.5	134	1	52,450	0.69	69.17	3.0
2017	hatchery	8.8	151	1	59,160	0.27	71.04	2.7
	seapen	7.6	139	1	57,670	0.57	89.46	2.7

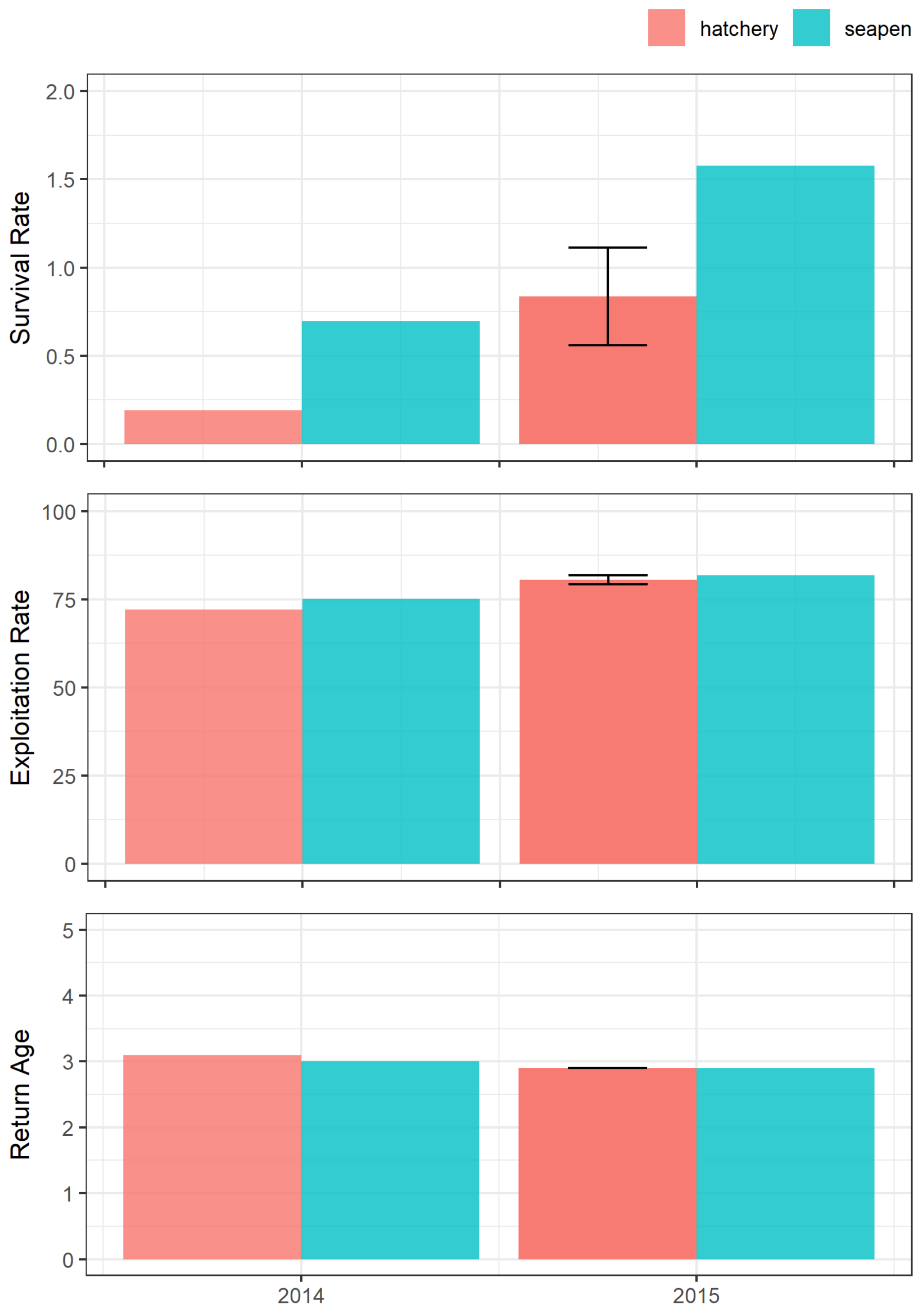

Figure 70: Survival rates (%), exploitation rates (%), and return ages for Chilliwack River Chinook salmon reared at Capilano River Hatchery and released either directly from the hatchery (red) or from seapens (blue) in 2014 and 2015. Bars indicate standard deviation or range for the 2015 hatchery release, wherein there were 2 release groups.

21. Cowichan River Fall Chinook

Cowichan River Chinook are an indicator stock for Strait of Georgia Chinook (see Section 10). From 1992-2009, Chinook were also released from seapens in the Cowichan estuary. Each year, approximately 200,000 subyearling smolts were released from the hatchery into Cowichan River with an additional 25,000 transferred to seapens in the Cowichan estuary prior to release. The objective of the seapen releases was to see if returns could be improved by avoiding in-river predation. However, high straying rates were seen from the seapen releases and they were stopped after 2009.

Our main focus is on release strategies used since 2000, however we have decided to include pre-2000 from Cowichan River to provide greater perspective on trends over time.

Survival rates of seapen releases have not been significantly different from those of hatchery releases, both in the 2000s (t-test; $p = 0.51$) and over the entire time series (Wilcoxon rank sum test; W = 586, $p = 0.99$, n = 77; Figure 72-Figure 73). The only period in which seapen releases saw higher survival rates was in the early 2000s. Exploitation rates have generally been higher for seapen releases than for hatchery releases, particularly in the late 1990s (Table 34; Figure 72). Over the entire time series, exploitation rates were significantly higher for seapen releases than for hatchery releases (67.9% versus 48.5%; t-test; $p < 0.001$). However, in the 2000s the difference became insignificant (seapen exploitation rates of 67.1% versus hatchery exploitation rates of 56.6%; t-test; $p = 0.069$; Figure 73). Return ages have been similar for the two release types, with a mean return age of 3.1 from seapen releases and 3.0 from hatchery releases from 2000-2009. Over the entire time series, return ages have been slightly higher for the seapen releases (Wilcoxon rank sum test; W = 414.5, $p = 0.045$, n = 77; Table 34; Figure 72).

In section 10 of this review, we ran a model to assess the importance of weight at release, day of release, release location, and ocean entry year in predicting survival rates. While release location was found to be an important predictor, post hoc analyses showed that seapen releases were not significantly different from direct river releases (Figure 48).

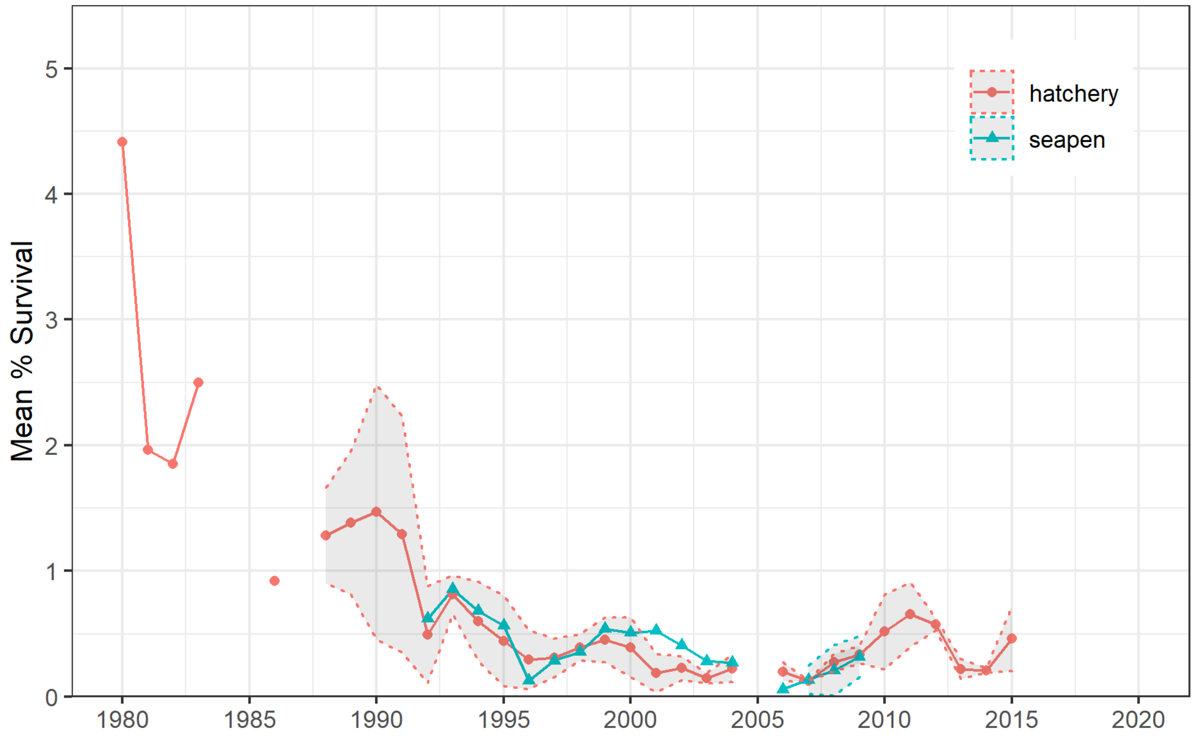

Figure 71: Mean percent survival of Cowichan River Chinook subyearling smolts released both in river (red circles) and from seapens in the estuary (blue triangles). Dashed lines around the mean and shaded grey represent the standard deviation.

Table 34: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Cowichan River Chinook released into Cowichan River or from seapens in the Cowichan estuary. Where greater than one group was released, standard deviation is given in parentheses.

OEY	RELEASE TYPE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
1992	hatchery	4.6 (0.8)	126 (14)	4	216,959	0.57	60.92	3.2
	seapen	6.3	150	1	53,723	0.62	83.43	3.2
1993	hatchery	5.4 (1.1)	128 (19)	4	214,576	0.82	49.99	2.9
	seapen	6.3	145	1	24,770	0.86	56.79	2.9
1994	hatchery	5.6 (1.0)	128 (14)	4	200,716	0.59	49.27	2.8
	seapen	6.2	145	1	24,875	0.68	73.50	2.9
1995	hatchery	5.5 (1.0)	139 (11)	4	199,551	0.47	37.11	3.0
	seapen	6.1	151	1	25,023	0.57	72.19	2.9
1996	hatchery	5.7 (1.3)	120 (16)	4	200,939	0.29	20.93	2.7
	seapen	6.8	131	1	25,114	0.13	56.71	3.3
1997	hatchery	5.2 (1.2)	114 (14)	4	201,892	0.31	44.47	2.8
	seapen	6.8	127	1	25,235	0.29	74.44	3.0
1998	hatchery	5.5 (1.4)	124 (19)	3	200,744	0.39	42.55	3.0
	seapen	6.3	145	1	24,915	0.36	74.09	3.0
1999	hatchery	5.4 (1.5)	118 (18)	4	200,363	0.45	48.62	3.1
	seapen	5.1	137	1	25,127	0.54	62.69	2.9
2000	hatchery	5.3 (1.9)	100 (29)	3	199,501	0.37	54.58	3.1
	seapen	8.7	138	1	25,078	0.51	67.34	3.1
2001	hatchery	5.5 (1.5)	110 (20)	3	200,177	0.20	66.33	3.2
	seapen	8.0	143	1	25,175	0.52	64.68	3.1
2002	hatchery	4.8 (1.0)	119 (15)	3	200,745	0.22	68.28	3.1
	seapen	5.7	141	1	25,163	0.41	90.44	3.3
2003	hatchery	5.4 (0.7)	131 (23)	3	200,416	0.15	61.67	2.9
	seapen	7.4	148	1	25,134	0.28	43.51	2.7
2004	hatchery	5.3 (1.2)	123 (21)	3	200,443	0.23	46.68	2.9
	seapen	6.5	147	1	25,144	0.27	69.59	3.0
2006	hatchery	4.8 (1.5)	125 (11)	2	200,183	0.20	49.47	2.7
	seapen	6.1	150	1	25,188	0.06	81.07	2.9
2007	hatchery	4.9 (0.9)	136 (8)	2	200,290	0.13	59.11	2.9
	seapen	9.0 (2.4)	161 (13)	3	87,479	0.13	64.39	3.3
2008	hatchery	6.7 (0.8)	132 (18)	4	408,849	0.26	62.11	2.8
	seapen	12.3 (3.6)	170 (19)	2	50,677	0.24	67.56	3.1
2009	hatchery	5.4 (0.2)	133 (8)	2	666,580	0.33	50.67	3.3
	seapen	10.0 (3.1)	159 (13)	2	50,398	0.30	69.16	3.3

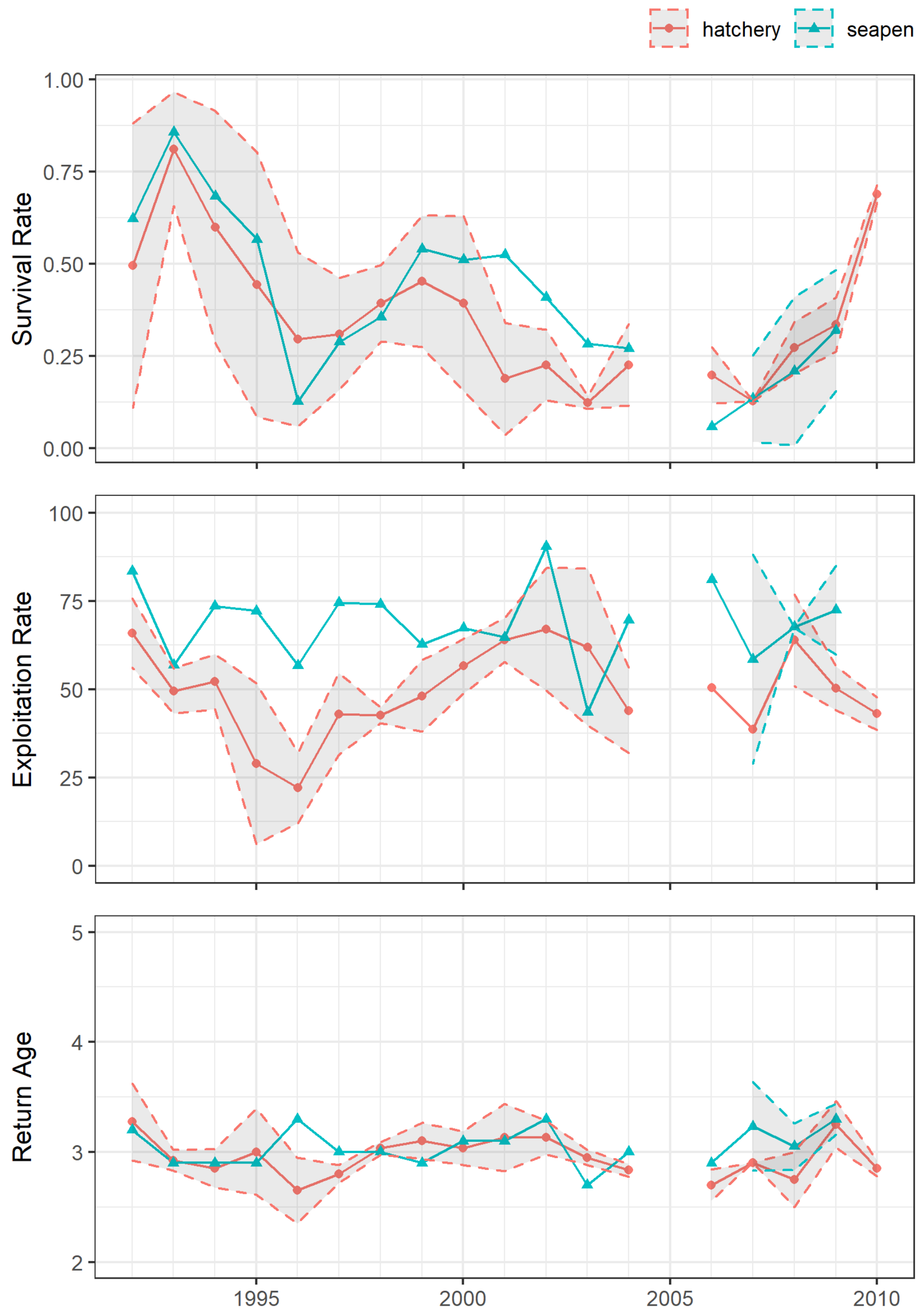

Figure 72: Survival rates (%), exploitation rates (%), and return ages for Cowichan River Chinook released directly into Cowichan River (red circles) or from seapens in the Cowichan estuary (blue triangles). Shaded areas around the mean represent one standard deviation.

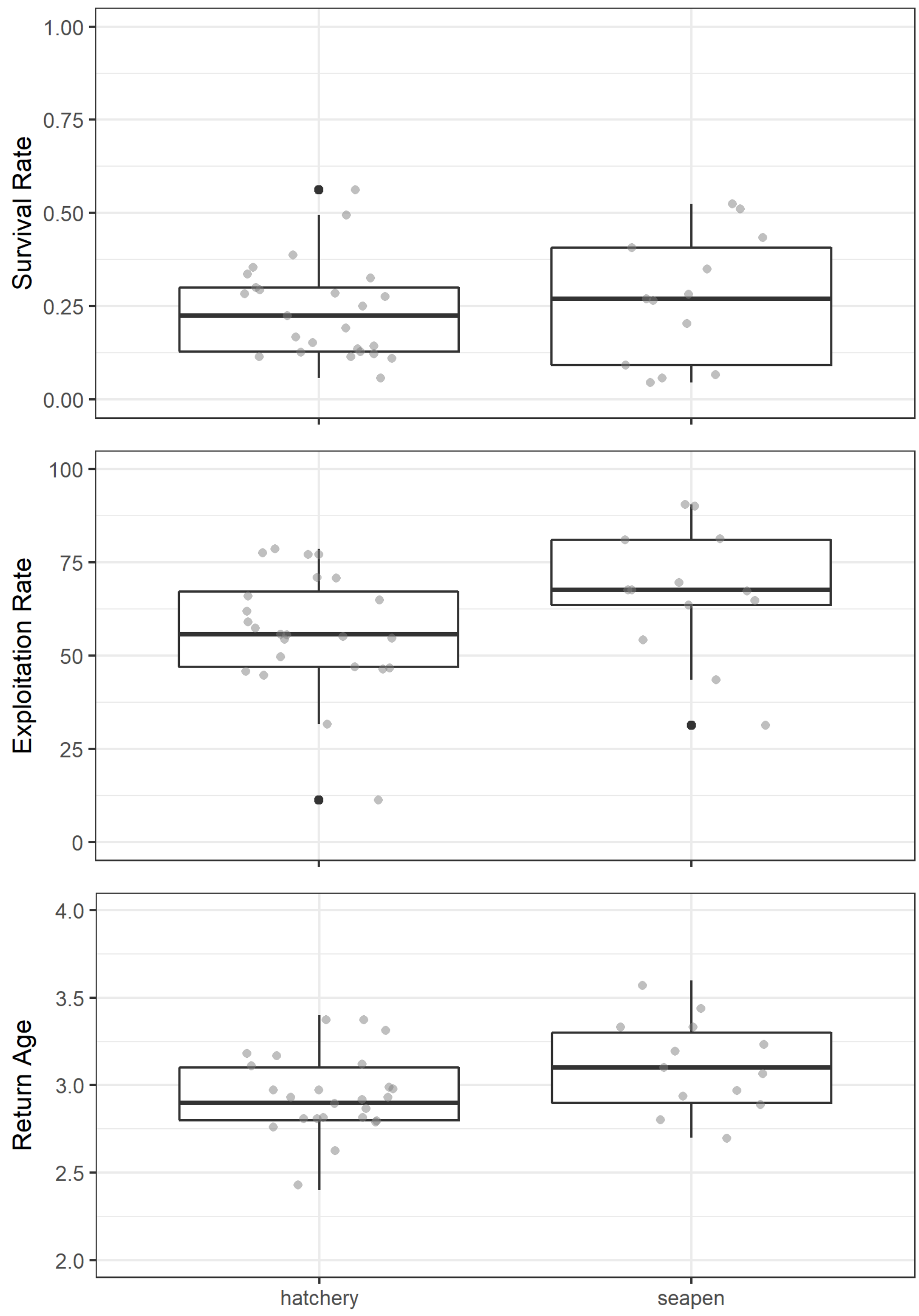

Figure 73: Survival rates (%), exploitation rates (%), and return ages for Cowichan River Chinook salmon released either into Cowichan River or from seapens from 2000-2009. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Black dots represent outliers while the grey dots show the data for all release groups.

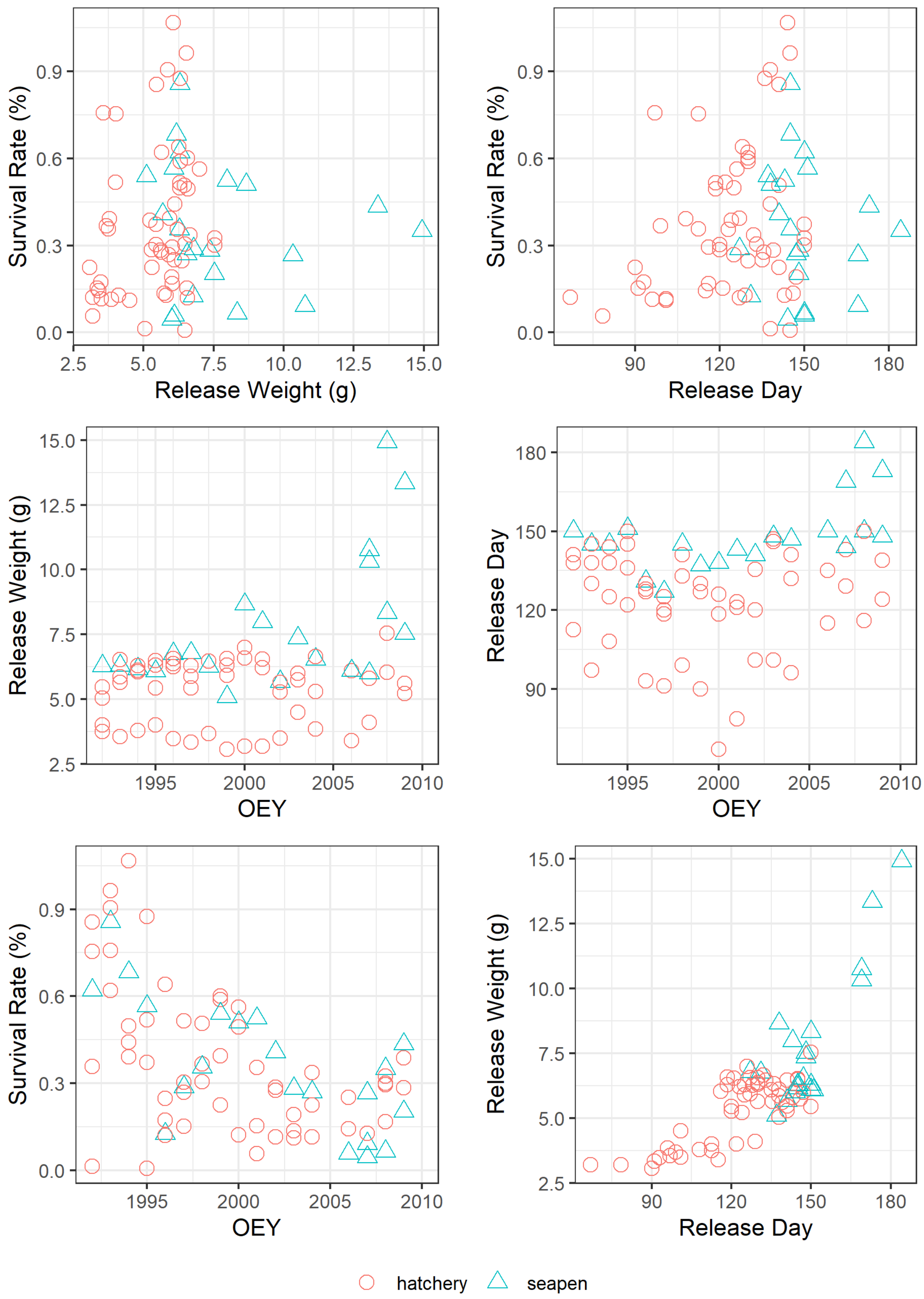

Figure 74: Data distributions of Cowichan River Chinook released directly from the hatchery into the Cowichan River (red circles), or from seapens in the Cowichan estuary (blue triangles) from 1992 to 2009.

22. Puntledge River Summer Chinook

Puntledge River Hatchery produces summer run Chinook salmon for conservation and assessment objectives. Survival rates of Puntledge River summer Chinook decreased in the 1980s from 0.88% in 1981 to 0.07% in 1988 (Figure 75). The mean survival rate of hatchery subyearling summer Chinook releases between 2005 and 2015 was 0.26% (SD ± 0.11%). In an effort to increase survival rates, a subset of summer Chinook releases were transferred to seapens in the Courtenay estuary each year for two to four weeks prior to release since the late 1980s. However, seal predation and warming estuary temperatures became problematic for the seapens, and with little improvements seen for the cost invested in them, seapen releases were discontinued in 2010. Data from 2000 to 2010 are presented below.

Survival rates from seapen releases were slightly higher than for those from the hatchery (mean of 0.37% versus 0.24%), however the difference was not significant (Welch's t-test; p = 0.079;

Table 35; Figure 76-Figure 77). There was also no difference in the mean exploitation rates or return ages of the two release types (t-test; p = 0.12 and Wilcoxon rank sum test; W = 75, p = 0.66, n = 26).

We examined several release covariates (release weight, release day, ocean entry year, and seapen or hatchery release) to determine which were best associated with the smolt-to-adult survival rates during the period of seapen releases from 2000-2010. Quadratic terms for weight and day of release were also added to account for non-linear responses. Given the annual variability in survival rates (Figure 76), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each treatment group in Figure 78.

The top model was an intercept-only model, suggesting that the release strategies for size/time of release and seapen acclimation had little influence on survival (Table 36). The intra-class correlation estimate was relatively low, with 26% of the total variation in the survival response explained by the random year effect (Figure 79). Residuals and normal quantile-quantile plots for the top model are provided in Figure 80. One of the 2000 seapen releases was identified as an outlier, with higher survival rates than any of the other release groups that year. There may be parameters other than those included in our model driving this unusually high survival of one of the two seapen releases in both 2000 and 2003.

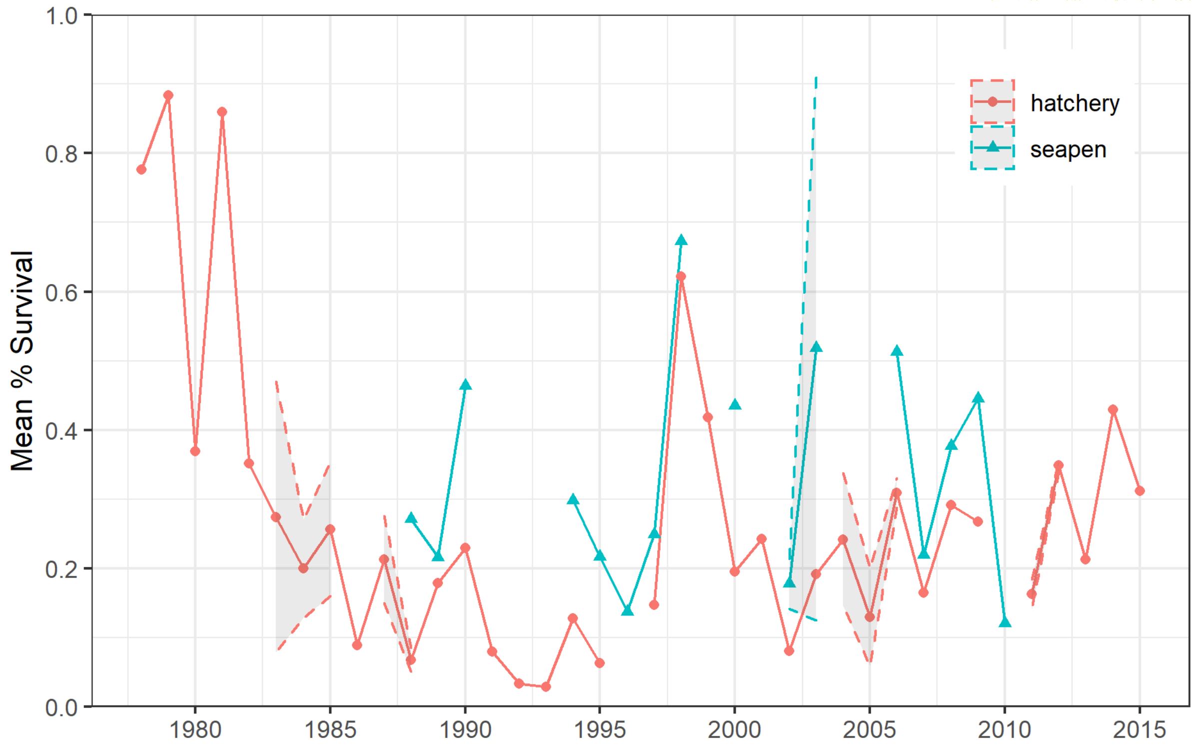

Figure 75: Mean percent survival of Puntledge River summer Chinook subyearling smolts released both from the hatchery (red circles) and from seapens in the estuary (blue triangles). Dashed lines around the mean and shaded grey represent the standard deviation.

Table 35: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Puntledge River summer Chinook released into the Puntledge River or from seapens in the Courtenay estuary. Where greater than one group was released, standard deviation is given in parentheses.

OEY	RELEASE TYPE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2000	hatchery	7.4 (0.5)	154 (0)	2	59,141	0.19	14.39	3.2
	seapen	10.0 (0.6)	158 (7)	2	63,307	0.47	36.54	3.2
2002	hatchery	7.1	148	1	122,158	0.16	43.18	3.3
	seapen	7.2 (0.4)	158 (5)	2	59,358	0.18	47.58	3.6
2003	hatchery	6.9 (0.4)	148 (0)	2	60,400	0.40	23.62	3.1
	seapen	10.6 (2.9)	158 (3)	2	60,296	0.52	39.65	3.1
2006	hatchery	8.9 (1.6)	164 (1)	2	119,261	0.31	16.40	3.0
	seapen	7.8 (0.3)	159 (0)	2	66,024	0.51	15.11	3.0
2007	hatchery	5.3	154	1	89,830	0.17	29.22	3.2
	seapen	7.1	161	1	89,397	0.22	26.20	3.4
2008	hatchery	4.0	182	1	117,057	0.29	25.22	3.0
	seapen	6.2	154	1	60,029	0.38	18.81	2.9
2009	hatchery	3.6 (0.1)	147 (2)	3	127,513	0.27	33.27	3.2
	seapen	6.0	174	1	49,258	0.45	29.16	3.1
2010	hatchery	-	148 (0)	2	87,853	0.09	26.23	3.0
	seapen	6.5	158	1	88,560	0.12	31.46	3.1

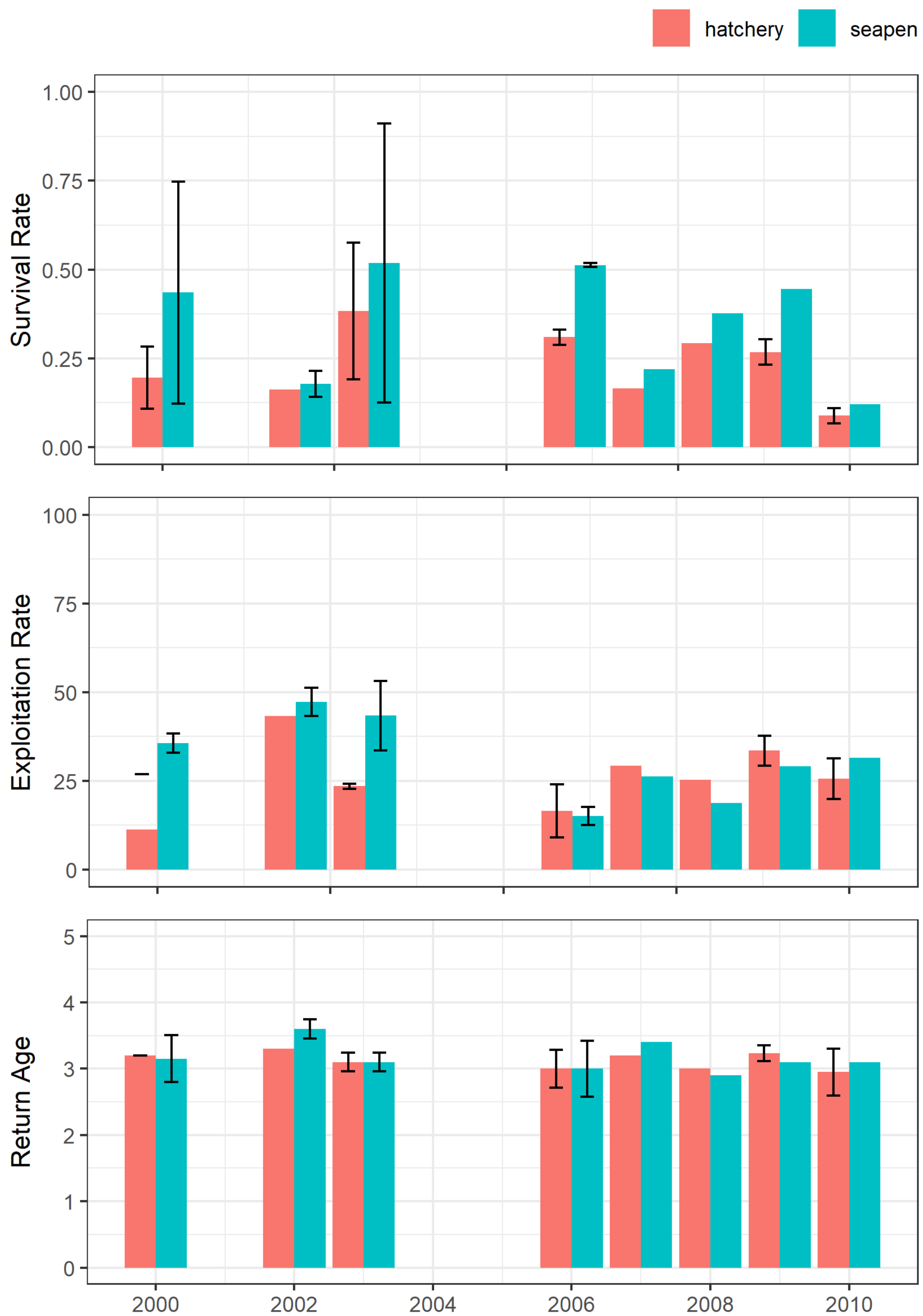

Figure 76: Mean survival rates (%), exploitation rates (%), and return ages for Puntledge River summer Chinook released from Puntledge River Hatchery (red) or from seapens in the Courtenay estuary (blue). Error bars represent one standard deviation.

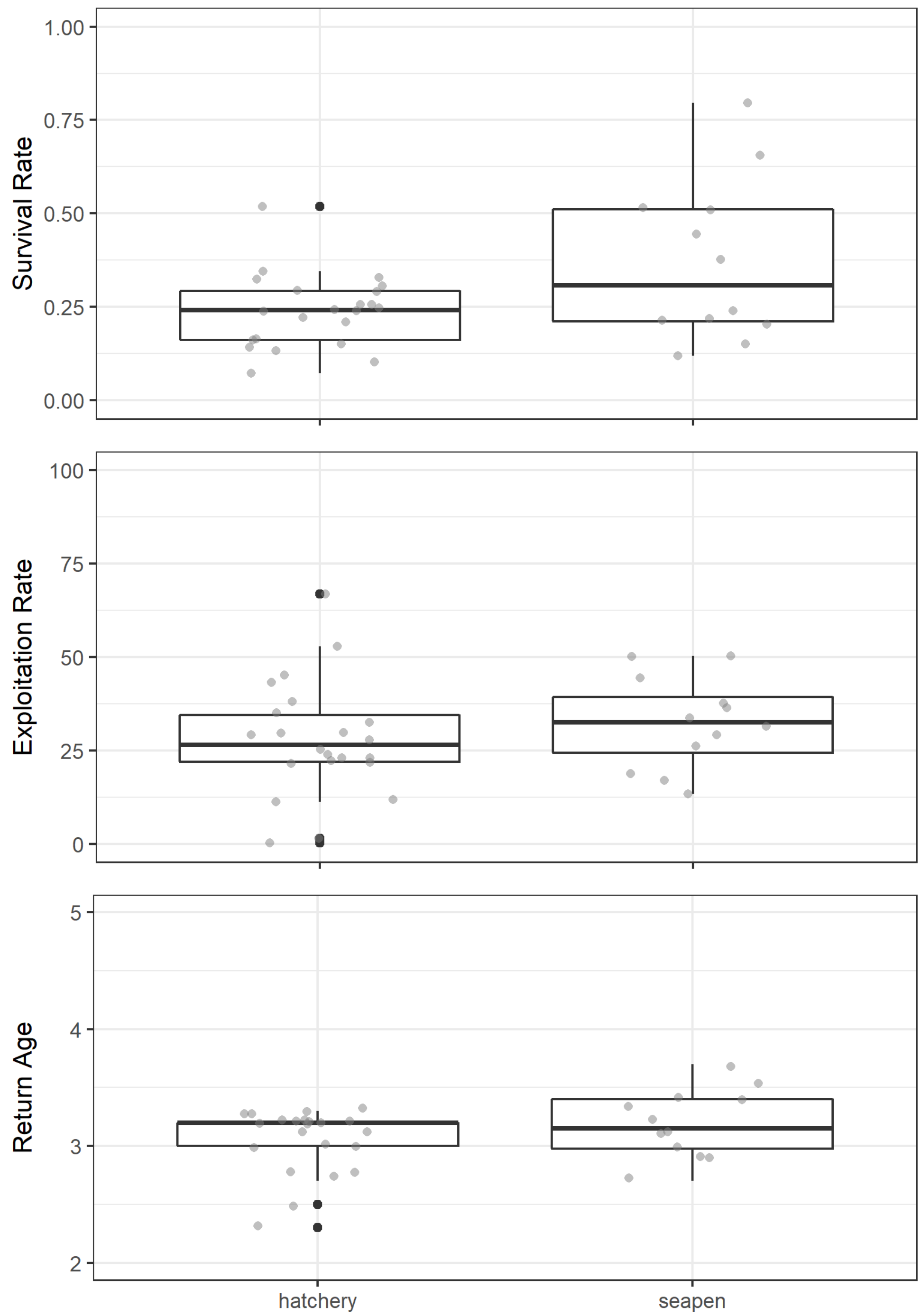

Figure 77: Survival rates (%), exploitation rates (%), and return ages for Puntledge River summer Chinook salmon released either from the Puntledge River Hatchery or from seapens in the Courtenay estuary from 2000-2010. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Black dots represent outliers while the grey dots show the data for all release groups.

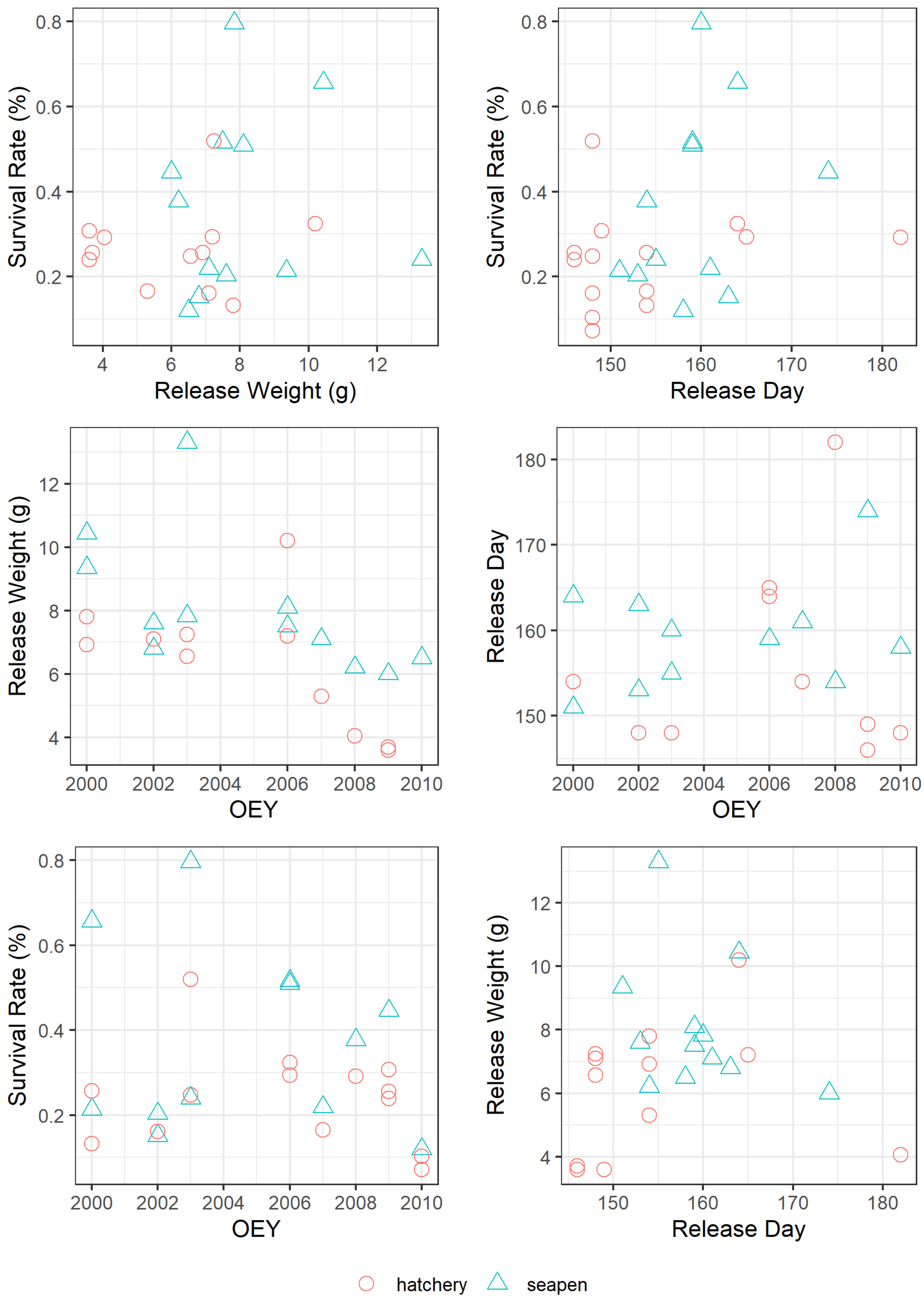

Figure 78: Data distributions of Puntledge River Chinook released either from the hatchery (red circles) or from seapens in the Courtenay estuary (blue triangles) from 2000 to 2010.

Table 36: Top three models showing fixed effects for predicting survival rates of Puntledge River summer Chinook salmon released from the hatchery and from seapens. The best model is bolded. ICC represents the intra-class correlation which describes the proportion of the variation in the model attributed to the random year effect.

INTERCEPT	SIZE	SIZE2	DAY	DAY2	OEY	RELEASE TYPE	DF	LOGLIK	DELTA	ICC
-6.095	-	-	-	-	-	+	4	-15.35	0	0.44
-5.903	**-**	**-**	**-**	**-**	**-**	**-**	**3**	**-16.81**	**0.02**	**0.26**
-6.126	0.032	-	-	-	-	-	4	-16.59	2.48	0.25

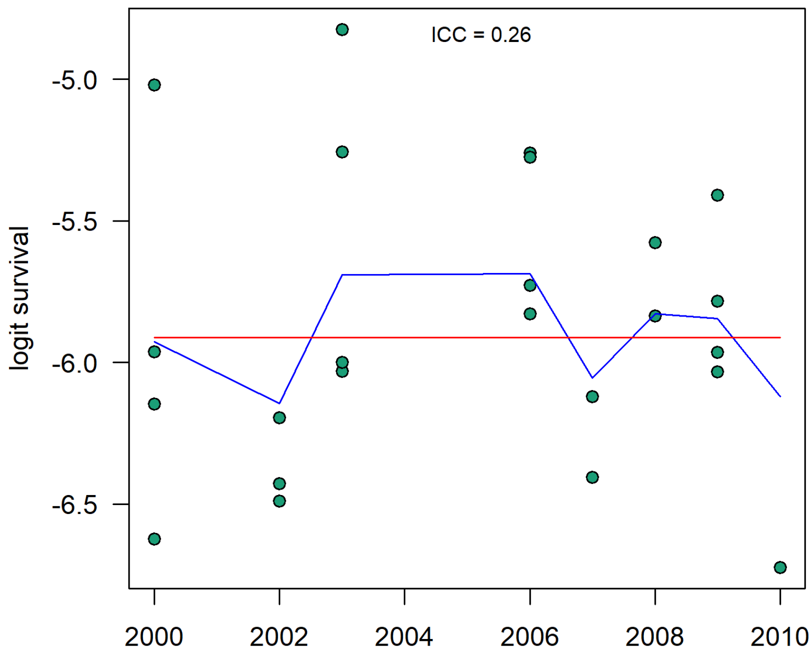

Figure 79: Estimated mean Puntledge River summer Chinook logit survival for different ocean entry years accounting for both the linear trend over time and deviations due to random year effects during the period of seapen releases. The red line indicates the estimated mean survival without random year effects (an intercept-only model with no release strategy effects) while the blue line represents both fixed and random effects.

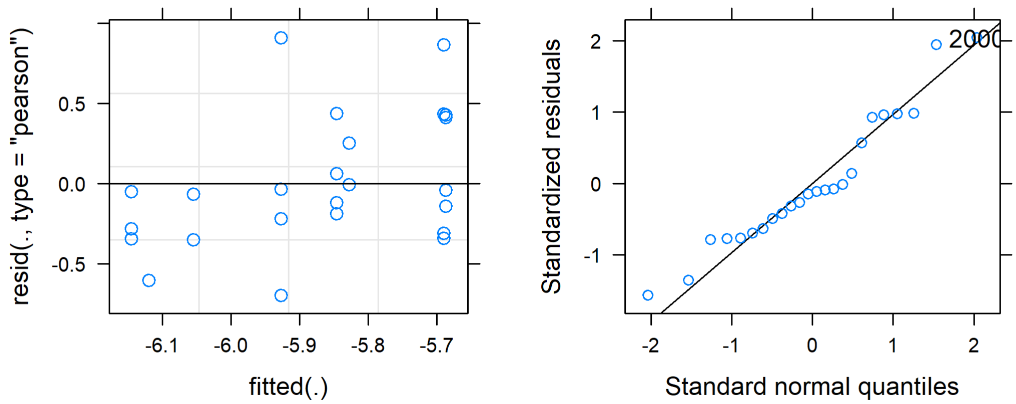

Figure 80: Residuals and quantile plot for the best Puntledge River summer Chinook survival model during the period of seapen releases.

23. Quinsam River Fall Chinook

Quinsam River fall Chinook are produced for harvest and assessment purposes (see Section 5). Since the late 1980s, smolts have been released both from the hatchery directly into Quinsam River and from seapens at various locations in Discovery Passage (Figure 81). The primary objective of the seapen releases is to produce fish for local harvest. Currently, approximately 1,900,000 fall Chinook are released as subyearling smolts from the hatchery, while 600,000 are first transferred to seapens for one to three weeks prior to release.

Between 2000 and 2015, there has been no significant difference in the mean survival rates of hatchery and seapen releases (Wilcoxon rank sum test; W = 3890, p = 0.49, n = 182) (

Table 37; Figure 82-Figure 83). However, seapen releases have been effective at producing more fish for harvest, with significantly higher mean exploitation rates (53.5% versus 35.6%) (Welch's t-test; p = <0.001). Seapen releases are also returning at significantly lower ages than the hatchery releases (3.8 versus 4 years old) (Wilcoxon rank sum test; W = 5305, $p <$ 0.001, n = 182).

We examined several release covariates (release weight, release day, ocean entry year, and seapen or hatchery release) to determine which were best associated with the smolt-to-adult survival rates during the period of seapen releases from 2000-2015. Quadratic terms for weight and day of release were also added to account for non-linear responses. Given the annual variability in survival rates (Figure 82), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each treatment group in Figure 84 (note that the two outliers released either prior to April 10 or after May 30, 2015 were not included in the model dataset).

The top model contained size at release with a quadratic size effect, as well as day at release, suggesting that increased size at release could increase survival up to a point, and that later releases were related to higher survival rates (Table 38; Figure 85). Thus, the weight and date of release have been stronger predictors of survival than the location of release (i.e. hatchery or seapen). The intra-class correlation estimated that 62% of the total variation in the survival response could be explained by the random year effect, and that the model with the random year effect was much better at predicting survival rates than one based solely on fixed effects (Figure 86). Residuals and normal quantile-quantile plots for the top model are provided in Figure 87. The residuals are heteroscedastic, suggesting that there may be some explanatory power missing from the model that is being captured by the random error term (e.g. environmental conditions). The few years of higher seapen survival appear to be outliers relative to the rest of the dataset.

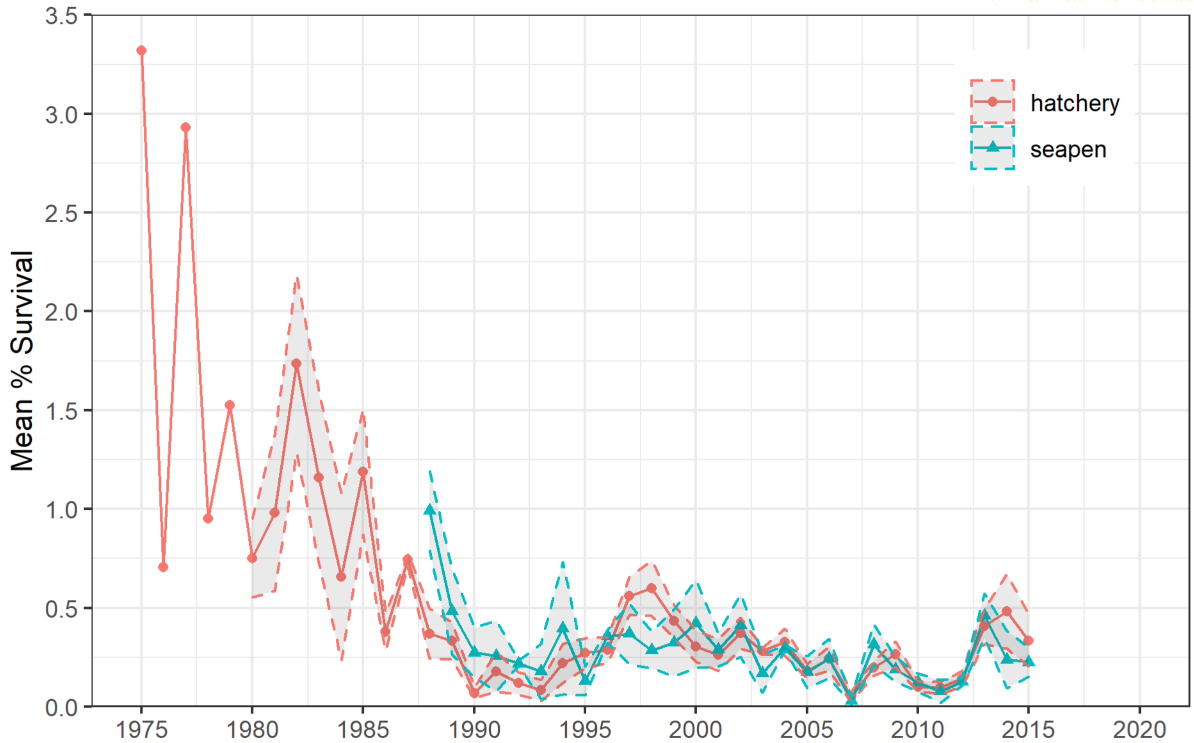

Figure 81: Mean percent survival of Quinsam River Chinook subyearling smolts released both from the hatchery (red circles) and from seapens in Discovery Passage (blue triangles). Dashed lines around the mean and shaded grey represent the standard deviation.

Table 37: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Quinsam River Chinook released either from Quinsam River Hatchery or from seapens in Discovery Passage. Standard deviations are given in parentheses. Preliminary data for incomplete return years shown in green.

OEY	RELEASE TYPE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2000	hatchery	7.6 (0.8)	136 (2)	6	167,749	0.31	38.03	4.2
	seapen	8.1 (0.8)	130 (7)	4	104,648	0.44	59.91	4.1
2001	hatchery	7.2 (1.8)	131 (6)	9	258,979	0.26	43.33	4.2
	seapen	9.4 (0.9)	129 (4)	3	88,355	0.29	53.11	4.1
2002	hatchery	7.2 (1.7)	130 (5)	8	251,227	0.38	37.96	4.2
	seapen	8.7 (0.9)	123 (4)	4	113,499	0.42	58.42	4.0
2003	hatchery	7.8 (0.2)	132 (4)	7	210,446	0.28	42.19	4.0
	seapen	8.0 (0.9)	128 (6)	4	110,723	0.18	49.27	3.6
2004	hatchery	6.9 (0.5)	129 (4)	7	195,579	0.33	35.84	3.9
	seapen	8.0 (1.0)	126 (2)	4	113,204	0.30	49.03	3.9
2005	hatchery	5.2 (0.2)	134 (4)	7	209,757	0.18	24.05	4.0
	seapen	8.7 (1.2)	126 (5)	5	108,597	0.20	52.28	3.7
2006	hatchery	5.1 (0.4)	129 (4)	7	181,128	0.25	43.46	4.1
	seapen	7.1 (0.8)	120 (4)	4	108,809	0.25	51.69	3.7
2007	hatchery	4.7 (0.7)	134 (3)	8	228,141	0.05	39.99	4.0
	seapen	6.7 (0.9)	119 (3)	4	117,282	0.03	56.88	3.9
2008	hatchery	5.8 (0.3)	131 (4)	8	531,550	0.20	38.34	4.0
	seapen	7.4 (0.5)	121 (2)	4	113,670	0.31	62.49	3.5
2009	hatchery	5.3 (0.2)	130 (4)	8	237,193	0.27	39.54	4.1
	seapen	6.8 (1.2)	123 (2)	4	118,009	0.18	50.48	3.8
2010	hatchery	5.6 (0.2)	129 (3)	8	537,575	0.10	27.86	4.0
	seapen	7.0 (1.1)	123 (1)	3	87,022	0.13	50.90	3.7
2011	hatchery	5.3 (0.2)	128 (4)	8	519,474	0.10	23.42	3.9
	seapen	6.6 (0.5)	122 (2)	3	86,314	0.09	49.44	3.9
2012	hatchery	5.2 (0.1)	127 (4)	7	472,371	0.14	37.37	4.0
	seapen	6.5 (1.0)	116 (5)	3	73,265	0.12	52.61	3.6
2013	hatchery	5.6 (0.4)	129 (2)	8	533,160	0.41	43.66	4.0
	seapen	7.7 (0.1)	123 (1)	4	91,139	0.46	73.58	3.6
2014	hatchery	6.0 (0.4)	130 (4)	9	510,743	0.51	41.21	3.9
	seapen	7.9 (0.8)	127 (1)	4	89,675	0.25	57.27	3.9
2015	hatchery	6.9 (1.7)	132 (20)	7	554,975	0.35	43.52	3.6
	seapen	8.8 (1.1)	124 (2)	3	58,994	0.23	58.11	3.5
2016	hatchery	7.0 (2.8)	138 (18)	8	599,967	0.25	65.06	3.4
	seapen	8.2 (0.8)	125 (6)	4	77,658	0.40	79.40	3.4
2017	hatchery	7.2 (2.4)	132 (17)	9	598,364	0.05	82.37	2.7
	seapen	7.7 (1.1)	121 (3)	3	39,581	0.07	91.44	2.7
2018	hatchery	5.4 (1.1)	128 (1)	2	97,492	0.02	100	2.0
	seapen	7.4 (0.9)	117 (4)	3	60,508	-	-	-

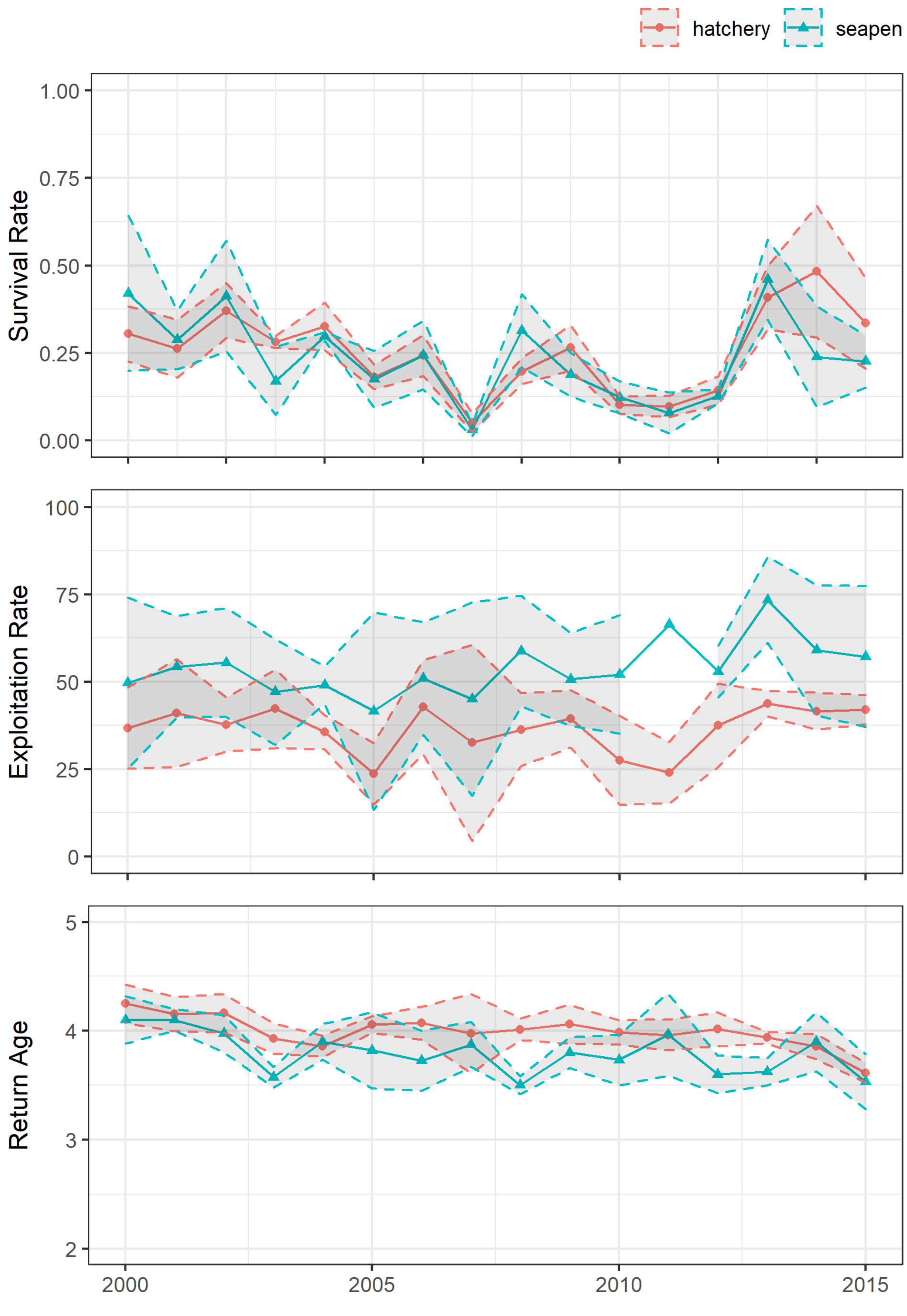

Figure 82: Survival rates, exploitation rates, and return ages for Quinsam River Chinook released either from Quinsam River Hatchery (red circles) or from seapens in Discovery Passage (blue triangles). Shaded areas around the mean represent one standard deviation.

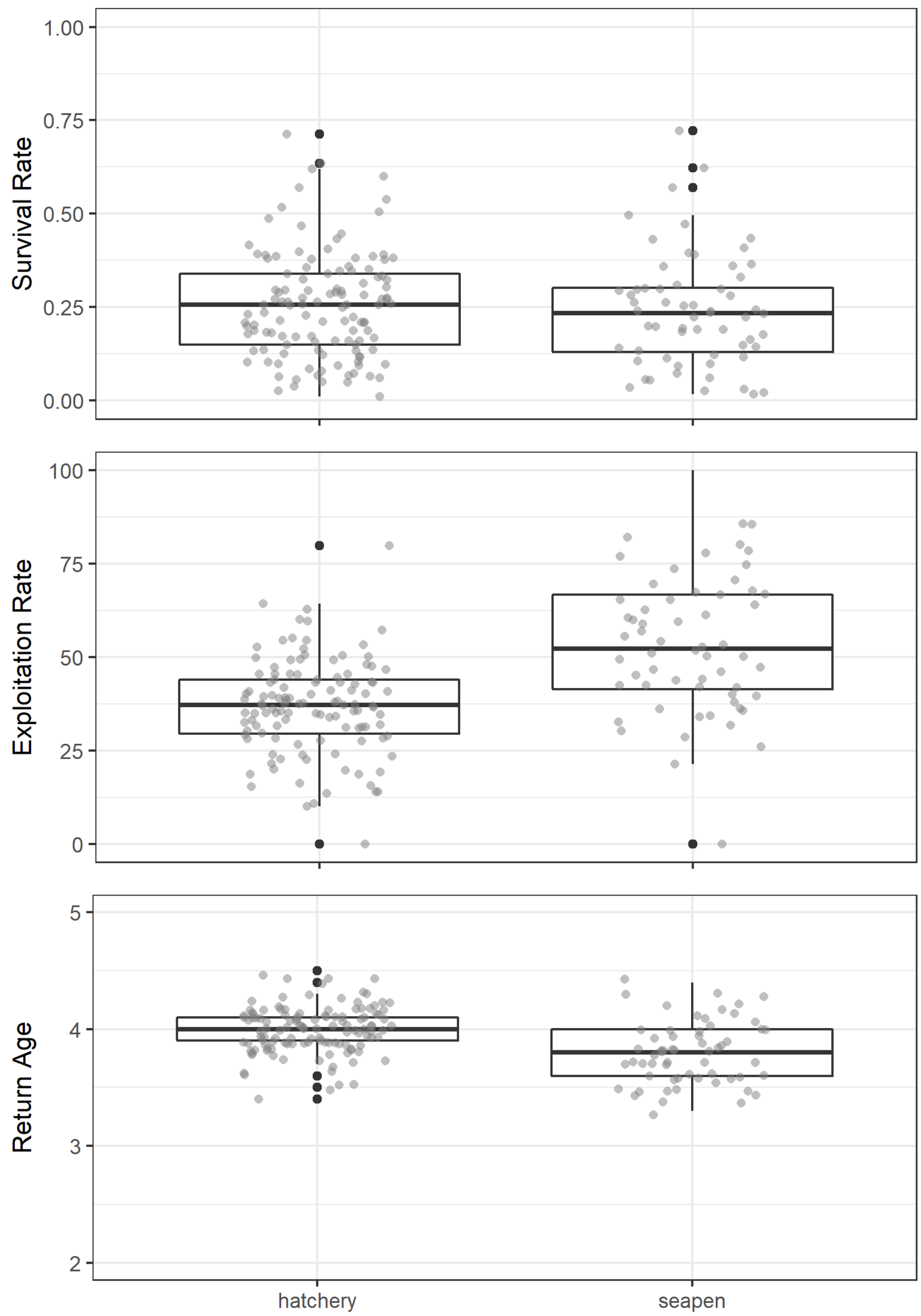

Figure 83: Survival rates (%), exploitation rates (%), and return ages for Quinsam River Chinook salmon released either from the Quinsam River Hatchery or from seapens in Discovery Passage from 2000-2015. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Black dots represent outliers while the grey dots show the data for all release groups.

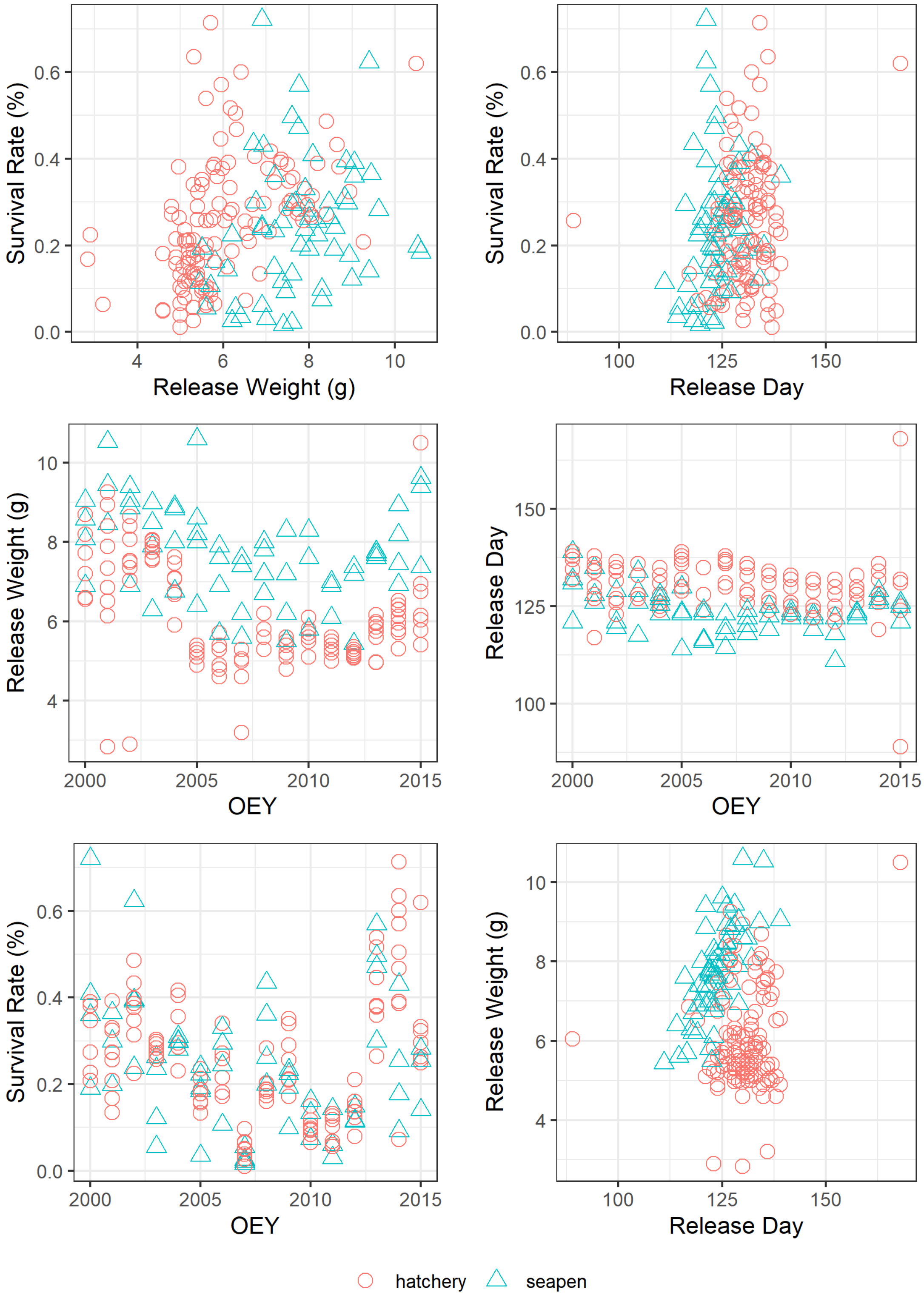

Figure 84: Data distributions of Quinsam River Chinook released either from the hatchery into the Quinsam River (red circles), or from seapens in Discovery Passage (blue triangles) from 2000 to 2015.

Table 38: Top models (delta < 2) showing fixed effects for predicting survival rates of Quinsam River Chinook salmon released from the hatchery and from seapens between 2000-2015. The best model is bolded. ICC represents the intra-class correlation which describes the portion of the variation in the model attributed to the random year effect.

INTERCEPT	SIZE	SIZE2	DAY	DAY2	OEY	RELEASE TYPE	DF	LOGLIK	DELTA	ICC
-3.668	0.027	-0.002	0.002	-	-	+	7	349.38	0	0.59
-3.665	0.027	-0.002	0.002	0	-	+	8	350.36	0.23	0.60
-3.657	0.026	-0.002	0.002	0	-	-	7	349.13	0.49	0.62
-3.659	**0.026**	**-0.002**	**0.002**	**-**	**-**	**-**	**6**	**348.01**	**0.56**	**0.62**

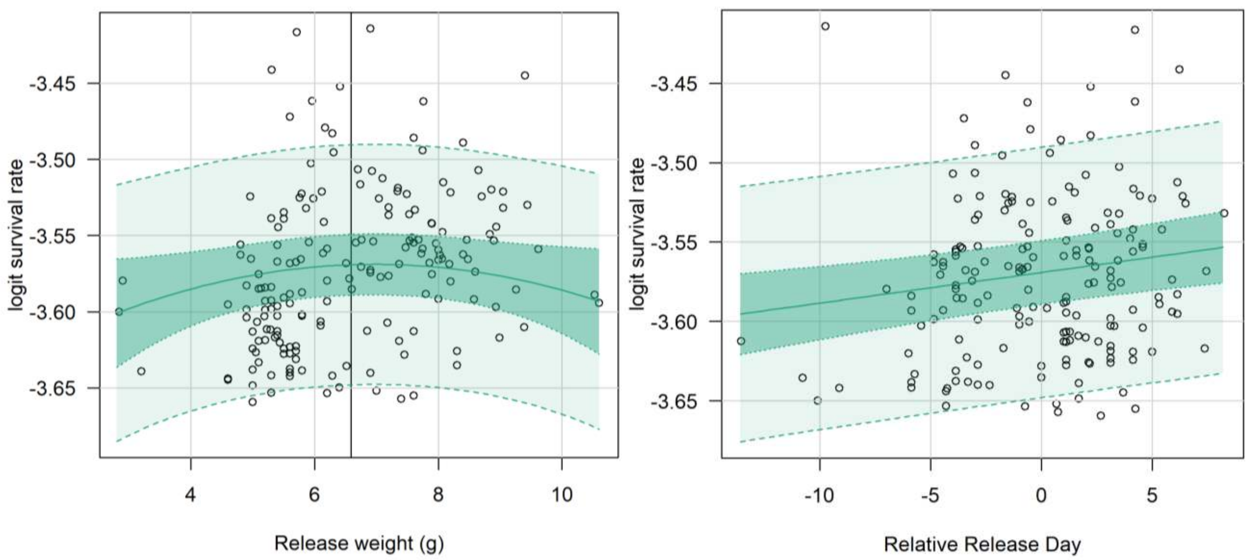

Figure 85: Mean logit survival of Quinsam River Chinook subyearling releases from both the hatchery and seapens. The 95% CIs (darker = fixed effects, lighter = random effects) are shown for the model fits to releases of different weights and release days. The vertical solid line indicates the median weight-at-release.

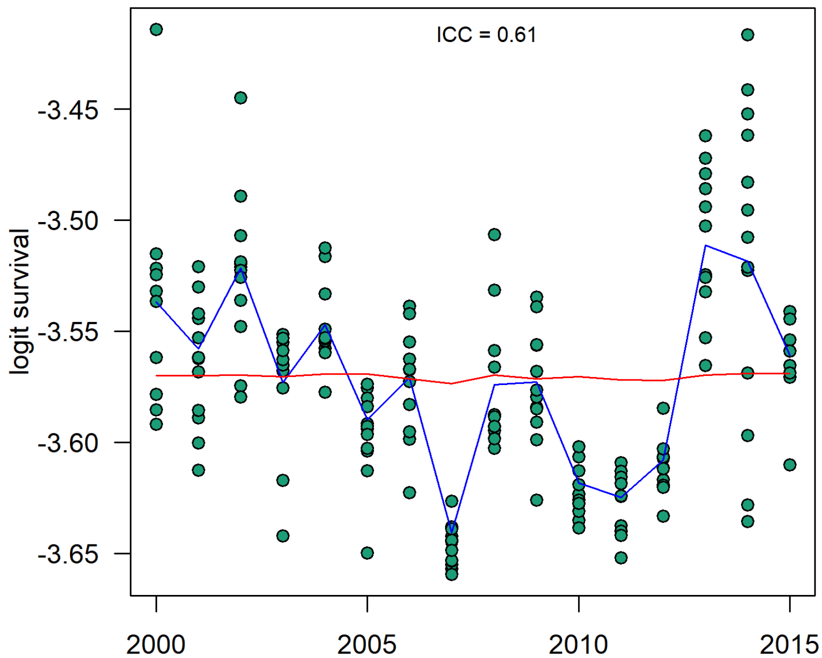

Figure 86: Estimated mean Quinsam River Chinook logit survival for different years accounting for both the linear trend over time and deviations due to random effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

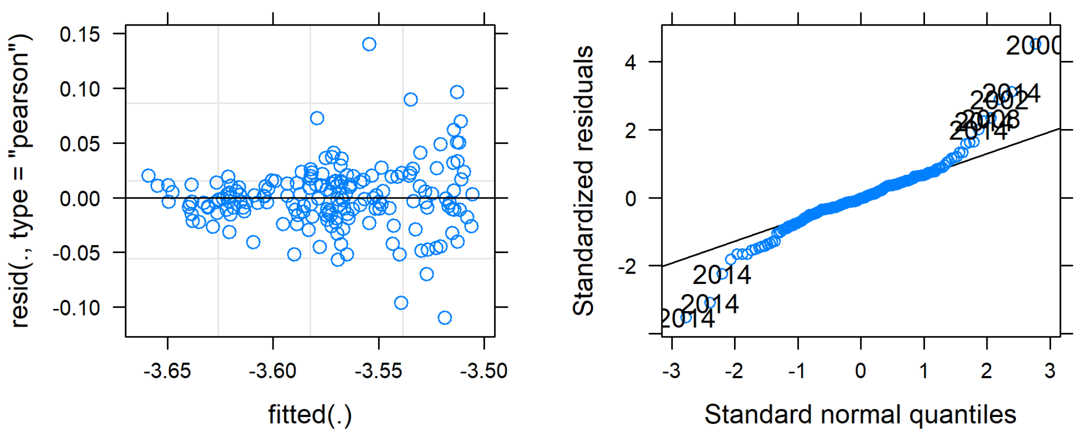

Figure 87: Residuals and quantile plot for the best Quinsam River Chinook survival model during the period of seapen releases (2000-2015).

24. Robertson Creek Fall Chinook

Robertson Creek Hatchery produces fall Chinook salmon for both assessment and harvest purposes. Currently, 6.1 million subyearling smolts are released from the hatchery each year, with an additional 300,000 transferred to seapens in Alberni Inlet for two to three weeks prior to release. The objective of these seapen releases has been to avoid poor freshwater conditions (i.e. predation and high river temperatures) and reduce competition with wild populations in the estuary. Survival rates had also dropped through the 1990s into the 2000s (Figure 88) and there was growing pressure to find alternative release strategies that could improve returns. The location of the seapens has changed over time. In the early 2000s they were located at the Harbour Quay in Port Alberni and from 2014 onwards they have moved further down Alberni Inlet to Underwood Cove.

While survival rates of the seapen releases have been higher in four of the five years with complete return data, there was no significant difference in the overall mean survival rates between seapen and hatchery releases (Wilcoxon rank sum test; $W = 37$, $p = 0.066$, $n = 36$) (Table 39; Figure 89-Figure 90). However, mean exploitation rates have been significantly higher for seapen releases than for hatchery releases (73.9% versus 64.7%) (t-test; $p = 0.011$). Mean return ages of the two release types were the same at 3.7 years old.

We examined several release covariates (release weight, release day, ocean entry year, and seapen or hatchery release) to determine which were best associated with the smolt-to-adult survival rates during the period of seapen releases from 2002-2004 and 2014-2015. Quadratic terms for weight and day of release were also added to account for non-linear responses. Given the annual variability in survival rates (Figure 89), ocean entry year was added as a random effect. The survival rates, weight of release, and day of release for different ocean entry years used for model fitting are shown for each treatment group in Figure 91.

The top model contained only release type suggesting that higher survivals were predicted for seapen releases compared to hatchery releases (Table 40). The intra-class correlation estimate showed that 67% of the total variation in the survival response could be explained by the random year effect (Figure 92). Therefore, release type (i.e. hatchery or seapen) as well as random year effects are important predictors of survival for Robertson Creek Chinook. Residuals and normal quantile-quantile plots for the top model are provided in Figure 93. The lower survival of seapen releases in 2004 appears to be anomalous.

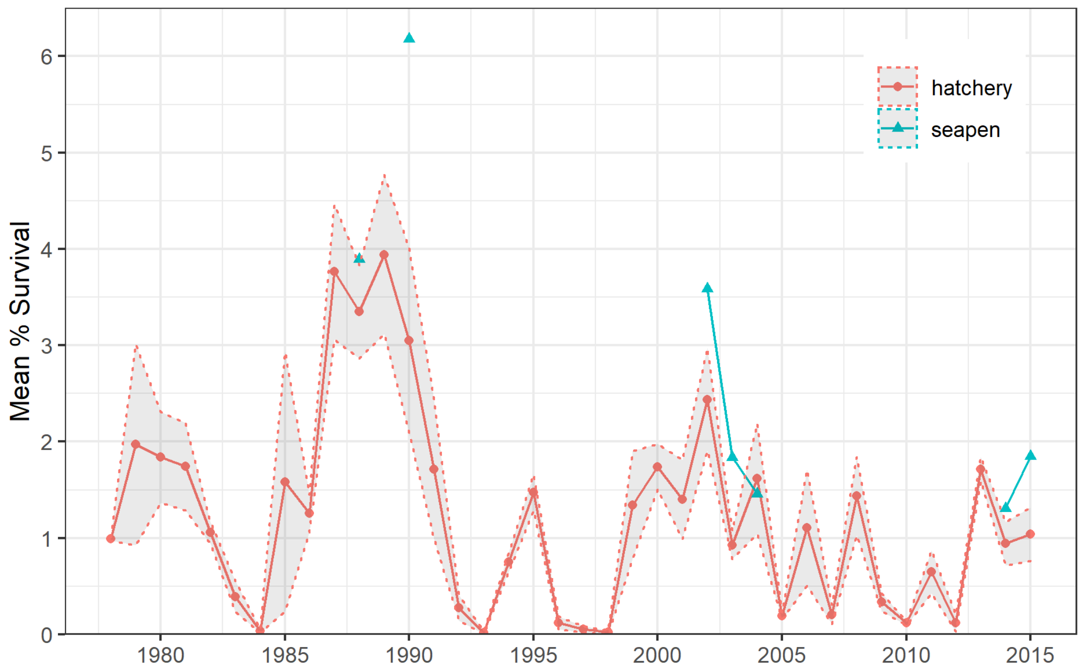

Figure 88: Mean percent survival of Robertson Creek Chinook subyearling smolts released both from Robertson Creek Hatchery (red circles) and from seapens in Alberni Inlet (blue triangles) by ocean entry year. Dashed lines around the mean and shaded grey represent the standard deviation.

Table 39: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Robertson Creek Chinook released either from Robertson Creek Hatchery or from seapens Alberni Inlet. Standard deviations are given in parentheses. Preliminary data for incomplete returns are shown in green.

OEY	RELEASE TYPE	SIZE (G) (SD)	DAY (SD)	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL (%)	EXPLOITATION (%)	AGE (YRS)
2002	hatchery	6.0 (0.5)	152 (1)	6	200,050	2.44	58.40	3.7
	seapen	6.6	145	1	26,327	3.58	79.99	3.8
2003	hatchery	6.3 (0.5)	149 (5)	6	200,014	0.93	68.22	3.9
	seapen	7.2	142	1	15,202	1.84	73.39	3.8
2004	hatchery	5.6 (1.0)	144 (1)	8	203,309	1.65	69.52	3.8
	seapen	5.3	142	1	14,940	1.46	65.88	3.9
2014	hatchery	5.9 (0.2)	143 (6)	5	438,715	0.94	57.82	3.7
	seapen	7.5	148	1	39,174	1.31	78.03	3.7
2015	hatchery	5.3 (0.3)	131 (6)	6	523,588	1.04	64.96	3.4
	seapen	-	129	1	40,230	1.85	71.64	3.4
2016	hatchery	5.0 (0.6)	134 (7)	5	650,944	1.43	73.02	3.2
	seapen	6.3	143	1	40,221	2.48	82.65	3.1
2017	hatchery	4.7 (0.3)	148 (5)	4	550,494	0.22	92.53	2.9
	seapen	-	156	1	41,117	0.41	97.66	2.9
2018	hatchery	6.0 (0.9)	140 (10)	4	186,285	0.01	100	2
	seapen	13.1	148	1	23,272	0.05	100	2

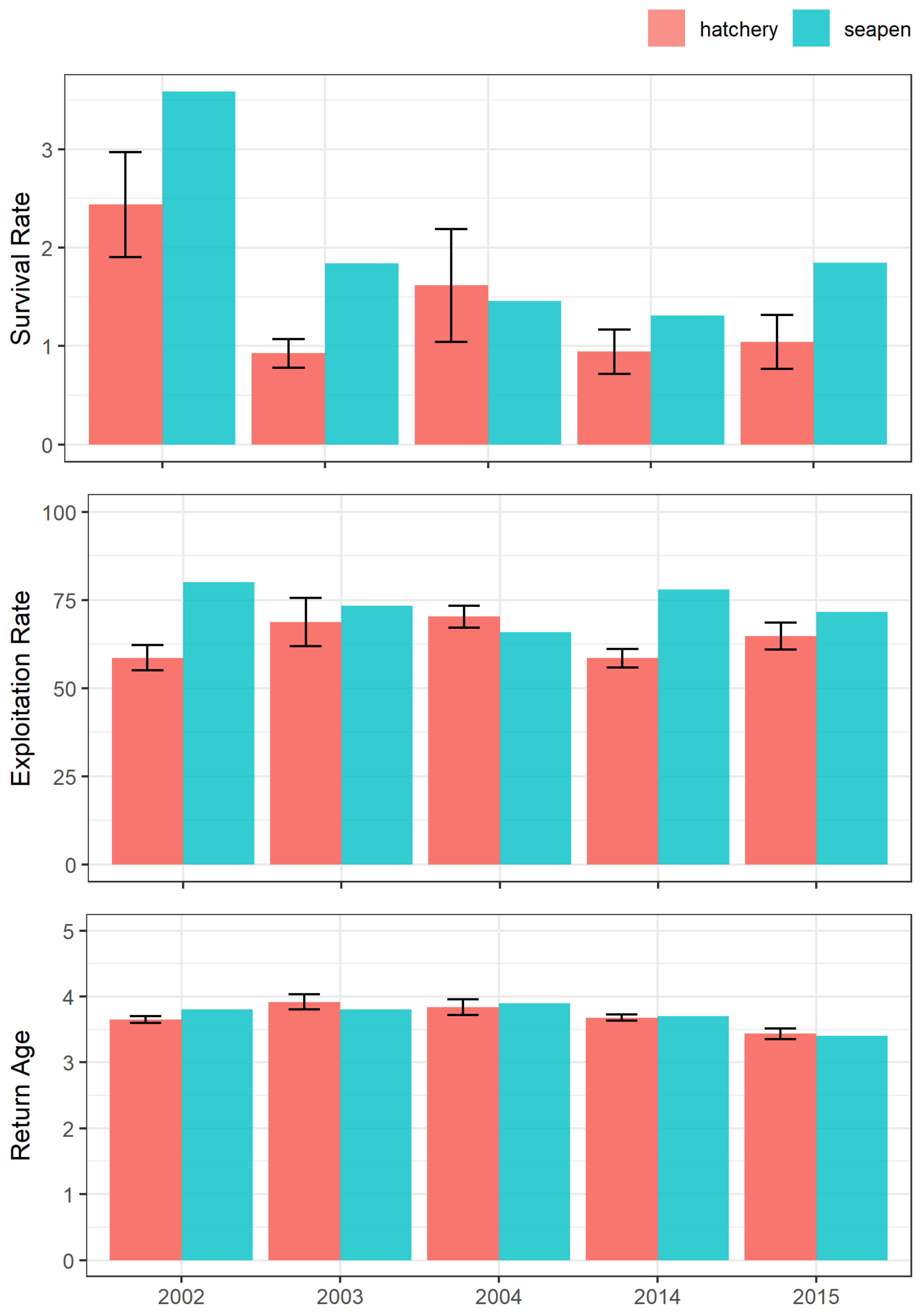

Figure 89: Mean survival rates (%), exploitation rates (%), and return ages for Robertson Creek Chinook salmon released either directly from the hatchery (red) or from seapens (blue) in 2002-2004, and 2014-2015.

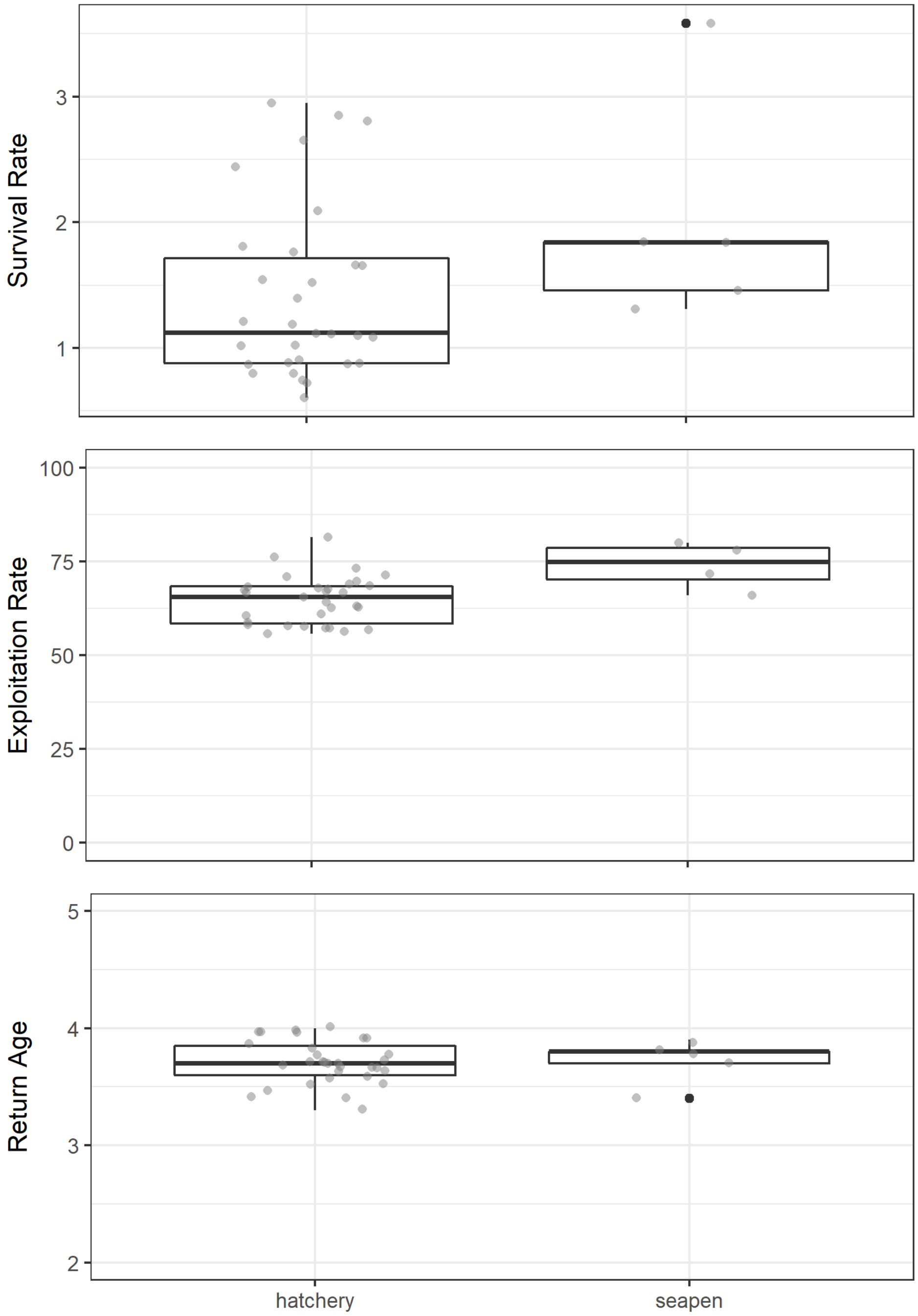

Figure 90: Survival rates (%), exploitation rates (%), and return ages for Robertson Creek Chinook salmon released either from the Robertson Creek Hatchery or from seapens from 2002-2004 and 2014-2015. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Black dots represent outliers while the grey dots show the data for all release groups.

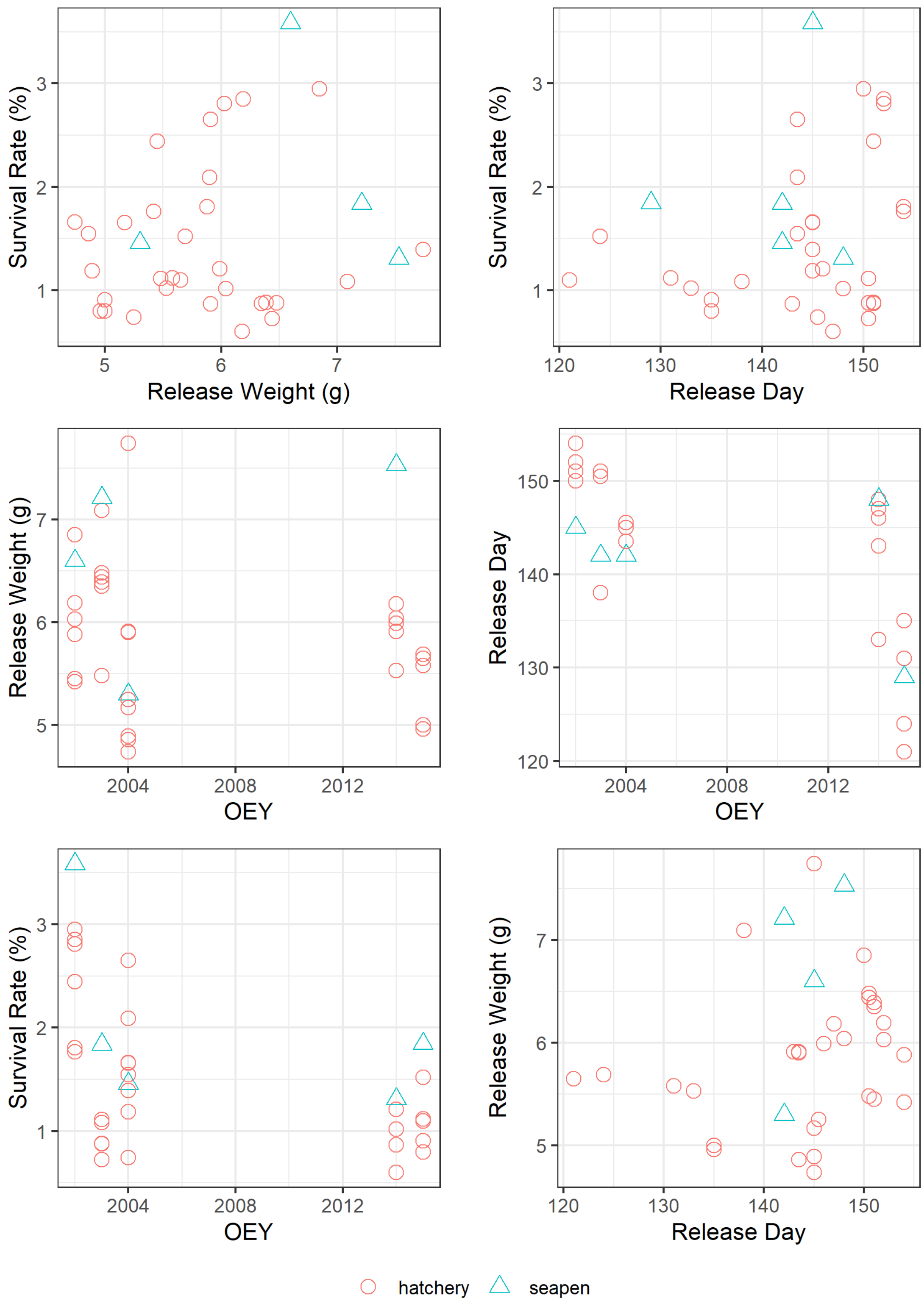

Figure 91: Data distributions of Robertson Creek Chinook released directly from the hatchery (red circles) or from seapens in Alberni Inlet (blue triangles) from 2002 to 2004 and from 2014 to 2015.

Table 40: Top models (delta < 2) showing fixed effects for predicting survival rates of Robertson Creek Chinook salmon released from the hatchery and from seapens between 2002-2004 and 2014-2015. The best model is bolded. ICC represents the intra-class correlation which describes the proportion of the variation in the model attributed to the random year effect.

INTERCEPT	SIZE	SIZE2	TIME	TIME2	OEY	RELEASE TYPE	DF	LOGLIK	DELTA	ICC
-4.36	**-**	**-**	**-**	**-**	**-**	**+**	**4**	**-11.02**	**0**	**0.67**
78.525	-	-	-	-	-0.041	+	5	-9.73	0.17	0.61
-5.002	0.11	-	-	-	-	+	5	-10.01	0.73	0.69
-5.253	0.158	-	-	-	-	-	4	-11.61	1.19	0.68
72.99	0.096	-	-	-	-0.039	+	6	-8.98	1.6	0.66
-8.962	1.403	-0.104	-	-	-	+	6	-9.14	1.92	0.7
72.779	0.144	-	-	-	-0.039	-	5	-10.62	1.94	0.65

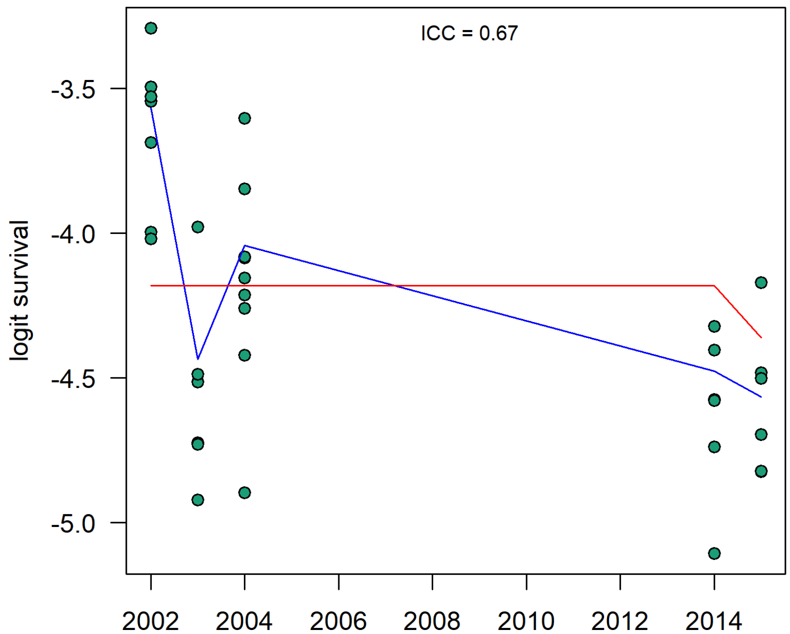

Figure 92: Estimated mean Robertson Creek Chinook logit survival for different years of seapen releases accounting for both the linear trend over time and deviations due to random effects. The red line indicates the estimated mean survival without random year effects while the blue line represents both fixed and random effects.

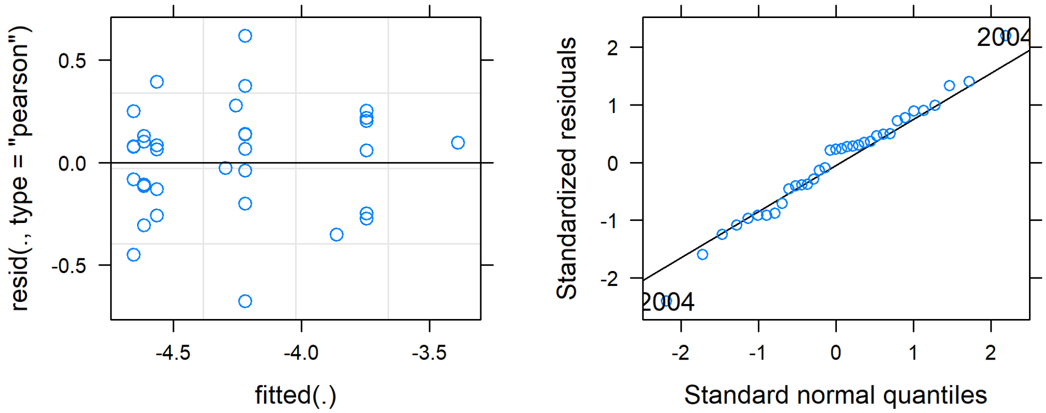

Figure 93: Residuals and quantile plot for the best Robertson Creek Chinook survival model during the period of seapen releases (2002-2004, 2014-2015).

25. Wannock River Chinook

Up until 2017, Wannock River Chinook were reared at Snootli Creek Hatchery near Bella Coola and transported to the Wannock River or to seapens in Rivers Inlet or the Wannock estuary for release. From broodyear 2017 onwards, these fish have been reared at the new Percy Walkus Hatchery located in Owikeno village on the Wannock River. The goal behind salmon enhancement in this system is to promote the sustainability, recovery and rebuilding of priority stocks in Rivers Inlet. In order to maintain the natural life history but reduce competition with wild fish, releases were divided between the river and seapens in the inlet. Since 2000, approximately 30,000 Chinook are released annually into the Wannock River and approximately 200,000 are transferred to seapens for about three weeks (until 5 g in size) prior to release directly into the marine environment. These releases occur between late May and early June to reduce overlap with the wild outmigration.

Data quality flags in the Enhancement Planning and Assessment Database indicate that much of the data for the enhancement of this stock are not suitable for assessing survival or exploitation rates. There is also no comprehensive escapement monitoring, which leave the data to inaccurately suggest 100% exploitation rates of this stock. However, there are four years of releases for which the data allow us to look at differences in survival rates and return ages between river and seapen releases. For the releases made in 2010-2011, and 2014-2015, there was no significant difference between survival rates (t-test; $p = 0.97$) or return ages (t-test; $p = 1$) (Table 41; Figure 94-Figure 95).

Table 41: Release parameters (OEY = ocean entry year, treatment, size (g), day), the number of unique release groups and total CWTs released, mean survival and exploitation rates (%), and mean return ages of Wannock River Chinook released either into the Wannock River or from seapens into the Wannock estuary.

OEY	RELEASE TYPE	SIZE	DAY	RELEASE GROUPS	TOT CWT RELEASES	SURVIVAL	EXPLOITATION	AGE
2010	hatchery	-	167	1	27,327	0.13	NA	4.0
	seapen	-	169	1	25,532	0.27	NA	4.1
2011	hatchery	4.5	159	1	29,260	0.22	NA	4.1
	seapen	5.4	155	1	28,940	0.29	NA	3.8
2014	hatchery	5	164	1	23,248	0.24	NA	3.9
	seapen	5	167	1	28,278	0.06	NA	4.1
2015	hatchery	-	167	1	29,650	0.11	NA	4.4
	seapen	-	167	1	29,156	0.06	NA	4.4
2018	hatchery	5.0	156	1	29,059	-	-	-
	seapen	4.0	146	1	29,092	-	-	-
2019	hatchery	5.2	158	1	29,666	-	-	-
	seapen	5.8	158	1	29,108	-	-	-

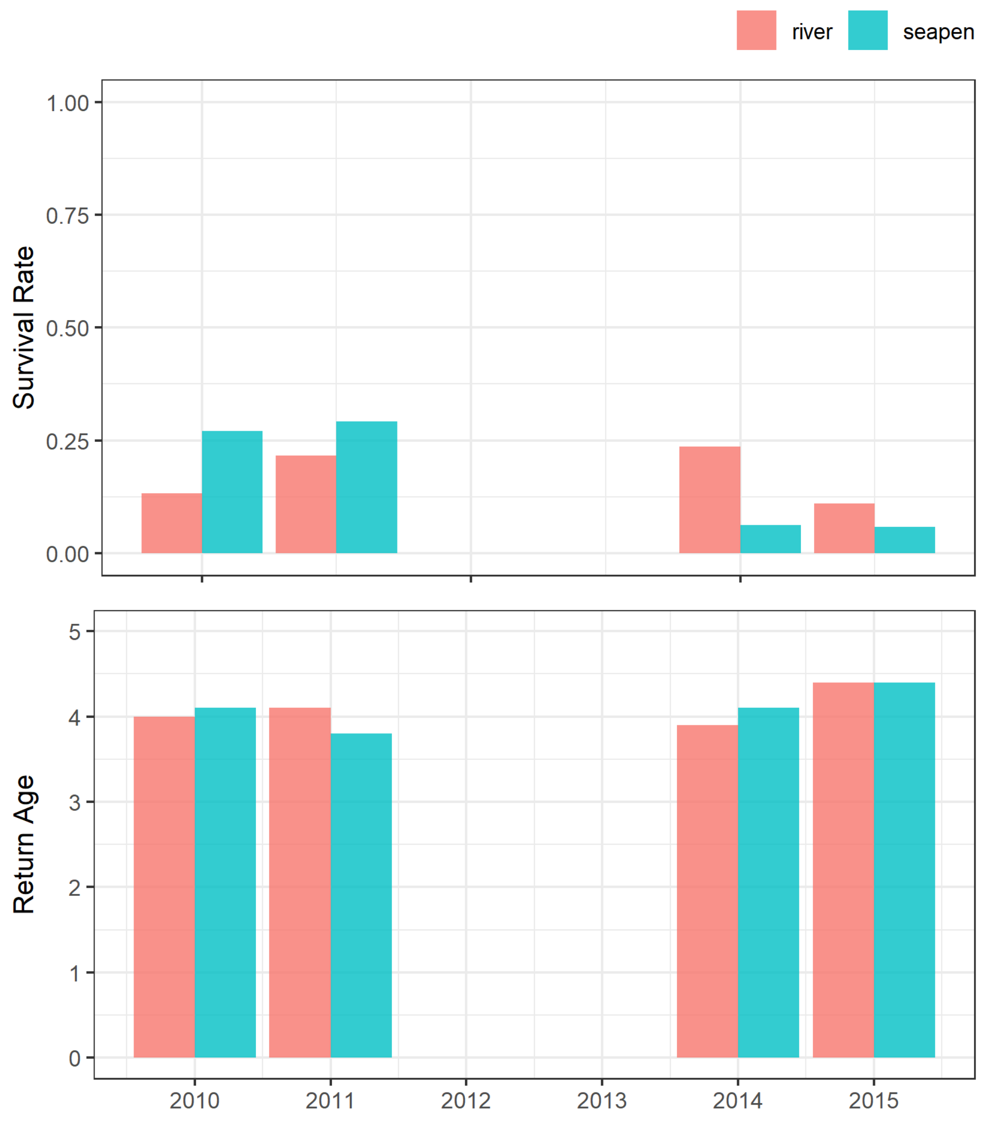

Figure 94: Survival rates (%) and return ages for Wannock River Chinook salmon released either into the Wannock River (red) or from seapens in the Wannock estuary (blue) in 2010-2011, and 2014-2015.

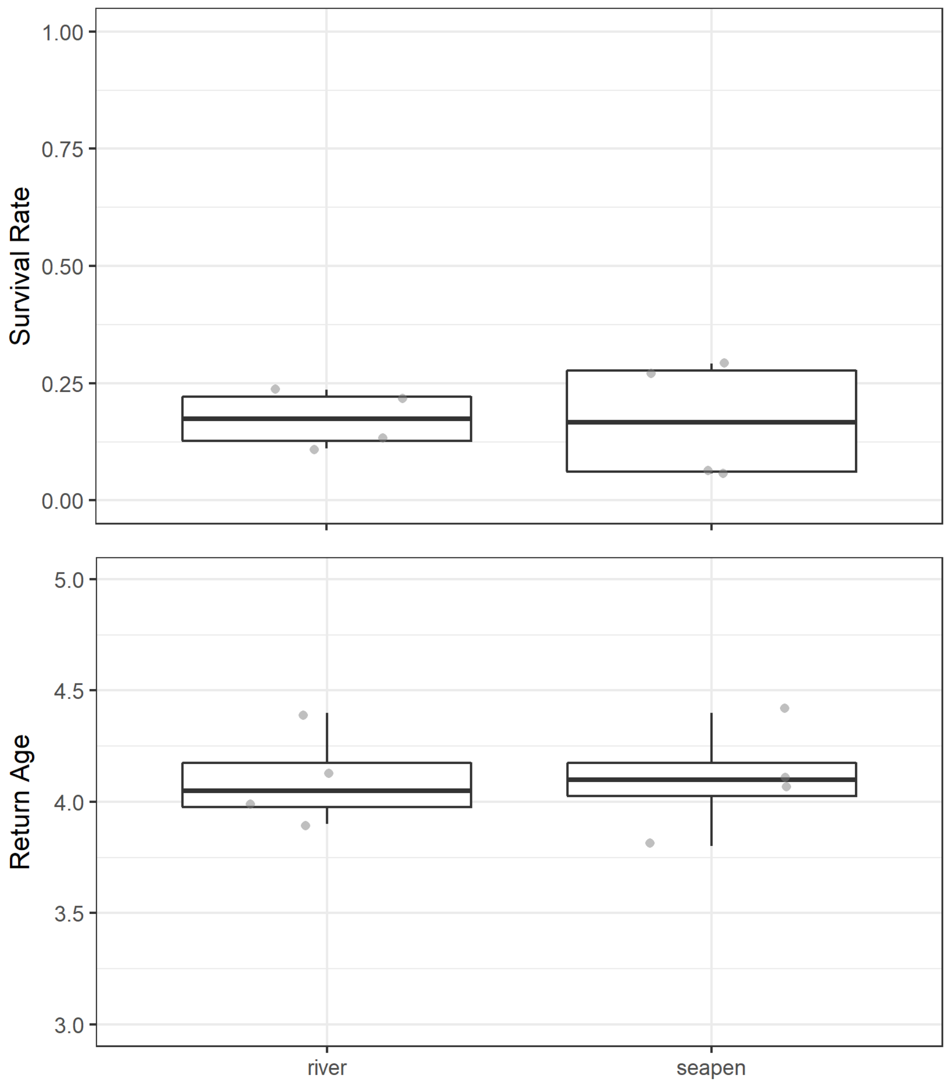

Figure 95: Survival rates (%) and return ages for Wannock River Chinook salmon released either into the Wannock River or from seapens in the Wannock estuary from 2010-2011 and 2014-2015. Boxplots represent the range of data from the first to third quartile with the horizontal line through the middle representing the median value. Black dots represent outliers while the grey dots show the data for all release groups.

SUMMARY AND DISCUSSION

In this report, we evaluated the outcomes of 25 experimental release studies at 11 DFO major operational hatcheries, two community economic development facilities, and one designated public involvement facility in British Columbia. Specifically, we evaluated the release of multiple life stages of the same stock, the release of salmon at different locations in their respective watersheds, the release of salmon earlier or later than usual, the release of salmon of different sizes, and the use of seapens for marine rearing prior to release.

SURVIVAL TIME SERIES

Each experimental release was placed in the broader context of historical survival trends for the stock of interest. In describing the trends in survival for each stock, we identified a few common patterns. Survival rates decreased dramatically in the 1980s for Puntledge River summer Chinook, Quinsam River fall Chinook, and Big Qualicum River fall Chinook and Coho, remaining at relatively low levels ever since. The same decrease was observed a few years later into the early 1990s for Cowichan River Chinook, Chilliwack River Coho, Inch Creek Coho, and Quinsam River Coho. Slight improvements in survival rates were observed in the late 1990s in both Puntledge River Summer Chinook and Quinsam River Chinook. These decreasing trends over time are not unique to hatchery releases; similar trends have been seen in wild stocks (Riddell et al. 2013, Zimmerman et al. 2015). Two stocks have exhibited large variability in survivals with no sustained period of low survivals: Robertson Creek Chinook and Chilliwack River Fall Chinook. A broader assessment of survival trends throughout BC can be found in *Part III: Rearing strategy effects on survival and return ages for British Columbia Chinook and Coho hatchery releases, 1972-2017*.

COMPARISON OF LIFE STAGES

The objectives behind releasing different life stages or life histories varies between facilities. For most, the goal has been to mimic the natural life history of the enhanced stock, thus maintaining life history diversity and supporting the use of historical spawning habitats throughout the watershed, or to increase survival rates. The effectiveness of this strategy can be indirectly measured by looking at the survival rates of the different life stages released. The performance of each life stage in terms of survival rates, exploitation rates, and return age was assessed.

Of the seven experiments releasing multiple life stages, four reported higher survivals for later life stages, two reported no difference, and one had insufficient data. Puntledge River summer Chinook had higher survival rates when released as subyearling smolts rather than as fry throughout the watershed, although exploitation rates and return ages were similar for the two life stages. For yearling releases with complete return data, the mean yearling survival rate was always higher than for subyearling smolts – a finding consistent across stocks (i.e. Robertson Creek, Phillips River, and Atnarko River). Exploitation rates for the yearling strategy were either similar (Robertson Creek, Atnarko River), or slightly lower (Phillips River) than the subyearling releases. Moreover, for return age, yearlings came back either at the same ages on average as subyearlings (Robertson Creek, Phillips River), or as older adults (Atnarko River). However if we consider the marine age, yearlings generally spent less time at sea than subyearlings. Given that the marine environment is where salmon gain most of their adult body mass, this could reduce the overall size of yearling returns, however this was not assessed in this study. In addition, yearlings will have had less overall exposure to marine fisheries. Meanwhile, there was no difference found between survival rates, exploitation rates, or return ages of Quinsam River fall Chinook fry and smolts or of Cheakamus River fry and yearlings, although the Cheakamus River releases do not yet have sufficient data to draw any significant conclusions. However, if the outcomes are the same but costs of production vary, fry releases at these facilities may be a preferred option.

Interestingly, at Robertson Creek, patterns in return ages oscillated with lower ages (i.e. higher proportions of jacks) every other year. This was also the only facility on the west coast of Vancouver Island. Therefore, there may be something in the environment driving this cyclic pattern in age at return. One factor known to vary ever other year is the abundance of pink salmon. Further research could investigate the relationship between pink salmon abundance and Chinook jacking rates on the west coast of Vancouver Island to determine how they might interact.

These direct comparisons between treatments do not account for any other parameters that may have been influencing the performance of the hatchery releases and only provide a partial understanding of the relationship between life stage, or life history, and production outcomes (i.e. survival, exploitation, or age). Life stage, or life history, will usually be confounded with the size and time of release; therefore, it is important to account for these factors when trying to determine the drivers of survival.

By modelling the effects of various release parameters (i.e. size, day, life stage, release site, ocean entry year) on survival rates, we were able to get a better understanding of factors affecting the experimental trials. Puntledge River, Quinsam River, and Robertson Creek all contained different release parameters in their top models. For Puntledge River Chinook, release weight was the most important predictor of survival, with heavier fish at release (i.e. subyearling smolts) having higher survival rates than the smaller fry. The year of ocean entry explained relatively little of the variation in survival rates. For Quinsam River Chinook, release weight and life stage were both significant predictors of survival, with heavier individuals in each life stage surviving better. Here, fry were modelled to have higher survivals than subyearling smolts of the same weight - an unrealistic scenario. Thus, weight was likely a more important predictor of survival than life stage. For these experimental releases, the year of ocean entry explained >50% of the variation in survival. For Robertson Creek Chinook, the weight at release, including the quadratic coefficient, was the best predictor of survival with higher survival of smaller-sized subyearling smolts and larger-sized yearlings. Here, the year of ocean entry also accounted for >50% of the variation in survival.

In summary, the production of different life stages can yield different outcomes, however this is likely in response to the underlying characteristics of the life stage (i.e. different life stages being released at different times or sizes). While 'life stage' alone can be a useful predictor of survival (e.g. Quinsam River, Snootli Creek), the random effects of ocean entry year still play a dominant role in determining production outcomes. Releasing multiple life stages or life history types can be advantageous in that it spreads the risk of significant losses in any single brood over multiple years. Furthermore, it allows for the more accurate representation of the natural system. However, the extended rearing period may be more costly and may increase the rates of jacks or jimmies (age-1s) in the returns (e.g. Robertson Creek). And, while some of these characteristics can be related to changes in survival, the random year effect appears to be one of the major drivers of variations in survival.

LATE/LARGE CHINOOK AND OTHER RELEASE TIMING TRIALS

In response to continuously low survival rates of Chinook and Coho salmon released into the Strait of Georgia, and with growing concerns for wild salmon populations, an experimental 'late/large' release strategy was developed to evaluate effects on survival, marine distribution, and interaction with wild salmon. Many previous studies in the literature have demonstrated higher survival rates for both Chinook and Coho when released at larger sizes (Tipping 2011, Irvine et al. 2013, Passolt & Anderson 2013). In addition, when these studies were first developed, there had been a significant reduction in catch of Coho in inside waters. It was believed that later, larger releases could increase Coho residency in the Strait of Georgia and that similar effects would be seen on Chinook. Furthermore, releasing fish later was expected to reduce overlap with wild outmigrants and thus reduce competition for resources. Predators may also have become accustomed to large numbers of spring migrants; therefore, delaying the releases would allow them to avoid a window of high predator abundance. It was expected that wild returns would increase as a result of offsetting hatchery releases. Thus, there was great interest in exploring this novel strategy to pursue conservation objectives.

The 'late/large' release strategy has been tried (using CWTs) on Chinook salmon at both the Quinsam River and Big Qualicum River Hatcheries. At the time of this report, only Big Qualicum had sufficient data for statistical analyses. Results from the 2011-2013 and 2015 releases showed no significant differences in the mean survival rates, exploitation rates, or return ages of the two treatments. However, the early experimental design (2011-2013) may have been problematic, as later/larger releases were trialed in September, August, and July, in order to establish the ideal methods for the late/large strategy (Esther Guimond, personal communication). The 2015 and preliminary 2016 return data suggest that June releases of larger Big Qualicum River Chinook may result in increased survival and exploitation rates with little effect on return age. Preliminary data from the Quinsam experiment also suggests that the late/large release has the potential to increase survival rates, exploitation rates, and return ages. This increase in return ages is particularly interesting, given that larger releases have been shown to shift the age at return downward (Morley et al. 1996, Tipping 2011, Spangenberg et al. 2014). In Part I of this project (*Review of Pacific Salmon Hatchery Release Strategies in Canada and the United States*), only three publications were found on the effects of release timing on return ages of Chinook; all three reported no effect. One explanation for the effects observed on the experiments we reviewed could be that the size of the fish in the late release groups was controlled to mimic the size they would have achieved in the marine environment had they been released on the usual date. There was no accelerated growth in the hatcheries, which is what typically leads to higher jacking rates. Otherwise, it would seem there is some mechanism at play that reduces the proportion of jacks in the returns when larger fish are released later.

Modelling the relationships between release parameters and survival within the late/large trials was only possible for Big Qualicum River Chinook. In this case, there was little influence of release strategies on survival estimates. In addition, the random ocean entry year effect accounted for 63% of the variation in survival rates over the span of the experiment. Therefore, conditions beyond the control of the hatchery were driving survival patterns. However, as described above, this analysis should be revisited once full recovery data are available for the 2016 and 2017 late/large releases.

Other releases of Chinook salmon at later dates include those done with Chilliwack River Chinook in the 1990s and Cowichan River Chinook from the 1990s to present. There were too little data to draw any major conclusions from the Chilliwack experiment; however, it appears that the early/conventional releases had higher survivals than the late releases, with little difference in exploitation rates or return ages. The Cowichan releases were designed to mimic the natural life history of the Cowichan River Chinook, with two distinct pulses leaving freshwater in March/April and May each year. Although these releases may not be considered 'experimental', the time series of early and late releases going all the way back to 1990 provides valuable insight into how Chinook have responded to different release dates over time. It appears that late releases had higher survivals than early releases for most years between 1990 and 2003. However, since the 2003 release year, survival rates of the two release groups have been very similar, with the exception of 2015. In 2015, the survival rate of the early release group was more than double that of the late release group for the first time in the entire time series. Exploitation rates of the two strategies were similar prior to 2003, however since then have become more variable with larger differences between the two groups each year. In addition, while return ages have been similar over most of the time series, the ages have been slightly older for the later releases every year since the 2008 release. These data suggest that the relationships between release strategies and production outcomes vary over time, and that

2015 may mark the most recent shift. Adapting release strategies to take advantage of these temporal trends could improve hatchery effectiveness.

LATE/LARGE COHO AND OTHER RELEASE TIMING TRIALS

The objectives of the late/large Coho release strategy are the same as those outlined above for Chinook: to determine whether or not later, larger releases have higher survival rates, different marine distributions, and reduced interactions with their wild counterparts to support conservation.

The late/large strategy has been trialed (using CWTs) with Big Qualicum River, Quinsam River, and Inch Creek Coho. At the time of this report, complete recovery data for statistical analyses were only available for Inch Creek Coho. Over the three years of this experiment, no significant difference was found between the mean survival rates, exploitation rates, or proportion of jacks returning of Coho of normal and later, larger release. Furthermore, modelling the effects of multiple release parameters on survival showed the best model to be one in which release strategies had no effect and the random effects associated with the year of ocean entry explained 87% of the variation in survival rates. In contrast, preliminary data from Big Qualicum River and Quinsam River Coho suggest higher survivals, similar or higher exploitation rates, and lower jacking rates for the late/large release strategy. The strategy has also been trialed at Chilliwack River Hatchery using parentage-based tagging. While we did not include this tagging method in our review, preliminary analyses by Esther Guimond of return data from the 2016 release found lower survival rates of the late Chilliwack release. The Inch Creek 2016 late release group also had lower survivals. Therefore, this strategy may be more suitable for Coho releases from the east coast of Vancouver Island than for those in the Lower Fraser. However, complete recovery data and analyses are required before these types of conclusions can be made.

Three other experiments were done on the timing of Coho using Chilliwack River, Inch Creek, and Quinsam River stocks. In these experiments, Chilliwack River and Inch Creek Coho responded differently to release timing. The Chilliwack experiments were done in select years of the early 1980s, 1990s, and 2000s, while the trial at Inch Creek Hatchery was done in the late 2000s. A mix of early, mid, and late releases were made from Chilliwack River Hatchery, however the time between release groups varied considerably from 0-34 days. What is interesting is that prior to the dramatic decline in survival rates in the late 1980s and 1990s, the mid or late release groups had higher survivals than the early release group. While the mid release group continued to have higher survivals than the other releases in the early 2000s, late releases post-decline had consistently lower survivals than the early releases. In contrast, the early releases at Inch Creek had lower survivals than the normal release groups in the late 2000s. Either these two stocks respond differently to release timing, or there may have been a shift in the nature of these relationship similar to that seen the mid-2000s for Chinook.

The Quinsam time of release experiment from 2004-2012 sought to revisit earlier experimentation from the 1980s that found late releases to perform the best (Bilton et al. 1982, 1984). Over the course of this more recent experiment, no significant difference was found between three different release times (approximately two weeks apart between April 20 and May 27). Note, however, that in this experiment, none of the late releases extended past the end of May, unlike the late releases in the 1980s or the more recent late/large releases. Furthermore, the 'best' performing strategy varied between years. It is believed that broad scale environmental conditions, such as the El Niño-Southern Oscillation (ENSO), may be behind the differences in outcomes between release strategies across years. Specifically, it was observed that the early release group had particularly poor survivals during La Niña years (i.e. 2007-2008, 2010-2012). While we did not include broad scale environmental parameters in our release strategy models, the year of ocean entry, as well as the day and the quadratic coefficient for day were important predictors of survival during this trial. Mid-timed releases or those slightly earlier than the mean release date have seen higher survivals, and survival rates have gradually increased over time. The random effects of ocean entry year, which would capture things like the ENSO, explained 44% of the variability in survival rates during this time.

Throughout the Coho time of release experiments, return ages were either unaffected by release timing, or increased with later release dates. This increase in age of later returns was also observed in some of the preliminary Chinook data. As described for the Chinook experiments, this finding was somewhat surprising, since 'large' releases have been associated with higher jacking rates in the literature (Bilton et al. 1982, Fagerlund et al. 1989, Koseki & Fleming 2006). However, some of the same experiments from the literature have also shown that later than conventional release timing may reduce the proportion of jacks (Bilton et al. 1982, Koseki & Fleming 2006). Therefore, it would seem that the combination of time and size, and maintaining a normal growth regime, can lead the late releases to return at older ages, or with fewer jacks despite their larger size at release.

SIZE AT RELEASE

Time and size of release are often confounded, with earlier releases being smaller than average and later releases being larger than average. While some of the above time of release experiments also vary the size at release, there were only two experiments that assessed release size specifically and controlled for release timing. In 2010-2012, Quinsam River Coho were released as either 26 g (normal) or 31 g (large) yearling smolts. In addition, 15 g (small) and 20 g (normal) yearling smolts were released from Inch Creek from 2012 to 2014. Neither experiment observed any significant differences in survival, exploitation, or jacking rates between release groups. Given the additional cost of rearing smolts to larger sizes, it appears larger releases may only be beneficial when also released later than normal, as described in the previous sections.

SEAPENS

The main objective for releasing salmon from seapens is to produce fish for harvest. Our analyses showed that of the six enhanced stocks with sufficient data on seapen releases, only Quinsam River and Robertson Creek saw higher exploitation rates from seapen releases than from hatchery releases. Seapen releases were also found to differ in the age structure of their adult returns at both Cowichan River and Quinsam River. Cowichan seapen releases were found to come back older than hatchery releases, while Quinsam River seapen releases come back at younger ages. Seapen releases exhibited similar survival rates to their hatchery-released counterparts.

FUTURE DIRECTIONS

A number of the release experiments in this report do not yet have complete recovery data, either because not enough time has passed since experiment completion for the recovery of all age groups, or the experiment is ongoing (Table 42).

A list of current experiments using CWTs and other tagging and assessment methods is provided in Table 42. All of these experiments are on Chinook and all are focused in southern BC. No size and time of release experimentation has been conducted in central or northern BC, with no planned experiments for these regions. While there are far fewer enhanced stocks in these regions, it is possible that they would respond differently to release strategies than southern stocks given the environmental variation along the coast. It is important that we explore the role of release strategies in hatchery effectiveness in all regions of the province.

Seeing where release strategies have had no effects is also important. Some of the experiments reviewed found no effect of release strategies. These experiments suggest either that conditions beyond the control of the hatcheries are driving trends in hatchery recoveries and biological traits, or that the limited datasets lacked the statistical power needed to detect an effect. To the first point, several previous studies have indicated that the random effect of ocean entry year is a primary factor influencing patterns in hatchery survivals (Green & Macdonald 1987, Morley et al. 1996, Koseki & Fleming 2006, Irvine et al. 2013). However, the factors driving these random effects remain unclear. Productivity of the early marine environment, predator abundance, food availability, competition, broader atmospheric systems like the ENSO, and other environmental factors could all be affecting hatchery recoveries and trends in biological traits. Very little research has been done to try to fill this gap in our knowledge, which provides an immense opportunity for future experimental studies. Given the high degree of environmental variability, experiments may in fact need to run for longer time periods and/or be repeated over time to be able to detect effects of hatchery practices. Therefore, moving forward, it will be important to have adequate resources allocated to such studies so that they can implement sound experimental designs over longer time periods and increase confidence in experimental outcomes.

In the development of future rearing and release strategies, one important factor to consider is diversity. A diversity of life histories and genetic variation allows salmon populations to adapt and maintain resilience to changing environmental conditions. However, the range of release sizes and dates has narrowed over time with unknown consequences for hatchery and wild populations (Irvine et al. 2013, Nelson et al. 2019). Rather than striving for a single 'optimal' strategy, future research should explore the effects of a diversified enhancement strategy. Hatchery managers have already recognized the benefits of enhancing multiple life histories of a given stock, calling it an insurance policy against years of poor survival. Thus, future enhancement strategies should consider the potential benefits of diversification.

Many of the experimental objectives identify 'interaction with wild salmon' as one of the outcomes of interest, and yet to date there has been little assessment of this objective. In Washington's review of hatchery science reform, interaction with wild salmon was also identified as a large gap in knowledge and an area requiring evaluation (Anderson et al. 2020). Furthermore, many hatcheries have based their current release timing on historical and outdated records of the wild outmigration timing. We know that peak river discharges are occurring earlier and that earlier wild out-migrations have been reported (Kovach et al. 2013). Therefore, hatchery experiments should monitor the abundance, migration timing, and condition of wild salmon concurrent to the release of hatchery fish so that strategies minimizing impacts on wilds can be implemented.

In addition to conducting focused experiments on the different environmental impacts on hatchery fish, hatcheries could also incorporate some degree of environmental monitoring into their enhancement programs. With more data available on environmental conditions leading up to, during, and post-release (e.g. river temperature, spring-transition dates in the early marine environment, predator abundance, etc.) we can begin to understand the relationships between these conditions and enhancement. With lessons learned from experiments and with time series of paired release-environmental conditions in hand, hatchery managers may be more adaptable and better able to meet production objectives in the face of uncertainty.

Table 42: Summary of experiments currently underway in BC with study duration and tagging or assessment methods.

STUDY TYPE	STOCK	RUN	SPECIES	BROOD YEARS	ASSESSMENT METHOD
Life History	Cheakamus River	Summer	Chinook	2014-ongoing	CWT
Colonization	Puntledge River	Fall	Coho	2015-ongoing	CWT
	Quinsam River	Fall	Chinook	2014-ongoing	Downstream migration counts and CWT
Size and time of release	Big Qualicum River	Fall	Chinook	2014-ongoing	CWT
	Quinsam River	Fall	Chinook	2014-ongoing	CWT
	Quinsam River	Fall	Coho	2014-ongoing	CWT
Rearing strategy	Sarita River	Fall	Chinook	2017 - ongoing	CWT
Fish Culture	Quinsam	Fall	Coho	2019	PIT tag
Heritability of adult size	Quinsam River	Fall	Chinook	2015-2022	PBT
Heritability of BKD and run timing	Puntledge River	Summer	Chinook	2013-ongoing	PBT
Seapen	Chilliwack (Capilano) River	Fall	Chinook	2013-ongoing	CWT
	Conuma R	Fall	Chinook	ongoing	PBT, TM
	Conuma R	Fall	Coho	ongoing	PBT
	Marble River	Fall	Chinook	2017-ongoing	TM
	Quinsam River	Fall	Chinook	Ongoing	CWT, PBT, TM
	Robertson Creek	Fall	Chinook	2013-ongoing	CWT, PBT, TM
	San Juan River	Fall	Chinook	2003-ongoing	CWT, TM
	Wannock River	Fall	Chinook	2017-ongoing	CWT

LITERATURE CITED

Anderson JH, Warheit KI, Craig BE, Seamons TR, Haukenes AH (2020) A review of hatchery reform science in Washington. Washington State Department of Fish and Wildlife.

Beamish RJ, Sweeting RM, Beacham TD, Lange KL, Neville CM (2010) A late ocean entry life history strategy improves the marine survival of Chinook salmon in the Strait of Georgia. NPAFC Doc 1282:14.

Bilton HT, Alderdice DF, Schnute JT (1982) Influence of time and size at release of juvenile Coho Salmon (*Oncorhynchus kisutch*) on returns at maturity. Can J Fish Aquat Sci 39:426–447.

Bilton HT, Morley RB, Coburn AS, Van Tynel J (1984) The influence of time and size at release of juvenile Coho salmon (*Oncorhynchus kisutch*) on returns at maturity: results of studies on three brood years at Quinsam Hatchery, B.C., in 1980. Can Tech Rept Fish Aquat Sci:98.

Burnham KP, Anderson DR (2002) Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach (2nd ed). Springer-Verlag, New York.

Fagerlund UHM, McBride JR, Dosanjh BS, Van Tine J, Greig M (1989) Effects of culture density and size of juveniles on growth and survival of pond-reared Coho salmon released from Quinsam hatchery in 1983 and 1984. Can Tech Rep Fish Aquat Sci:41.

Green PEJ, Macdonald PDM (1987) Analysis of mark-recapture data from hatchery-raised salmon using log-linear models. Can J Fish Aquat Sci 44:316–326.

Hurvich CM, Tsai C-L (1989) Regression and time series model selection in small samples. Biometrika 76:297–307.

Irvine JR, O'Neill M, Godbout L, Schnute J (2013) Effects of smolt release timing and size on the survival of hatchery-origin Coho salmon in the Strait of Georgia. Prog Oceanogr 115:111–118.

Koseki Y, Fleming IA (2006) Spatio-temporal dynamics of alternative male phenotypes in Coho salmon populations in response to ocean environment. J Anim Ecol 75:445–455.

Kovach RP, Joyce JE, Echave JD, Lindberg MS, Tallmon DA (2013) Earlier migration timing, decreasing phenotypic variation, and biocomplexity in multiple salmonid species. PLoS One 8.

Morley RB, Bilton HT, Coburn AS, Brouwer D, Van Tine J, Clarke WC (1988) The influence of time and size at release of juvenile Coho salmon (*Oncorhynchus kisutch*) on returns at maturity; results of studies on three brood years at Quinsam Hatchery, B.C. Can Tech Rep Fish Aquat Sci:120.

Morley RB, Fedorenko AY, Bilton HT, Lehmann SJ (1996) The effects of time and size at release on returns at maturity of Chinook salmon from Quinsam River Hatchery, B.C., 1982 and 1983 releases. Can Tech Rep Fish Aquat Sci 0:I–88.

Nelson BW, Shelton AO, Anderson JH, Ford MJ, Ward EJ (2019) Ecological implications of changing hatchery practices for Chinook salmon in the Salish Sea. Ecosphere 10:1–19.

Passolt G, Anderson JJ (2013) A model linking ocean survival to smolt length. 184–190.

Riddell B, Bradford M, Carmichael R, Hankin D, Peterman R, Wertheimer A (2013) Assessment of status and factors for decline of Southern BC Chinook Salmon: Independent panel's report. Prep with Assist DR Marmorek AW Hall, ESSA Technol Ltd, Vancouver, BC Fish Ocean Canada (Vancouver BC) Fraser

River Aborig Fish Secr (Merritt, BC):xxix + 165 pp.+ Appendices.

Spangenberg D, Larsen DA, Gerstenberger R, Brun C, Beckman BR (2014) The effects of variation in rearing conditions on growth, smolt development, and minijack rate in yearling Chinook salmon: A hatchery scale experiment. Trans Am Fish Soc 143:1220–1230.

Tipping JM (2011) Effect of juvenile length on Chinook salmon survivals at four hatcheries in Washington state. N Am J Aquac 73:164–167.

Zimmerman MS, Irvine JR, O'Neill M, Anderson JH, Greene CM, Weinheimer J, Trudel M, Rawson K (2015) Spatial and temporal patterns in smolt survival of wild and hatchery Coho salmon in the Salish Sea. Mar Coast Fish 7:116–134.