Growth of Snake River chinook salmon

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Revisions and additions to Draft 1:

1. Identification of problems and refinement of database.
2. Further restrictions on allowable fish.
3. Traditional allometry used for weight/length relationship.
4. Revised subdivisions of fish groups with developed mathematical treatment.
5. Increased prey energy density in consumption for bio-energetics modeling.
6. Interpretation of growth indicators.
7. Suggestions for growth modeling.

1 Summary

Growth rates and scope for Snake river chinook salmon are examined in order to 1) understand the spatial and temporal patterns of salmon growth; and 2) provide a foundation to model growth under simulated alternative river-conditions.

This analysis reveals that three basic measures of growth: instantaneous weight gain, instantaneous length gain and consumption rates are generally consistent but the differences between them are useful for making inferences about the growth process. Changes in “growth in length” do not necessarily accompany an equivalent change in the “growth in weight” because of changes in the morphology of juvenile salmon as they smolt, and changes in consumption do not necessarily accompany changes in growth or weight.

Growth of Snake River juvenile salmonids is a function of their run, rearing type, system of origin, temperature, position in the system and time of year.

2 Growth analysis

2.1 Introduction

There are several ways to measure growth. It can be determined by development of an individual organ or system, an increase in the mass or weight of the organism as a whole, an increase in the length of the organism, or (in principle) any positive or negative change in a morphometric parameter of the organism.

Growth records of Snake River juvenile chinook salmon are restricted to changes in either the length or weight of the fish. Not only are these measures nonlinearly related but their allometric relationship changes during the parr-smolt transition and varies between the runs (Hoar, 1988; Beckman et al. 1996; Beeman et al. 1994). These changes need to be understood for effective modeling of growth.

The ecological context of growth is examined through bio-energetic modeling. Much work on such ecological models for fish growth has been done and ultimately they depend on the fish’s energy expenditure and prey consumption. Several assumptions about the fish and the system are necessary, but this mechanistic method ties growth to temperature profiles and biological parameters of the system as a whole. Since the parameters vary between “groups” of fish because they are distinct in space and time, it suggests that each group be modeled separately. For example, yearling hatchery chinook released into the Grand Ronde river in the spring of 1996 might be considered one group.

We are seeking to characterize the growth of a group of fish in a simple, yet distinct manner. Uni-modal distributions of parameters with as small a variance as possible are highly desirable. One of the central purposes of this analysis is to determine what those groupings are and characterize the parameters that make them unique.

2.2 PIT tag recapture database

The PIT tag recapture database was used to identify the over 55500 tag identities of released juvenile chinook that were subsequently recovered and remeasured. The tag-ids were used to obtain release and recapture information from PSMFC’s PTAGIS database. The release information for each fish was obtained from the tagging database and related to the general release information through the release file id. Analogously, recapture information was obtained from the recapture or “observations” data. Each record therefore contained release information (e.g. location, date, temperature), individual fish information at release and at recapture (e.g. length and weight) and recapture information (similar to release information). From this superset of all possible fish, analysis was restricted to:

1. Juvenile chinook salmon released in the Snake river system, i.e. released in any river or stream that is a tributary of the Snake river.
2. Residence time in the river between 1 and 200 days.
3. Length measure between 30 and 250 mm.
4. Weight or length measured on both release and recovery.
5. Data defined in the PIT tag recapture database and subject to sufficient values for attributes, and/or success at correcting problems identified in Table 1.

Table 1 Data problem, number of records affected, treatment method

Problem	Treatment
Mislabeled fish that had incorrect run or rearing type.	If it could not be resolved then it is omitted. For example, fish labelled with rearing type of “1” or “2” was omitted.
Impossible growth rate (e.g. average gains or losses of 20% or more of weight per day. Note: Further restrictions were applied later, but this initial screening attempted to remove gross errors.	These could be due to date or size values being incorrect. All of these types of problems are omitted with the following exception: A large number of fish apparently had the length value reduced by exactly 100. This was evident from plots of the weight/length relationship and a sharp truncation of the scatter plot of lengths vs. weights. 437 of these unusual data points were fish were recaptured at LGR and with a recapture file ID of the form CFM95***.RE1. This suggests a systematic error and each of these fish had 100 grams added to their recapture weight.
Invalid date, location or other meta-data parameter.	omitted
Recovery after ocean residence. This is inferred from long periods between release and recapture (years).	omitted
Weight missing at release or recapture.	Weights were calculated when possible.

Over 35,000 individual records met all criteria. The data spanned 10 years of PIT-tag studies beginning in 1988 although it was not until 1992 that any significant recapture studies began.

Methods for calculating weight from length.

Length, though a useful measure of growth, is an insufficient measure for mass-balance bioenergetic models. However, length is an easily measured growth parameter, and is often used as an index for weight (Ricker 1979; Riddell & Leggett 1981; Beeman et al. 1994). All chinook salmon records were examined for availability of length and weight data. A summary of the data is in Table 2 and shows that 33028 - 18479 = 14549 recapture weights and 33028 - 11644 = 21384 release weights were missing for records where length is available. For fitting of a bioenergetic model, therefore, it was valuable to obtain these missing weights.

Table 2 Summary of available weight and length data from PIT tag database. *n* = number of recapture records. “x” = attribute is available. Blank = attribute not used for calculation of *n*. “NA” means that the attribute is not available. For example, there are 17747 records for which there is no release weight but there is release length regardless of recapture information.

n	Release weight	Recapture weight	Release length	Recapture length	Met all data restrictions
55538			x		
33028					x
8600	x	x	x	x	x
11644	x				x
33028			x		x
11644	x		x		x
18479		x			x
33028				x	x
18479		x		x	x

Allometric relationships for developing fish vary during development, likely in response to the priorities of vital functions at the particular life stage (Osse et al. 1995). The allometric weight-length relationship for a fish in a particular growth stanza is traditionally (Ricker 1979):

$$W = aL^b \text{ or,} \tag{1}$$

$$\log W = \log a + b(\log L) \tag{2}$$

Modeling the log of the weights would have the form:

$$\log W_i = \beta_0 + \beta_1 \log L_i + \varepsilon_i \tag{3}$$

where:

- W = weight in g.
- L = length in mm.
- β_0, β_1 = regression parameters

Eqn. (1) and Eqn. (2) apply to a given fish within a growth stanza and this requirement is gradually tightened in three stages of model fitting:

Stage 1: General relationship for all Snake River chinook

All chinook are considered the same and a general weight-length relationship is obtained by fitting Eqn. (2). The regression line is highly significant ($p < .0001$ and $R^2 = 0.9639$) and the regression parameters are converted back for plotting on a weight vs. length graph. See Figure 1.

Stage 2: Releases and recoveries treated separately

Releases and recoveries are treated separately to determine if there is a system-wide change in the allometric relationship of weight to length between release and recovery.

The best fit for released chinook has the coefficients shown in Table 3 with $p < .0001$ and $R^2 = .958$. The best fit for recovered chinook has the coefficients shown in Table 4 with $p < .0001$ and $R^2 = .957$. Overlays of the two separate lines shows that the relationships are similar (both regression lines are drawn in both the left and right panels of Figure 2). A t-test of the slopes and intercepts of the regressions concludes that both the slope and intercepts are different ($p < .001$ for both slope and intercept.)

Table 3 Coefficients for the weight-length relationship in Eqn. (3) for released chinook

	Value	Std. Error	t value	Pr(>|t|)
β_0	-11.3309	0.0334	-339.6413	0.0000
β_1	2.9792	0.0075	397.8144	0.0000

Table 4 Coefficients for the weight-length relationship in Eqn. (3) for recovered chinook

	Value	Std. Error	t value	Pr(>|t|)
β_0	-11.6657	0.0202	-577.3893	0.0000
β_1	3.0507	0.0043	715.6941	0.0000

Stage 3: Importance of covariates to weight-length relationship for recovered fish.

Since smolting chinook change in body form and behavior (Dickoff et al. 1995; Hoar 1988;

Ricker 1979), the apparent bi-modal distribution of lengths at a given weight (Figure 3) could be a result of the pooling of data on actively migrating smolts and resident or slowly migrating parr. The recapture data clearly show two separate trajectories (Figure 2). Graphically the different runs and rearing types seem to have different relationships as shown in Figure 4.

We seek a general linear model to assess the importance of covariates that contribute to the variance of the weights and consider the following:

$$\begin{aligned} \log W_i \;=\; & \beta_0 + \beta_1 \log L_i + \beta_{2j} R_{ij} + \beta_{3k} T_{ik} + \beta_4 N_i + \beta_5 M_i \\ & \beta_{6j} R_{ij} N_i + \beta_{7j} R_{ij} M_i + \beta_{8k} T_{ik} N_i + \beta_{9k} T_{ik} M_i + \varepsilon_i \end{aligned} \tag{4}$$

where:

- W_i = recapture weight
- L_i = recapture length
- R_{ij} = 1 for j = 2, 3, 5 (the base case is for run 1) or 0 otherwise. An index variable.
- T_{ik} = 1 for k = “U” or “W” (the base case is for hatchery fish “H”) or 0 otherwise. An index variable.
- N_i = release month (1 thru 12)
- M_i = recapture month (1 thru 12)
- $R_{ij}N_i$ = interaction effect between run j and release month
- $R_{ij}M_i$ = interaction effect between run j and recapture month
- $T_{ik}N_i$ = interaction effect between rearing type k and release month
- $T_{ik}M_i$ = interaction effect between rearing type k and recapture month
- ε_i = unmodeled variability (error)
- $\beta_{x\,(j \text{ or } k)}$ = regression parameters for x=1, 2, 3, ... 9

The least squares fit of Eqn. (4) gave results tabulated in Table 5.

Table 5 Regression results for recaptured chinook. Run 1, Type H chinook (Hatchery yearlings) are considered to be the base case.

	Value	Std. Error	t value	Pr(>|t|)
(Intercept)	-11.2962	0.0303	-373.2289	0.0000
logreclen	2.9671	0.0058	512.5952	0.0000
run2	-0.0399	0.0135	-2.9636	0.0030
run3	-0.4536	0.0138	-32.7887	0.0000
run5	-0.7694	0.0184	-41.7562	0.0000
typeU	0.3973	0.0270	14.7285	0.0000

Table 5 Regression results for recaptured chinook. Run 1, Type H chinook (Hatchery yearlings) are considered to be the base case.

	Value	Std. Error	t value	Pr(>|t|)
typeW	-0.0032	0.0082	-0.3890	0.6973
recmo	0.0032	0.0013	2.4482	0.0144
relmo	-0.0044	0.0015	-2.8165	0.0049
run2recmo	0.0009	0.0019	0.4813	0.6303
run3recmo	0.0650	0.0027	23.7866	0.0000
run5recmo	0.0880	0.0040	22.2209	0.0000
typeUrecmo	-0.0462	0.0060	-7.6869	0.0000
typeWrecmo	-0.0001	0.0015	-0.0677	0.9460
run2relmo	0.0031	0.0018	1.6810	0.0928
run3relmo	0.0254	0.0043	5.9695	0.0000
run5relmo	0.0544	0.0048	11.2872	0.0000
typeUrelmo	-0.0269	0.0063	-4.2697	0.0000
typeWrelmo	0.0013	0.0017	0.7677	0.4426

Analysis with single term deletions was used to find a more parsimonious model. The Pearson chi-squared version of AIC ($C_p = \chi^2 + 2p$, where p is the number of parameters) was used. With the large data set, model improvements as a result of adding terms are to be expected without a penalty to the AIC. Conventionally, if inclusion of a term reduces the AIC, then the resulting model is justified despite the loss of parsimony. For example, $C_p = 355.170$ using Eqn. (4). Dropping the recapture month and run interaction term increases this value to $C_p = 372.849$ and therefore should be retained in the model.

Table 6 Effect of dropping one term from Eqn. (4). “relmo” is the release month, “logreclen” is the log(recapture length), and “:” indicates the interaction of two variables.

	Df	Sum of Sq	RSS	Cp
<full model>			354.438	355.170
logreclen	1	5063.059	5417.496	5418.190
recmo:run	3	17.794	372.232	372.849
recmo:type	2	1.189	355.627	356.282
relmo:run	3	2.966	357.404	358.021
relmo:type	2	0.407	354.845	355.500

Arguably, a biologically significant model is more desirable than the ideal statistical model and terms that contribute little to the overall SS (such as the release month and run interaction term) will be omitted.

Based on the results presented in Table 6, the recapture month and run are retained in the model along with their interaction term. If smolting is assumed to be a principle cause of the bimodality in the weight-length relationships, and we expect the different runs to smolt at different times during the year, then this model has a biological basis as well:

$$\log W_i = \beta_0 + \beta_1 \log L_i + \beta_{2j} R_{ij} + \beta_3 M_i + \beta_{4j} R_{ij} M_i + \varepsilon_i \tag{5}$$

for all i and j = 2, 3, or 5 (corresponding to run types 2, 3, and 5 because the base condition is for run type 1—yearling chinook). All terms are significant at the $p < 0.0001$ level and R^2 = 0.967. The coefficients are listed in Table 7. Although the common regression for the recovery data had an $R^2 = 0.957$, and this is a small improvement for the population as a whole, we are interested in the fit of the curves for the larger fish where they clearly diverge into two different weight / length trajectories. The data is sparser for these larger fish and thus they have less influence over the overall fit.

Table 7 Coefficients for model in Eqn. (5)

	Value	Std. Error	t value	Pr(>|t|)
β_0	-11.2594	0.0213	-527.5684	0.0000
β_1	2.9576	0.0042	696.7594	0.0000
β_{22}	-0.0327	0.0118	-2.7569	0.0058
β_{23}	-0.3923	0.0094	-41.7862	0.0000
β_{25}	-0.5414	0.0128	-42.3714	0.0000
β_3	0.0006	0.0005	1.1641	0.2444
β_{42}	0.0030	0.0016	1.8888	0.0589
β_{43}	0.0776	0.0014	54.6400	0.0000
β_{45}	0.0968	0.0022	43.6859	0.0000

Recapture weights will now be modeled as:

$$\log W_{ij} = \beta_0 + \beta_1 \log L_i + \beta_{2j} R_{ij} + \beta_3 M_i + \beta_{4j} R_{ij} M_i + \varepsilon_i \tag{6}$$

Transforming the equation and coefficients, we get the following relationships for the four different recapture runs:

$$W_{spring} = 1.288532\times10^{-5} \cdot e^{0.00061467M} \cdot L^{2.9576} \tag{7}$$

$$W_{summer} = 1.247138 \times 10^{-5} \cdot e^{0.00363613M} \cdot L^{2.9576} \tag{8}$$

$$W_{fall} = 8.704195 \times 10^{-6} \cdot e^{0.07819781M} \cdot L^{2.9576} \tag{9}$$

$$W_{unknown} = 7.498455 \times 10^{-6} \cdot e^{0.09742522M} \cdot L^{2.9576} \tag{10}$$

Stage 4: Importance of covariates to weight-length relationship for released fish.

As for the recovery data, a general linear model was used to assess the importance of covariates that contribute to the variance of the release data:

$$\begin{aligned} \log W_i = {} & \beta_0 + \beta_1 \log L_i + \beta_{2j} R_{ij} + \beta_{3k} T_{ik} + \beta_4 N_i \\ & \beta_{5j} R_{ij} N_i + \beta_{6k} T_{ik} N_i + \varepsilon_i \end{aligned} \tag{11}$$

where:

- W_i = release weight
- L_i = release length
- R_{ij} = 1 for *j* = 2, 3, 5 (the base case is for run 1) or 0 otherwise. An index variable.
- T_{ik} = 1 for *k* = “U” or “W” (the base case is for hatchery fish “H”) or 0 otherwise. An index variable.
- N_i = release month (1 thru 12)
- $R_{ij}N_i$ = interaction effect between run *j* and release month
- $T_{ik}N_i$ = interaction effect between rearing type *k* and release month
- ε_i = unmodeled variability (error)
- $\beta_{x\ (j\ or\ k)}$ = regression parameters for x=1, 2, 3, ... 6

A summary of this analysis is shown in Table 8.

Table 8 Effect of dropping one term from Eqn. (11). “relmo” is the release month, “loglen” is the log(release length), and “:” indicates the interaction of two variables.

	Df	Sum of Sq	RSS	Cp
<full model>			206.319	206.944
loglen	1	2322.646	2528.965	2529.542
relmo:run	3	3.297	209.616	210.097
relmo:type	2	1.386	207.706	208.234

The type term (and its interactions are dropped) but the release month and run terms are retained to be consistent with the recovery models, even though “run” and “release month” are not as significant for released fish as “run” and “recovery month” are for recovered fish. The regression model for fish on release is then:

$$\log W_{ij} = \beta_0 + \beta_1 \log L_i + \beta_{2j} R_{ij} + \beta_3 N_i + \beta_{4j} R_{ij} N_i + \varepsilon_i \qquad (12)$$

for all *i* and *j* = 2, 3, or 5 (corresponding to run types 2, 3, and 5 because the base condition is for run 1—yearling chinook). All terms are significant at the $p < 0.01$ level and $R^2 = 0.960$. The coefficients are listed in Table 9. Despite their significance, there is only a small gain in understanding the variability in weights. Recall that $R^2 = 0.9585$ for released chinook using the simpler model shown in Eqn. (3).

Table 9 Coefficients for model in Eqn. (12)

	Value	Std. Error	t value	Pr(>|t|)
β_0	-11.4644	0.0394	-290.7816	0.0000
β_1	3.0068	0.0083	360.5314	0.0000
β_{22}	0.0190	0.0195	0.9713	0.3314
β_{23}	-0.1736	0.0385	-4.5121	0.0000
β_{25}	-0.3105	0.0331	-9.3778	0.0000
β_3	0.0012	0.0007	1.5938	0.1110
β_{42}	-0.0026	0.0023	-1.1454	0.2521
β_{43}	0.0295	0.0070	4.2457	0.0000
β_{45}	0.0648	0.0061	10.6042	0.0000

Transforming the equation and coefficients, we get the following relationships for the four different runs on release:

$$W_{spring} = 1.04967\times10^{-5} \cdot e^{0.00115769M} \cdot L^{3.0068} \tag{13}$$

$$W_{summer} = 1.069789 \times 10^{-5} \cdot e^{-0.00146683M} \cdot L^{3.0068} \tag{14}$$

$$W_{fall} = 8.824214 \times 10^{-6} \cdot e^{0.03068822M} \cdot L^{3.0068} \tag{15}$$

$$W_{unknown} = 7.695056 \times 10^{-6} \cdot e^{0.06592357M} \cdot L^{3.0068} \tag{16}$$

Application of formulas and relationship to each other

For fish that are grown for a very short period of time, the exact value of calculated release weight and the recapture weight can be very significant in determining growth. This is especially important for fish that are released very early or very late in the year. If separate release and recovery equations are used, a fish that *does not change in length* would have distinct weights calculated for release and recovery and that difference can be as much as 28% for a 100 mm fall chinook. This extreme example is for a fish released in December where the release formula predicts a 13.2 g fish and the recovery formula predicts an 18.3 gram fish. At the beginning of the year, the differences are reversed and a 100 mm fish would have weights modeled as 9.4 and 7.7 grams respectively. During the months of April, May and June this difference is less than 5%. Nearly half of the released and recovered fall chinook in the database were released in these months and 40% were released in July and August when the errors are 8 and 13% respectively. In the case of spring chinook, the difference is much less and varies linearly from -2.2% in January to -2.8% in December.

The longer that the fish grow in the system, the less significant is this difference, however to eliminate the cases of 1) incorrect growth direction (negative vs. positive) and 2) impossible growth rates; the recovery equations were used to model all weights. This insures that fish that grow only a small amount between release and recovery will have weights that reflect that growth. Nearly half the records are for fish that were in the river less than 10 days between release and recovery.

Perez-Gomas and Skalski (1997) examined changes in length of yearling chinook in the reach between LGR and LGS and conclude that they grow. This group took an average 9.3 days to travel the distance (median, 8.8) The length increment of these fish is certainly significant, however, their weight increment seems to be less upon examination of the graphs (see Figure 5). None of the fish they used in the study had release weights measured and only one fish had weight measured on recovery. In order to look at growth in weight, modeled weights have to be used. Using the single weight-length relationship for these fish on recovery, they appear to grow (shown), but using the separate relationships for the release and recaptured fish as detailed earlier, they did not appear to grow in weight (not shown). Indeed this begs the question of how to best to determine weight from length.

Arguably, the regressions are not calibrated for these fish (yearling hatchery chinook) in the impounded portions of the Snake river and therefore cannot be used reliably for that specific group, but given the biology of smolting, we do expect a change in their length-weight relationship as smolting progresses. Release-recovery studies that track both length and weight will be necessary to determine if weight growth is as significant as length growth.

A second group that they examined was a group of 43 PIT-tagged wild spring chinook that traveled from GRANDR to LGR in an average 33 days (median, 31). This group also increased significantly in length and their weight growth is also readily apparent (see Figure 6).

2.3 Wisconsin model: Review parameters and sources.

The “Wisconsin model” was developed by limnologists at the University of Wisconsin to model aquatic species interactions. There is an interface for it that exploits modern input and output methods and it has a users manual. All of the modeling assumptions are outlined therein and are not repeated in detail here, but an overview of the essential growth model follows.

Implementation of the model was done independently of the Wisconsin model interface in order to bundle it into a program that would quickly and efficiently read each of the records and then apply the bioenergetics model. In back-to-back comparisons, there were some differences in model predictions and these implementation errors are unresolved.

Growth in grams per day is defined:

$$
\begin{aligned}
G &= (C - R - D - U - F)W\frac{d_y}{d_r} \\
&\text{where:} \\
C &= c_a W^{c_b} p k_a k_b \\
R &= r_a W^{r_b} e^{r_q T} e^{(r_{to} - r_{tm} T)V} \\
D &= S_{da}(C - F) \\
U &= u_a T^{u_b} e^{u_g p}(C - F) \\
F &= fC \\
&\text{for:} \\
V &= v_a W^{r_{k4}} e^{v_b T} \\
d_r &= \text{alpha} + \text{beta} \cdot W \text{ (predator energy density)} \\
d_y &= \text{prey energy density} \\
f &= \text{proportion indigestible} \\
W &= \text{fish weight in grams} \\
\\
k_a &= \frac{c_{k1} \cdot l_1}{(1 + c_{k1} \cdot (l_1 - 1))} \\
k_b &= \frac{c_{k4} \cdot l_2}{(1 + c_{k4} \cdot (l_2 - 1))} \\
l_1 &= \exp(g_1(T - c_q)) \\
l_2 &= \exp(g_2(c_{tl} - T)) \\
g_1 &= \left(\frac{1}{(c_{to} - c_q)}\right)\log\left(\frac{0.98(1 - c_{k1})}{0.02c_{k1}}\right) \\
g_2 &= \left(\frac{1}{(c_{tl} - c_{tm})}\right)\log\left(\frac{0.98(1 - c_{k4})}{0.02c_{k4}}\right)
\end{aligned}
\tag{17}
$$

I assumed that the basic parameters used for modeling consumption (C), respiration(R), excretion (U) and egestion (F) were constant for chinook (Hanson et al. 1997) (see Table A4).

Simulations of growth require stream temperature, T, which must be known for each day that growth is simulated, and an ecological parameter, P, that is a temperature-independent proportion of the maximum consumption rate.

Temperature profiles

Fitting the P-values in this model requires a temperature history for each individual fish. Because the fish were moving in both space and time and the data is incomplete, several methods for generating temperature profiles were considered.

1. $T_i = T_0$ for each day i where day 0 is the release day (Release temperature).
2. $T_i = T_f$ for each day i where day f is the recovery day (Recovery temperature).
3. $T_i = T_0 + \frac{i}{f}(T_f - T_0)$ (Linear interpolation between release and recovery).
4. A temperature profile was generated for each individual fish based on available daily temperature data from three sources: 1) PIT-tag database release and recapture records; 2) USGS gauging station records at Peck, ID and Anatone, WA; and 3) CBR Real-time data. Multiple records for a given site and date are averaged.

   Fish are assumed to move linearly from the release to the recovery site and for each day i (i = 0, 1, 2,... f) their position x is determined as decreasing from x_{rel} to $x_{rec} = 0$. Temperature records from the data sources at positions y_j (j = 1,2,3,...n) are noted for days i=0 to i=f. If there is no single value of y_j that matches x, then an upstream and downstream site with temperatures on day i are located and designated y_u and y_d respectively.

   In creating a temperature profile for each fish, record "quality" is important. Temperature record quality is determined by proximity of date and location. For example, a fish is released at a known location on a known date and the temperature is recorded. This is higher quality than any estimates between sampling locations and between sampling dates.

   The following criteria are used to create a temperature history for the growth of each fish. The highest quality temperature vector is created by applying the criteria in order. This ensures that the start and end values are determined first, followed by good quality intermediate values and concluded with lesser quality interpolated values. D was chosen to be 20 kilometers.

$$T_i = \begin{cases} T_{0,x} & \text{for } i = 0...\min(i), T_0 = T_{min(i),max(y)} \\ T_{f,0} & \text{for } i = t...\max(i), T_f = T_{max(i),min(y)} \\ T_{iy_u}\left(\frac{x-y_d}{y_u-y_d}\right) + T_{iy_d}\left(1-\left(\frac{x-y_d}{y_u-y_d}\right)\right) & \text{u and d indicate the nearest up and down-stream sites} \\ T_{iy_{\{u,d\}}} \quad \text{if}(\text{abs}(x-y_{u,d}) < \text{D}) & \text{where D is a chosen distance} \\ T_{max(k<i)y_{\{u,d\}}}\left(\frac{i-k}{m-k}\right) + T_{min(m>i)y_{\{u,d\}}}\left(1-\left(\frac{i-k}{m-k}\right)\right) & \end{cases}$$

5. T_i are drawn from a model of river temperatures for all locations and dates. This is unimplemented.

P-values

P-values are “proportion values” as opposed to “probability values”. The terminology is maintained following model developers. In the bioenergetics model, P is a critical value that controls growth as the proportion of the maximum consumption rate that the individual fish can maintain, independent of temperature. In principle, it encompasses stream productivity, competition and other factors that may affect fish consumption and growth. In general applications of the Wisconsin model, these have to be fit to existing data before growth simulations can be run. The P-values can be calculated for individual fish that have the following attributes in their records: weights at the beginning and end of a small time frame, and a known temperature history between beginning and end (Stewart et al. 1983).

Bartell et al. (1986) and Kitchell et al. (1977) both observe that the model is better able to model consumption rate based on growth than predict growth based on consumption. This is due to the high sensitivity of growth to parameter P (Bartell et al. 1986; Beauchamp et al. 1989).

2.4 Growth indicators

Several methods were used to measure juvenile chinook growth:

Growth indicator 1

Proportion of maximum consumption as determined by fitting the bioenergetics model where temperatures are based on a temperature profile linear between the release and recapture temperatures. This indicator is the p-value from fitting the bioenergetics model with temperature method three.

A high P-value indicates that the fish are able to grow at a fast rate for the temperature they are experiencing. For a large group of fish with a common rearing history (i.e. same run, type and river system), P-values were aggregated and their distributions examined.

Comparison of p-value distributions based on different temperature profiling methods are not noticeably different, i.e. the plots of P value distributions in Figure 19 and Figure 20 show the same general patterns. Likely, only for an individual fish, will the exact method of temperature modeling be important.

There is some evidence that the P-values vary with temperature. This is likely due to changes in the productivity of the system since it intended to be de-coupled from the modeled activity level of the fish.

If the separate weight-length relationships are used to determine weights at release and recapture for fish that only have length recorded, it is quite likely to generate “impossible” weight changes especially for very short growing periods. To avoid this problem, the recovery equations were used to generate both release and recovery weights. (See **Application of formulas and relationship to each other**).

Growth indicator 2

This is similar to indicator 1, but the proportion of maximum consumption is determined by fitting the bioenergetics model with temperature profiles based on all available temperature data. These are P-values from fitting the bioenergetics model with temperature method four.

Growth indicator 3

Average daily increment of weight based on the release and recovery weight, where modeled weights are used if data is absent. Average daily growth rate is calculated as the change in weight from release to recovery divided by the time in days and the average weight of the fish. This is a good estimate of the average, daily, relative growth increment. It is defined as:

$$G = \frac{2 \cdot (W_{rec} - W_{rel})}{days \cdot (W_{rec} + W_{rel})} \tag{18}$$

Growth indicator 4

Average daily increment of weight based on a constant, average daily weight gain, where modeled weights are used if data is absent. Because growth indicator 1 is sensitive to the size of the fish on release (especially for smaller fish), growth indicator 2 is based on compounding of the relative growth rate. It is equivalent to a compound interest rate:

$$W_{rec} = W_{rel}(G+1)^{days} \tag{19}$$

where G is the rate of growth in grams per gram per day. This is equivalent to a computationally simpler though less intuitive form (Ricker, 1979):

$$G = \frac{(\log W_{rec} - \log W_{rel})}{(days)} \tag{20}$$

Eqn. (20) is less sensitive to positive growth rates and more sensitive to negative growth rates than Eqn. (19). To convert between these indicators:

$$\exp(G_{\text{Eqn 20}}) = G_{\text{Eqn 19}} + 1 \tag{21}$$

Growth indicator 5 and 6

These are analogous to growth indicators 3 and 4 but use length instead of weight.

Comparison of growth indicators

I found 33108 records of Snake River salmon growing for more than 1 day, less than 200 days and with lengths between 30 and 250 mm and with recovery weight less than 250 g. Many of these fish could not have a P-value (Indicators 1 and 2) calculated because data was missing or incorrect (no release or recovery temperatures, weights or lengths missing etc.) For fish that had valid weights and temperatures, the ones with the lowest growth rates were the most difficult to fit with the bioenergetics model. In some cases, the model failed to fit a consumption rate at all. This was not unreasonable since over 80% of the fish for which a P-value could not be calculated were yearling (Run 1) chinook and if they were moving through the system as smolts are likely to have a much slower growth rate than resident parr.

Despite this, over 17000 records had all six indicators calculated and four of these: (indicators 1,2,4 and 6) are compared and shown in Figure 7. The best correlated measures are Indicators 2 and 4. For indicator 2, all available temperatures are used to model the growth. We expect any two measures to be correlated, but not exactly. It is possible for fish to grow at fast or slow rates and still feed at a fixed proportion of their maximum consumption rate. Temperature, variation in the energy density of their prey, the proportion indigestible, etc. all affect the true growth rate for a fish feeding at a given P value.

Of the six indicators, some of them are considered undesirable. Indicator 4 is preferred for weight growth over indicator 3 because it better represents the curvilinear nature of growth in fish and requires no more information. Indicator 6 is chosen over indicator 5 for analogous reasons. A decision between indicator 1 and 2 is somewhat less simple. Indicator 1 requires only two temperature readings but is therefore sensitive to their exact values and their ability to represent the true thermal experience of the fish. Indicator 2 attempts to use as much temperature information as possible. Although more difficult to gather, the additional information is valuable since the bio-energetic dynamics are temperature dependent.

Figure 7 compares indicators 1, 2, 4, and 6 for all the fish records examined. The bottom row of three graphs shows the relationship between the three indicators chosen: 2,4, and 6.

2.5 Application of size and growth information to juvenile chinook ecology

There are several possible analyses for the data, once the growth indicators have been determined. This study screened the following:

1. Comparison of different growth indices.
2. Influence of release length on survival to recovery.
3. Influence of release size on growth rate.
4. Influence of average growth temperatures on growth rate.
5. Spatial variation in growth rate.
6. Influence of total number of fish on growth indicators.
7. Characteristics of juveniles that return as adults.

Influence of release length on survival to recovery

Several studies have demonstrated the significance of release size on return survival (Bilton 1984; Martin and Wertheimer 1989; Ward et al. 1989) for salmon. Whether this size advantage is conferred at all stages of the life cycle is not clear. Examination of the relationship of release length on survival to recovery while the fish are juveniles may shed light on the influence of this factor during the early life history. Survival to recovery is not the same as general survival. The recovery database does not include all detections of PIT tagged fish, only those that were removed from the river and remeasured. Many fish that have length and or weight recorded at the time of tagging are subsequently *detected* at downstream locations, however, only a few of these are *recovered* and remeasured.

The effect of initial length on survival to recovery and remeasurement was determined by examining the frequency distribution of weights of recovered fish sizes compared to released fish. For this analysis, large releases (counts) were identified and subset based on recoveries of 20 or more fish. To ensure the largest possible number of groups, the SNAKER-released, wild sub-yearling chinook designated “1,5,W” were included with the other wild sub-yearling chinook. The recovered fishes’ release lengths (*y*) were considered to be a random sample from the release lengths (*x*). Three tests were performed on the release and recovery data: 1) Kolmogorov-Smirnov goodness-of-fit for the distributions as a whole, 2) Welches modified t-test for comparison of the means, and 3) an equal variance test. The null hypotheses are respectively: $H1_0 : f(y) = f(x)$ $H2_0 : \bar{y} = \bar{x}$ $H3_0 : var(x) = var(y)$.

Although there are some discrepancies in the actual number of released fish and the number of records for each release, it was assumed that the meta-data was wrong in these cases and that the individual records were in fact valid, i.e. the meta-data may indicate a release of *n* fish, there may in fact be >*n* records of individual fish from that release.

Table A5, through Table A8 show detailed results for these comparisons. In the case of wild yearling chinook, in only seven out of 120 tests of H2, the null hypothesis was rejected it appears that recovered fish are randomly distributed from the releases. Similarly for the wild sub-yearling chinook, in only two out of 22 cases of H2, the null hypothesis was rejected and it appears that the recovered fish were randomly distributed from the releases.

In the cases of hatchery fish, in 27 out of 63 tests of H2 for sub-yearling chinook, the null hypothesis was rejected, and for 22 out of 150 tests of H2 for yearling chinook, the null hypothesis was rejected. This suggests that the influence of release size on survival to recovery varies between the rearing types. Growth indicators for a population of fish that have differential survival based on release size will be biased if the individual growth indicators are correlated with the release size (see below).

Unexplored potential biases include:

- differential survival of larger fish due to handling stress suffered more acutely by the smaller fish
- differential probability of recapture of larger fish
- influence of time between release and recapture (the shorter the time period, the less chance of a noticeable signal)
- influence of particular system or season.

Influence of release size on growth

The influence of release size on growth is important because it examines:

- the bias of growth indicators suggested above due to differential survival
- detection of differential growth opportunities for fish of different sizes
- adjustment of intra-group growth parameter distributions.

Release size (length) is a significant predictor of subsequent growth. Figure 8 through Figure 10 show how the three indicators relate to eight groups of fish. In almost all cases, the negative correlation suggests that the smaller fish are growing better than their larger counterparts. This could be due to prey selectivity, habitat availability, or other factors that contribute to growth opportunities. Larger fish may have trouble finding suitable prey or may grow more slowly due to smoltification and migration energy requirements. The most significant lines are for the subyearling chinook that are more likely to be active feeders in the system. Regression lines for the yearling fish (run 1) are very flat and some are insignificant.

Temperature related growth

Indicator 2 required creating a temperature profile. Method 3 and Method 4 for temperature profile modeling were considered. For many fish, the methods produced identical profiles, but for some fish the differences are significant. Figure 11 compares the average temperature of the method 3 and 4 profiles for each record.

Indicator 2 showed a very strong signal in response to temperature. Figure 12 shows the relationship of indicator two to the average temperature from method 4. Since the P-value calculated with the bioenergetics model is designed to be independent of temperature, this suggests that it reflects productivity in the system. The negative or zero correlation that exists for Run 1 may simply demonstrate that these fish are doing very little feeding in the system.

Indicators 4 and 6 are perhaps less informative. Figure 13 shows the relationship of growth indicator 4 (weight) to average temperatures from methods 3 and 4 respectively. Figure 14 shows the relationship of growth indicator 6 (length) to average temperatures from method 4.

Both indicator 4 and indicator 6 are very similar for a given type and run. The results for comparisons of different types and runs are more complicated. Hatchery and wild fish have somewhat opposite patterns in their growth-temperature relations, with hatchery sub-yearling chinook showing an increase in growth rate with temperature and wild sub-yearling chinook showing a negative or non-existent relationship of growth rate to temperature. A summary of the regression relations are shown in the table that follows.

Table 10 Relationship of Indicators to average temperatures determined by method 4.

		Average of temperatures using method 4			
		Wild		Hatchery	
Indicator		Yearling	Subyearling	Yearling	Subyearling
2 : P-value	p	.092	0	.017	0
	R2	.00079	.23	0	.36
4 : Weight	p	0	.953	.27	0
	R2	.026	0	0	.36
6 : Length	p	0	.62	.28	0
	R2	.034	0	.00016	.28

Arguably, these regressions have many problems. Most notable is the inconsistency of the length of time between release and recapture, the longer that time difference, the less likely that the growth rate is correlated to this average, because the intervening temperature experience of the fish has an increasing chance of being different than that average. A weighted regression (using 1/days as the weight; not shown) gave slightly different results but these differences were small.

Growth in warm waters is important because reservoir temperatures as well as lower Snake river temperatures regularly exceed 20 ˚C in the summer while the optimum growing temperature for chinook salmon is closer to 15 ˚C. Identifying fish that were exposed *only* to warm temperatures is little more difficult. Only 50 fish were reported to have been released and recovered in water > 20 ˚C. Forty eight of them were Snake river hatchery sub-yearling chinook released at SNAKER or LGRCOL sites and recovered at LGR or LGS. Many more records (>680) show recovery in temperatures > 20 ˚C but the release temperatures varied from 13.5 to 20.5 For fish that are released in comparatively cooler water and recovered in warm water, it is not known precisely what portion of their in-stream growth occurred under the warm conditions.

The best data available are records of fish that are release and recovered in 20˚C water (for higher) A comparison of the warm-exposed fish to those released and recovered in water temperatures strictly below 20˚C shows very little difference in the growth indicators.

It is not clear whether this growth data set can be used to determine the effects of warm water on the growth of these fish. Indicators 1 and 2 were difficult to obtain for these fish and those that did have P-values calculated were at a very high level. This may indicate that the true temperature experience of these fish is not well represented by the release and recovery temperatures. Alternatively, behavioral modifications of the fish affect their true temperature experience or the productivity issues are significant.

Influence of total number of fish on growth indicators.

The mean and median of the growth indicators was used to characterize the different distributions by system, run, and type. These, in turn were compared to the smolt indices for the years 1971 to 1997 when good records were available. Correlations are weak and any interpretation should be done carefully. For example, positive correlation does not necessarily imply that more smolts and the growth rate are linked. Perhaps, a year that is good for smolt numbers will be good for smolt growth—an intuitive but non-informative conclusion. Figure 17 and Figure 18 show the relationship between the mean and median values of the growth indicators of Snake River wild sub-yearling chinook to the smolt indices at LGR. The lines shown are the least-squares regression line.

Characteristics of juveniles that return as adults

Very few of the fish in this database subsequently returned as adults. There are over 2200 records of PIT-tagged fish returning to GRA, however, most of these were not recovered prior to being detected as adults. As a result, it is questionable as to whether the recovery data will be helpful for determining the effect of growth rate on survival. Only 30 of these fish were recovered as juveniles and remeasured, and of these, 11 were wild chinook.

The release length is generally available and the released sizes of the fish that returned as adults appears to be slightly greater than for the fish in the recovery data base.

2.6 Spatial variability in growth

Two method for examining spatial differences in growth use multiple recovery records. A third method uses all the records and distinguishes between fish in different locations.

Multiple recovery records

Multiple recapture records were examined for differences in growth between the first and second recapture. The data was screened to find fish that had been recovered exactly twice. For individual fish that were recovered three or more time, only two of the recovery records were used. The priority system for omitting extra recovery records was:

- Any recovery records when duration between any release and subsequent recovery was less than one day.
- Shortest duration(s) between release and recapture under five days
- Any (and in some cases all) recovery records when duration of recovery was less than five days from original release.
- Middle (duration) record(s) of three or more if first recovery was greater than five days.

Table 11 Counts of available data according to run and rearing type for chinook recaptured more than once.

Run	Hatchery	Unknown	Wild
1	148	0	220
2	11	0	28
3	72	0	139
5	8	61	154

Second, the multiple recapture records were further screened to identify records where the second recapture point was distinct from (and downstream of) the first point.

The results of these methods are summarized in Table 12 through Table 15. Results for the distinct recovery site method are shown in Figure 15 and Figure 16.

Table 12 Spatial examination of growth using multiple recovery records for Run:1, Type:W. In each case: x is the first recovery and y is the second recovery. Null hypotheses are:

1) $f(x) = f(y)$. 2) $\mu_x = \mu_y$. 3) $\sigma_x^2 = \sigma_y^2$.

	The two recoveries are from:	Division between first and second recovery based on	n above & below division point	mean of indicators for 1st and 2nd recovery	Test results
Length: Indicator 6	Any locations	none	210 210	.000874 .000766	1) p = 0 2) p = 0.8334 3) p = 0
	Different locations	first recapture location	83 83	.00189 .00183	1) p= 0 2) p = .9413 3) p = 0
Weight: Indicator 4	Any locations	none	191 191	.00713 .00167	1) p = 0.0017 2) p = 0.005 3) p = 0
	Different locations	first recapture location	76 76	.00996 .00544	1) p= 0.1157 2) p = 0 3) p = 0.0058
P-value: Indicator 2	Any locations	none	78 78	.162 .159	1) p = 0.81 2) p = 0.8163 3) p = 0.8278
	Different locations	first recapture location	41 41	0.1884 0.1995	1) p= 0.420 2) p = 0.667 3) p = 0.593

Table 13 Spatial examination of growth using multiple recovery records for Run:1, Type:H. In each case: x is the first recovery and y is the second recovery. Null hypotheses are:

1) $f(x) = f(y)$. 2) $\mu_x = \mu_y$. 3) $\sigma_x^2 = \sigma_y^2$.

	The two recoveries are from:	Division between first and second recovery based on	n above & below division point	mean of indicators for 1st and 2nd recovery	Test results
Length: Indicator 6	Any locations	none	147 147	.00638 .00372	1) p = 0.1082 2) p = 0.0128 3) p = 0
	Different locations	first recapture location	39 39	.0142 .00498	1) p= 0 2) p = .001 3) p = 0
Weight: Indicator 4	Any locations	none	138 138	0.0155 0.00945	1) p = 0.0895 2) p = 0.0013 3) p = 0
	Different locations	first recapture location	34 34	.0350 .0131	1) p= 0.0057 2) p = 0 3) p = 0
P-value: Indicator 2	Any locations	none	105 105	0.178 0.170	1) p = 0.531 2) p = 0.434 3) p = 0.0236
	Different locations	first recapture location	10 10	.314 .314	1) p= 0.168 2) p = 0.185 3) p = 0.848

Table 14 Spatial examination of growth using multiple recovery records for Run:3, Type:W. In each case: x is the first recovery and y is the second recovery. Null hypotheses are: 1) $f(x) = f(y)$. 2) $\mu_x = \mu_y$. 3) $\sigma_x^2 = \sigma_y^2$..

	The two recoveries are from:	Division between first and second recovery based on	n above & below division point	mean of indicators for 1st and 2nd recovery	Test results
Length: Indicator 6	Any locations	none	139 139	.0133 .0132	1) p = 0.418 2) p = 0.8615 3) p = 0
	Different locations	first recapture location	53 53	.0138 .0125	1) p= 0.1324 2) p = .1802 3) p = 0
Weight: Indicator 4	Any locations	none	134 134	0.0450 0.0447	1) p = 0 2) p = 0.9084 3) p = 0
	Different locations	first recapture location	52 52	.0467 .0413	1) p= 0 2) p = 0.162 3) p = 0
P-value: Indicator 2	Any locations	none	120 120	.405 .477	1) p = 0.003 2) p = 0 3) p = 0.0521
	Different locations	first recapture location	44 44	.408 .550	1) p= 0 2) p = 0 3) p = 0.01

Table 15 Spatial examination of growth using multiple recovery records for Run:3, Type:H. In each case: x is the first recovery and y is the second recovery. Null hypotheses are: 1) $f(x) = f(y)$. 2) $\mu_x = \mu_y$. 3) $\sigma_x^2 = \sigma_y^2$.

	The two recoveries are from:	Division between first and second recovery based on	n above & below division point	mean of indicators for 1st and 2nd recovery	Test results
Length: Indicator 6	Any locations	none	71 71	0.0130 0.014	1) p = 0.0205 2) p = 0.3042 3) p = 0
	Different locations	first recapture location	21 21	0.0157 0.012	1) p =.196 2) p =.1387 3) p = .001
Weight: Indicator 4	Any locations	none	71 71	0.0560 0.0567	1) p = 0.264 2) p = 0.497 3) p = 0
	Different locations	first recapture location	21 21	.0627 .0416	1) p= 0.0948 2) p = 0.0129 3) p = 0.0014
P-value: Indicator 2	Any locations	none	59 59	0.440 0.571	1) p = 0.0042 2) p = 0.0017 3) p = 0
	Different locations	first recapture location	17 17	.510 .541	1) p= 0.751 2) p = 0.607 3) p = 0

The fish differ in how their growth indicators change in time. Whether this is the result of productivity, temperature, or behavior of the fish is not clear. Although we can be confident that the “different locations” screen for fish (second method) virtually ensures that the second recovery is downstream from the first, the spatial difference may be slight although for many of the fish the distinction is between a “SNAKER” site for the first recovery and “LGR” site for the second recovery.

- Yearling wild fish indicators show little difference between 1st and 2nd recovery, except the weight indicator which drops.
- Yearling hatchery fish indicators for weight and length drop, but the P-value indicator doesn’t change between 1st and 2nd recovery.
- Subyearling wild fish indicators don’t change between 1st and 2nd recovery, except the P-value indicator which increases.
- Subyearling hatchery fish indicators don’t change between 1st and 2nd recovery except the weight indicator which drops.

Indicator 4 drops significantly for all groups except the subyearling wild fish as they move lower in the system and the season progresses, whereas only for the yearling hatchery fish does indicator 6 drop.

Growth in different regions of the system

This is the third method of examining spatial differences in growth. The records were divided into two groups based on whether the fish were *both released and recovered* above or below a certain specified point in the system. (There is actually a third group of course that was released above the point and recovered below, but they are not included in this discussion.) This is similar to the second method in that the growth of the different groups is not overlapping, but the division point is specified and the groups consist of different individuals. Though Lower Granite Dam was considered, the specified point was the confluence of the Snake and the Clearwater as representing a boundary between the free-flowing and impounded portions of the system.

Figure 19 and Figure 20 show distributions of growth indicators for fish released and recovered exclusively above the confluence. Note that they are mostly unimodal with some possible exceptions.

Tests of the mean do not assume equal variance. Test of the median are valid but are less powerful (about 65% depending on the details of the test) than tests of the mean when such tests are possible (Zar, 1996). Figure 21 shows the distribution of Indicator 2 for fish grown either above or below the confluence and Table 16 compares these distributions. Similarly, Figure 22 shows the distribution of Indicator 4 for fish grown either above or below the confluence and Table 17 compares these distributions; and Figure 23 shows the distribution of Indicator 6 for fish grown either above or below the confluence and Table 18 compares these distributions.

The bimodal distribution of the wild yearling chinook growth distributions prompted a more detailed examination of the growth indicator distributions. General linear models to explain the variance in the p-values are very unbalanced due to gaps in the spatial and temporal heterogeneity of the distribution of these fish.

Table 16 Comparison of Indicator 2 (P-value) above and below the confluence

				Indicator 2 above confluence				Indicator 2 below confluence			
Low value	High value	Type	Run	Count	Mean	STD	Median	Count	Mean	STD	Median
0	1	W	1	2955	0.13964	0.03575	0.1057	261	0.29281	0.01912	0.3309
0	1	W	3	966	0.42067	0.02654	0.4334	14	0.48292	0.02344	0.53501
0	1	H	1	1227	0.27044	0.06237	0.1973	3874	0.25984	0.0347	0.2415
0	1	H	3	624	0.42773	0.06832	0.4407	439	0.59852	0.07006	0.652

Table 17 Comparison of Indicator 4 (Weight growth indicator) above and below the confluence

				Indicator 4 above confluence				Indicator 4 below confluence			
Low value	High value	Type	Run	Count	Mean	STD	Median	Count	Mean	STD	Median
-0.04	0.14	W	1	6203	0.00749	0.02503	0.00171	285	0.01497	0.01088	0.01772
-0.04	0.14	W	3	1074	0.04615	0.02065	0.04804	14	0.04021	0.01453	0.04222
-0.04	0.14	H	1	8407	0.03821	0.03442	0.0337	4245	0.01035	0.01583	0.00897
-0.04	0.14	H	3	698	0.05454	0.03261	0.05528	480	0.03257	0.02141	0.03843

Table 18 Comparison of Indicator 6 (Length growth indicator) above and below the confluence

				Indicator 6 above confluence				Indicator 6 below confluence			
Low value	High value	Type	Run	Count	Mean	STD	Median	Count	Mean	STD	Median
-0.02	0.08	W	1	6566	0.00172	0.0086	0.00058	285	0.00528	0.00281	0.00559
-0.02	0.08	W	3	1081	0.01369	0.00507	0.01417	14	0.01264	0.00316	0.01266
-0.02	0.08	H	1	8827	0.01603	0.01429	0.014	4286	0.00516	0.00598	0.00422
-0.02	0.08	H	3	713	0.01164	0.00998	0.01136	499	0.00992	0.00852	0.0114

Table 19 Significance tests for differences between upstream and downstream growth parameters. Null hypothesis for mean: “Downstream growth is not less than upstream growth”. Null hypothesis for median: “Median values are the same for upstream and downstream growth”. Indicator 2 is the P-value, Indicator 4 is the weight growth rate, and Indicator 6 is the length growth rate.

Growth indicator	Type	Run	Change in mean	p -value for $H_0{:}\mu_{down} \geq \mu_{up}$	p - value for $H_0{:}m_{down} = m_{up}$
2	W	1	greater	1	0
2	W	3	greater	0.923	0.0595
2	H	1	less	0.062	0
2	H	3	greater	1	0
4	W	1	greater	1	0
4	W	3	less	0.0767	0.0597
4	H	1	less	0	0
4	H	3	less	0	0
6	W	1	greater	1	0
6	W	3	less	0.1213	0.0597
6	H	1	less	0	0
6	H	3	less	0.091	0.8614

Wild yearling chinook

This is a biologically diverse group of fish, coming from headwaters in the Salmon, Clearwater and other tributaries throughout the Snake River drainage. None of the growth indicators (means) decrease for these fish below the confluence and the null hypothesis of growth below the confluence being greater than or equal to the growth above the confluence is not rejected for any of the three indicators. Note however that these indicators are all at much lower levels than for the other three groups.

The bimodal distribution of indicator 2 for the “released below the confluence” (Figure 21, lower panel, title: “1 W”) was also bi-modal for release date, comprised of those released in the spring and those released in the late summer or fall (Table 20) and the above-below analysis of growth indicators is repeated (Table 21) and shown in Figure 24. The late and early releases are essentially opposite. One interpretation is that the autumn releases of wild yearling chinook remain as parr (i.e. do not smolt), pass the winter in the river system with very low growth and as they move into the spring and summer, their growth rate increases (compared to the winter) is much higher even if they are low in the system. Note that the effect is less pronounced for indicator 2 which is consistent with the fact that this is a temperature dependent proportion of the maximum consumption rate.

Table 20 Details of wild yearling chinook. Summary of indicator 2 distributions.The early fish were released prior to Julian day 175, i.e. in the spring or early summer. The late fish were released after Julian day 175, i.e. in the late summer or fall.

Low value	High value	Type	Run	All growth above or below confluence	Released earlier or later than Julian day 175	Count	Mean	STD	Median
0	1	W	1	above	early	519	0.28877	0.0502	0.2693
0	1	W	1	above	late	2429	0.13268	0.02924	0.1088
0	1	W	1	below	early	224	0.38273	0.02234	0.4116
0	1	W	1	below	late	39	0.15043	0.00187	0.1497

Table 21 Significance tests for differences between upstream and downstream growth parameters for wild yearling chinook only. Early fish were released pre Julian day 175 and late fish post Julian day 175. H_0 for mean: “Downstream growth not less than upstream growth”. H_0 for median: “Median values are = upstream and downstream”.

Growth indicator	Type	Run	release group	$H_0{:}\mu_{down} \geq \mu_{up}$	$H_0{:}m_{down} = m_{up}$
2 (P-value)	W	1	early	1	0
2 (P-value)	W	1	late	0.9923	0
4 (Weight)	W	1	early	1	0
4 (Weight)	W	1	late	0	0
6 (Length)	W	1	early	1	0
6 (Length)	W	1	late	0.1621	0

We can not reject the null hypothesis for length (indicator 6) for the late fish below the confluence even though it is rejected for the weight indicator. These different results for the growth indicators could be due to the changes in body shape for these fish as they smolt. Wild fish above the confluence move significantly slower than their downstream counterparts (average 0.548 vs. 5.26 km/day respectively). The “early” wild yearling chinook travelled at an average speed of 5.23 km/day—indistinguishable from the downstream group.

Hatchery yearling chinook

All growth indicators decrease for these fish below the confluence compared to their counterparts above the confluence. Hatchery yearling chinook are released in the spring and early summer, with those above the confluence generally released slightly ahead of those in the lower river.

Hatchery yearling chinook are significantly larger than their wild counterparts on release and live in a river system more like the early releases of wild yearling chinook, than the over-wintering late releases. The hatchery fish upstream of the confluence grew faster than their downstream counterparts by all indicators and traveled faster (16.53 vs. 10.87 km/day). If the Imnaha river hatchery releases from site “522.308.074” are excluded, the average speed for upstream hatchery fish is reduced to 9.74 km/day. These migration rates are comparable to rates determined from PIT tag interrogation data (Zabel et al. 1998). This shows that the “system” is important for distinguishing the growth of different groups of chinook. Beckman et al. (1996) confirm the positive correlation of size with migration rate. Their growth indicators below the confluence are consistently the lowest for any of the four groups examined.

Wild sub-yearling chinook

Comparison of above and below is difficult for this group of fish. There were very few of these fish released below the confluence. Drawing general conclusions from this small sample is tricky and we fail to reject the null hypotheses for any of the three indicators. Thirteen of these 14 fish were released during a 20 day period in 1993. They were all released at a SNAKER site and recovered at LGR. Several issues are pertinent to interpreting these results: Temperature effects could allow higher consumption without accompanying growth. The travel rates both above and below the confluence are very slow compared to the yearling chinook (mean and median < 1) but increase below the confluence.

Hatchery sub-yearling chinook

Growth indicators for these fish suggest they are consuming more but growing less below the confluence compared to above the confluence. Indicator 2 (P-value) is greater, but indicator 4 (weight growth) is decreasing.

The hatchery fish move very quickly compared to the wild fish—by more than an order magnitude and their rates are comparable above and below the confluence. They are also released at a larger size then the wild fish.

During 1992 and 1993, Tom Curet (1993) studied the food habits of sub-yearling chinook in Lower Granite reservoir. During his sampling period, he *excluded* fish over 75mm during April and May and over 85mm during June. However, the average release size of sub-yearling chinook (all wild) in the recapture database recovered below the confluence of the Snake and Clearwater Rivers during these years (n= 119) was 79 mm and they had a mean recovery length of 133.5. Two possible explanations are:

1. the recovery data is wrong in some way: either the fish attributes (e.g. lengths) or the codes (e.g. "sub-yearling chinook") are wrong.
2. The fish grow significantly before recovery at a detection site.
3. Curet excluded a large number of fish that were potentially sub-yearling chinook.
4. The bias of recovery methods in favor of recapturing larger fish is highly significant.

He also concludes that the P-value (indicator 1 or 2 in this analysis) is .274 for these fish, whereas I conclude it is much higher (almost .6). This difference could be due to:

1. General implementation of the bio-energetic model.
2. Input data such as temperature profiles. There is no information about how temperature profiles are input.
3. Assumptions about weight-length relationships of the captured fish. There is no mention of how growth increment is calculated.

Although he does not declare prey density or digestibility values for the bioenergetic model runs, I inferred prey density from the stomach content analyses (Curet 1993) and published prey energy density calculations (Groot et al. 1995; Hanson et al. 1997; Hoar 1997). I assumed that ranges of prey density published by Hanson et al. represented minimum and maximum values for certain prey types and that the proportions of prey types found in the stomachs sampled by Curet represented consumption overall. Prey energy densities by this method were therefore between 2700 and 4220 J/g. Since the prey density and P-values compensate each other to a certain extent in the bioenergetics model, using his values of 2700 to 4200 J/g for prey density means that for a 100 g chinook at 15˚C in my formulation of the bioenergetics model, the P-value should be between ~.2 - .25 to get the same growth increment. I believe that in general, Curet's growth conclusions are not comparable to the ones presented in this analysis.

2.7 Suggestions for chinook growth modeling

Distributions of weight or length increments could be used to model the growth of any particular group of fish, but to take advantage of temperature and spatial effects, growth can be best modeled through the P-value. Some caution should be taken in modeling growth in this manner because the bio-energetics model is sensitive to certain inputs. Bartell et al. concluded that the model was most sensitive to P-values and the allometric consumption parameters *ca*. Attempts have been made to reduce the variability of P although it will still be possible to grossly over- or under-grow fish. The allometric parameters for consumption are assumed to be constant for juvenile chinook, even though we have seen that the weight-length allometric parameters change with smolting.

A simple method is to calculate P-values with a deterministic and stochastic component that incorporates the spatial differences in growth between groups and the temperature effect on P-value. The deterministic part as a linear function of temperature—the coefficients particular to the group and location, and the stochastic part as a random normal deviate. Growth of the fish will then be calculated through the bioenergetics model given a temperature profile and initial weight.

The P-value for a fish will be calculated in two steps. First the “normalized proportion” is determined from:

$$P' = A'_{ijkl} + B'_{ijkl}T + Z_{ijkl} \tag{22}$$

where

- $P' = \operatorname{asin}(\sqrt{P})$. The arcsine transform is commonly used to normalize proportion data.
- A' = intercept from regression
- B' = slope from regression
- T = temperature
- Z = random normal variate with mean = 0 for *i, j, k,* and *l*
- *i* = run index, either *yearling* (1) or *subyearling* (3)
- *j* = rearing-type index, either *wild* (W) or *hatchery* (H)
- *k* = system index, either *Snake, Clearwater, Salmon, Grand Ronde, Imnaha, or Mainstem* (the Lower River, i.e. below the confluence of the Clearwater and the Snake)
- *l* = timing index in case *i* = 1 and *j* = W, either *smolt* (early) or *parr* (late)

Second, the true proportion value (P-value) is then back-calculated as:

$$P = \sin(P')^2 \tag{23}$$

The table that follows details the fit and parameters for Eqn. (22).

Table 22 Regression coefficients for Eqn. (22), using the arcsine transformed proportion data. NA indicates too few fish.

Run (i)	Type (j)	early or late (julian 175 cutoff) (l)	System (k)	R2	p	intercept A'	slope B'	Variance of residuals	Count
1	W	early	Snake	NA	NA	NA	NA	NA	NA
1	W	early	Clwtr	0.0022	0.7608	0.6204	-0.0056	0.0887	48
1	W	early	GR	0.0045	0.1954	0.5355	-0.0043	0.0328	373
1	W	early	Imnaha	0.0230	0.6969	0.4846	0.0097	0.0306	9
1	W	early	Salmon	0.0180	0.1261	0.4437	0.0086	0.0682	133
1	W	late	Snake	NA	NA	NA	NA	NA	NA
1	W	late	Clwtr	0.1227	0.0000	0.5394	-0.0221	0.0396	335
1	W	late	GR	0.0485	0.0000	0.3972	-0.0096	0.0154	1315
1	W	late	Imnaha	0.0447	0.0033	0.3621	-0.0054	0.0019	191
1	W	late	Salmon	0.0696	0.0000	0.5474	-0.0193	0.0410	563
3	W	NA	Snake	0.0594	0.0000	0.2861	0.0278	0.0252	969
3	W	NA	Clwtr	0.0124	0.4314	0.4592	0.0088	0.0183	52
3	W	NA	GR	NA	NA	NA	NA	NA	NA
3	W	NA	Imnaha	NA	NA	NA	NA	NA	NA
3	W	NA	Salmon	NA	NA	NA	NA	NA	NA
1	H	NA	Snake	NA	NA	NA	NA	NA	NA
1	H	NA	Clwtr	0.0294	0.1531	0.3576	0.0281	0.0937	74
1	H	NA	GR	0.0728	0.0000	0.7461	-0.0311	0.0474	627
1	H	NA	Imnaha	0.1305	0.0034	1.4035	-0.0912	0.0542	65
1	H	NA	Salmon	0.0223	0.0012	0.7732	-0.0265	0.0694	492
3	H	NA	Snake	0.0353	0.0000	0.2681	0.0290	0.0666	577
3	H	NA	Clwtr	0.0323	0.1932	0.2522	0.0209	0.0346	54
3	H	NA	GR	NA	NA	NA	NA	NA	NA
3	H	NA	Imnaha	NA	NA	NA	NA	NA	NA
3	H	NA	Salmon	NA	NA	NA	NA	NA	NA
1	W	NA	LOWER	0.2776	0.0000	0.2706	0.0274	0.0139	261
3	W	NA	LOWER	0.2020	0.1069	-0.5785	0.0872	0.0189	14
1	H	NA	LOWER	0.0001	0.5278	0.5466	-0.0011	0.0351	3893
3	H	NA	LOWER	0.1156	0.0000	0.6727	0.0191	0.0634	447

Recalibration of the deterministic and stochastic parameters will need to be made when other data becomes available.

3 References

Bartell, S. M., J.E. Breck, and R. H. Gardner. 1986. Individual parameter perturbations and error analysis of fish bioenergetics models. Can. J. Fish Aquat. Sci. 43:160-168.

Beauchamp, D.A., D. J. Stewart, G.L. Thomas. 1989. Corroboration of a bioenergetics model for sockeye salmon. Trans. am fish soc. 118:597-607.

Beckman, B.R., D.A. Larsen, B. Lee-Pawlak, and W. W. Dickhoff. 1996. Physiological assessment and behavioral interaction of wild and hatchery juvenile salmonids: the relationship of fish size and growth to smoltification in spring chinook salmon. BPA Project 92-022. Bonneville Power Administration, P.O. Box 3621, Portland, OR 97208-3621.

Beeman, J.W., D.W. Rondorf, and M.E.Tilson. 1994. Assessing smoltification of juvenile spring chinook salmon (*Oncorhynchus tshawytscha*) using changes in body morphology. Can. J. Fish. Aquat. Sci. 51:836-844.

Curet, T.S. 1993. Habitat Use, Food Habits and the Influence of Predation on Subyearling Chinook Salmon in Lower Granite and Little Goose Reservoirs, Washington. Masters Thesis, University of Idaho.

Dickhoff, W. W., B. R. Beckman, D. A. Larsen, C. V. W. Mahnken, C. B. Schreck, C. Sharpe and W. S. Zaugg. 1995. Quality assessment of hatchery reared spring chinook salmon smolts in the Columbia River basin. American Fisheries Society Symposium 15:292-302.

Groot C. and L. Margolis, 1991. Pacific Salmon Life Histories. UBC Press. Vancouver, BC, Canada.

Groot C., L. Margolis, and W. Clarke. 1995. Physiological Ecology of Pacific Salmon. UBC Press. Vancouver, BC, Canada.

Hanson, P.C., T.B. Johnson, D.E. Schindler, and J.F. Kitchell. 1997. Fish Bioenergetics 3.0 for Windows. UW Sea Grant Institute. University of Wisconsin. Madison, WI.

Hoar, W. S. 1988. The Physiology of smolting salmonids. In Fish Physiology, VolumeXI. Hoar, W. S. and D. J. Randall, editors. Academic Press 1988.

Kitchell, J.F., Stewart, D.J., and D. Weininger. 1977. Application of a bioenergetics model to Yellow Perch and Walleye. J. Fish. Res. Board Can. 34:1922-1935.

Osse, J.W.M., and J.G.M van den Boogaart. 1995. Fish larvae, development, allometric growth and the aquatic environment. ICES mar. Sci. Symp. 201:21-34.

Perez-Gomas, J.A. and J.R. Skalski. 1997. The design and analysis of salmonid tagging studies in the Columbia Basin, Volume V: Analysis of In-river growth for PIT-tagged spring chinook smolt. BPA Project 9105100. Bonneville Power Administration, P.O. Box 3621, Portland, OR 97208-3621.

Ricker, W. E. 1979. Growth rates and models. In Fish Physiology, Volume VIII. Hoar, W. S., D. J. Randall and J. R. Brett. Academic Press.

Riddell, B.E. and W.C.Leggett. 1981. Evidence of an adaptive basis for geographic variation in body morphology and time of downstream migration of juvenile Atlantic salmon (*Salmo salar*) Can. J. Fish. Aquat. Sci. 38:308-320.

Stewart, D.J., D. Weininger, D.V. Rottiers, and T.A. Edsall. 1983. An energetics model for lake trout, *Salvelinus namaycush*: application to the Lake Michigan population. Can. J. Fish. Aquat. Sci. 40: 681-698.

Zabel, R.W., J.J. Anderson, and P. Shaw. 1998. A multiple-reach model describing the migratory behavior of Snake River yearling chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Aquat. Sci. 55:658-667.

Zar, J.H. 1996. Biostatistical Analysis. Prentice Hall, NJ.

Table A4 Growth parameters used in Eqn. (17)

Consumption parameters		Activity related parameters	
ca	.303	act	9.7
cb	-0.275	bact	0.0405
cq	5	sda	0.172
cto	15		
ctm	18	Excretion/Egestion parameters	
ctl	24	fa	0.212
ck1	0.36	fb	-0.222
ck4	0.01	fg	0.631
ctm	18	ua	0.0314
		ub	0.58
Respiration parameters		ug	-0.299
ra	0.00264		
rb	-0.217	Predator energy density parameters	
rq	0.06818	alpha1	5764
rto	0.0234	beta1	0.9862
rtm	0	alpha2	7602
rtl	25	beta2	.5266
rk1	27.5		
rk4	0.13	Prey energy density parameters	
		dy	5400 [1]

1. Small salmonids are assumed to be opportunistic (sources). Prey energy densities were initially assumed to be 3000 calories/gram, but were revised to 5400. From a modeling perspective, this allowed fish to grow at a wider range of rates and still contain their P-values between 0 and 1.

Table A5 Wild sub-yearling chinook tests of influence of release length on recovery. For each hypothesis test, bold indicates a *p* < .05

Release file ID	Number of fish recovered	Actual number of release records available	Ostensible release size from PTAGIS	days between release and recovery: (mean)	(std.)	p(H1)	p(H2)	p(H3)
WPC93160.229	27	34	53	11	14	0.8214	0.8388	0.5034
WPC93167.229	22	44	84	14	20	0.4197	0.1616	0.1011
WPC94137.E29	45	33	33	16	18	0.3062	0.5723	0.4503
WPC94144.E50	42	109	110	17	18	0.1025	0.2233	0.1241
WPC94145.E29	25	39	60	13	14	0.627	0.778	0.8144
WPC94146.A51	32	32	40	17	12	0.4337	0.2427	0.2693
WPC94151.W58	35	105	108	17	20	**0.007969**	**0.03343**	0.7911
WPC94151.W61	29	94	95	32	28	0.7183	0.5832	0.9531
WPC94152.A51	20	12	27	19	16	0.3738	0.09187	0.2237
WPC94152.E29	23	37	59	15	19	0.4596	0.4357	0.3704
WPC94160.A51	35	51	76	14	15	0.8008	0.6734	0.545
WPC94160.E50	10	119	120	54	21	0.553	0.4473	0.9429
WPC95145.346	24	20	24	22	20	0.7482	0.6501	0.9244
WPC95145.E22	35	23	29	20	19	0.6571	0.9497	0.6901
WPC95145.E24	29	37	37	21	21	0.9657	0.5729	0.7893
WPC95150.229	13	44	48	34	27	0.4807	0.2771	0.09952
WPC95151.W56	39	59	59	25	21	0.8383	0.4272	0.828
WPC95151.W58	12	21	21	36	28	0.9015	0.758	0.01616
WPC95151.W86	13	37	37	57	29	0.05993	**0.002702**	**9.894e-06**
WPC95158.E29	23	77	88	33	23	0.3855	0.3276	0.4164
WPC95159.E21	22	22	22	23	20	0.8717	0.2579	0.9864
WPC95166.W58	14	42	42	42	16	0.1217	0.1156	**0.008636**

Table A6 Hatchery sub-yearling chinook tests of influence of release length on recovery. Bold indicates a p value for the hypothesis test less than .05

Release file ID	Number of fish recovered	Actual number of release records available	Ostensible release size from PTAGIS	days (mean)	days (std.)	p(H1)	p(H2)	p(H3)
BDA97097.013	59	2514	2514	12	8	**0.0004583**	**3.267e-05**	**0.001708**
BDA97098.012	54	2516	2517	13	7	**0.01161**	**0.002413**	**0.005292**
BDA97099.005	48	2509	2509	12	11	**0.01449**	**0.02779**	0.08874
BDA97100.003	66	2512	2512	9	8	**0.001771**	**0.01033**	0.888
BDA97155.011	32	2495	2495	25	14	**2.049e-06**	**3.994e-06**	**0.0008019**
BDA97155.012	31	2464	2464	23	9	**0.0004407**	**0.0002472**	**0.02569**
BDA97156.003	38	2484	2484	22	11	**0.005481**	**0.01802**	0.463
BDA97156.005	34	2470	2470	24	13	**0.0003981**	**0.0005488**	0.09639
RNI95170.AS1	227	2795	2795	72	31	**0.005497**	0.3818	0.3785
RNI95178.AS2	226	2497	2497	75	45	**8.878e-05**	**0.002277**	**1.51e-05**
RNI95186.AS3	236	3528	3529	68	36	**7.97e-06**	**0.0001407**	**0.0001458**
RNI95215.FB1	55	827	827	2	3	0.1342	0.6888	**2.098e-05**
RNI96156.CW1	51	1258	1258	67	38	0.3453	0.2098	0.2025
RNI96156.PL1	50	1250	1250	60	41	0.6661	0.3219	0.3649
RNI96163.CW2	44	1253	1253	60	40	0.1041	0.1379	0.302
RNI96163.PL2	54	1249	1250	57	54	0.5556	0.3634	**0.01495**
RNI96170.CW3	48	1263	1263	73	72	**0.02437**	0.1323	0.1691
RNI96170.PL3	50	1261	1261	55	70	0.1512	0.3272	0.09726
RNI96177.CW4	36	1250	1250	58	40	**0.0001829**	**0.000674**	0.3159
RNI96177.PL4	57	1250	1250	36	42	**0.0007728**	**0.003849**	**0.004442**
RNI97148.PD1	414	6976	6976	30	27	**2.919e-07**	0.8512	**1.957e-07**
RNI97150.PD1	525	6978	6980	30	25	**2.919e-07**	0.4941	0.1074
RNI97154.PL1	81	1266	1266	17	13	**0.0244**	0.0787	0.052
RNI97161.PL2	54	1250	1250	22	12	**0.002441**	**0.006895**	0.02237
RNI97168.PL3	62	1249	1249	18	14	**0.00145**	**0.05381**	0.6599
RNI97175.PL4	78	1251	1251	19	19	**0.007499**	0.05693	0.08481
RNI97182.PL5	54	1263	1263	25	24	**0.04359**	0.06089	0.6195
WPC95142.BC1	91	1220	1320	57	26	**0.002312**	0.06234	0.6052
WPC95142.BC2	99	1317	1417	62	28	**0.0003695**	0.321	0.2401
WPC95142.BC3	95	1124	1219	64	34	0.4943	0.3314	**0.03874**
WPC95142.PL1	130	1353	1457	57	44	0.2612	0.5522	0.06786
WPC95142.PL2	143	1341	1395	48	41	0.09734	0.7274	0.541
WPC95142.PL3	104	1326	1427	70	56	0.3112	0.3369	0.1454
WPC96093.T13	148	2456	2457	12	5	**0.0007363**	**0.00167**	0.2859
WPC96094.T01	199	2497	2497	12	6	**0.04726**	**0.006911**	**0.004698**
WPC96094.T09	166	2490	2491	10	5	**0.0004329**	**0.0001185**	**0.00172**
WPC96095.T07	194	2487	2488	10	6	**0.005314**	0.07358	**0.01484**
WPC96096.T03	173	2490	2491	11	6	**0.02273**	0.1353	0.7294
WPC97097.T16	67	2445	2445	12	7	**0.004287**	**0.04005**	**0.03505**
WPC97098.T13	70	2489	2500	11	7	**0.01158**	0.07806	0.2787
WPC97099.T07	64	2488	2488	9	7	**0.0003876**	**2.601e-05**	**7.832e-05**
WPC97100.T03	83	2494	2498	10	8	**0.008169**	**0.003609**	0.3674
WPC97154.BC1	47	1253	1253	26	10	**1.08e-05**	**0.0003936**	0.8421
WPC97161.BC2	45	1256	1256	24	12	**0.002184**	0.9724	**7.906e-25**
WPC97162.14B	37	1251	1251	16	10	0.4085	0.5298	0.3887
WPC97163.06B	42	1250	1250	37	48	**0.0002083**	**0.001209**	0.7443
WPC97164.14B	32	1250	1250	18	13	**0.004394**	**0.0318**	0.5875
WPC97165.06B	53	1262	1262	24	19	**0.0003052**	**0.005022**	0.2243
WPC97168.BC3	42	1249	1249	29	12	**0.003352**	**0.001259**	0.634
WPC97175.BC4	35	1250	1250	39	7	**0.001093**	**0.002853**	0.6074
WPC97182.BC5	28	1251	1251	44	10	**0.02037**	**0.03861**	0.626

Table A7 Wild spring chinook tests of influence of release length on recovery. Bold indicates a p value for the hypothesis test less than .05

Release file ID	Number of fish recovered	Actual number of release records available	Ostensible release size from PTAGIS	days (mean)	days (std.)	p(H1)	p(H2)	p(H3)
BCJ93312.GR1	23	210	212	167	34	**0.003751**	**0.0009021**	0.9295
BCJ94335.CC1	25	201	201	146	221	0.5909	0.574	0.4265
BDA92307.001	35	98	101	26	64	0.4996	0.6079	0.8566
BDA92314.001	44	117	121	15	49	0.09926	0.6173	0.8821
BDA93244.004	30	141	142	45	71	0.8	0.3088	0.8271
BDA94130.001	27	67	69	2	3	0.1692	0.1496	0.6281
EJL92281.CF2	20	15	32	3	4	**0.007002**	**0.002199**	**2.574e-06**
EJL92294.CFT	13	34	36	2	2	0.9	0.28	0.8795
EJL93232.MCT	28	67	67	13	50	0.8751	0.6659	0.5644
EJL93233.MCT	79	152	155	18	60	0.688	0.9417	0.6242
EJL93234.MCT	37	95	100	1	0	0.1899	0.2918	0.1945
EJL93235.MCT	74	161	163	13	41	0.7878	0.7102	0.616
EJL93237.MC2	56	100	102	16	54	0.8836	0.1668	0.4085
EJL93238.MC2	44	90	96	4	11	0.9501	0.2994	0.07978
EJL93238.MCT	40	99	100	11	42	0.3153	0.365	**1.014e-05**
EJL93239.MCT	51	150	156	13	48	0.4569	0.7722	0.7571
EJL93241.MCT	55	84	92	4	5	0.6699	0.3092	0.0963
EJL93243.MCT	20	22	31	13	53	0.9458	0.7287	0.4495
EJL93245.MCT	47	51	97	26	73	0.9561	0.8196	0.8003
EJL93246.MCT	31	41	54	9	44	0.7483	0.9891	0.8449
EJL93247.MCT	21	32	35	3	7	0.8277	0.8536	0.9638
EJL93248.MCT	36	42	46	1	0	0.8212	0.7631	0.5652
EJL93249.MCT	40	85	96	8	38	0.954	0.5035	0.8795
EJL93250.MCT	234	486	496	6	30	0.3255	0.4048	0.648
EJL93251.MCT	78	120	120	7	42	0.06636	0.9745	0.6199
EJL93253.MCT	58	114	115	8	28	0.5321	0.8765	0.2921
EJL93255.MCT	61	97	101	9	41	0.5034	0.6683	0.6803
EJL93256.MCT	111	227	233	6	36	0.2909	0.8807	**9.49e-11**
EJL93257.MCT	29	43	46	0	0	0.6465	0.7063	0.5465
EJL93259.MCT	35	102	108	9	45	0.6971	0.3168	**3.442e-09**
EJL93260.MCT	44	69	69	1	2	0.4165	0.6104	0.6443
EJL93261.MCT	43	90	131	12	51	0.6677	0.699	0.9377
EJL93263.MCT	48	82	83	2	4	0.2465	0.6065	0.2833
EJL93264.MCT	35	55	59	8	38	0.9825	0.8722	0.6862
EJL93268.MCT	58	99	100	9	40	0.2395	0.2706	**3.553e-12**
EJL93271.MCT	95	200	201	5	30	0.5307	0.6316	0.001986
EJL93272.MCT	166	333	345	8	39	0.5911	0.4083	0.8705
EJL93273.MCT	207	312	315	5	27	0.222	0.3326	0.3784
EJL93274.MCT	176	273	275	7	35	0.459	0.5527	0.8167
EJL93275.MCT	87	110	112	1	3	0.2938	0.3612	0.5265
EJL93276.MCT	36	54	55	2	3	0.5448	0.7144	0.6488
EJL93277.MCT	75	110	113	4	32	0.2133	0.84	0.1948
EJL93278.MCT	62	100	103	1	2	0.3925	0.5413	0.2132
EJL93281.MCT	55	101	110	1	2	0.759	0.3194	**5.929e-13**
EJL93282.CFT	22	99	106	1	0	0.2335	0.5823	0.7291
EJL93282.MCT	75	100	105	6	33	0.4875	0.8877	0.7857
EJL93283.MCT	27	43	43	1	3	0.784	0.9969	0.6436
EJL93284.MCT	18	23	36	1	1	0.7879	0.8817	0.6719
EJL93286.MCT	27	46	46	8	38	0.944	0.9926	0.9435
EJL93287.MCT	34	54	55	1	0	0.678	0.5232	0.6163
EJL93289.MCT	23	33	39	1	1	0.8557	0.6658	0.8147
EJL93295.MCT	26	36	36	1	0	0.7608	0.8225	0.1692
EJL93296.MCT	23	36	80	1	0	0.1395	0.2842	0.204
EJL93301.MCT	21	27	27	11	49	0.8212	0.7926	0.9324
EJL94242.CFT	22	79	95	2	0	0.4352	0.4375	0.0973
EJL94252.CFT	22	83	85	16	57	0.7054	0.4275	0.116
EJL94253.CFT	20	92	111	1	1	0.3053	0.4284	**0.0116**
EJL94296.CFT	23	156	160	11	49	0.9973	0.7472	0.9776
JAH94252.001	36	86	86	21	0	0.4586	0.8649	0.9647

Table A7 Wild spring chinook tests of influence of release length on recovery. Bold indicates a p value for the hypothesis test less than .05

Release file ID	Number of fish recovered	Actual number of release records available	Ostensible release size from PTAGIS	days (mean)	days (std.)	p(H1)	p(H2)	p(H3)
JKB94089.RRT	10	44	59	31	49	0.8175	0.5368	**0.02869**
JKB94253.RRT	38	97	101	3	2	0.3831	0.8872	0.9704
JKB94256.RRT	20	39	47	2	1	0.5387	0.2326	0.4543
JKB94257.RRT	20	49	80	14	54	0.7463	0.6347	0.7351
JKB94258.RRT	21	49	72	11	45	0.2147	0.1125	**0.001495**
JKB94275.RRT	52	126	139	1	0	**0.02206**	0.1937	0.648
JKB95277.RRT	35	128	129	1	0	0.5927	0.1985	0.3373
JKB95300.RRT	46	216	224	4	26	**0.01254**	0.05955	0.7047
KMC94214.MC1	35	480	480	77	73	0.5523	0.31	**0.08818**
PMS96227.LR1	31	177	179	168	63	0.9835	0.5183	0.5735
PMS96228.LR1	23	107	107	162	69	0.144	0.3695	0.5298
PMS96239.CA1	30	121	121	134	74	0.8555	0.7495	0.6173
PMS96243.CA1	32	239	247	161	76	**0.08187**	0.2881	0.5201
PMS97251.IM1	30	439	439	89	77	**0.03181**	0.08543	0.334
PMS97252.IM1	32	463	463	121	76	0.5537	0.5011	0.6999
PTL93270.001	38	299	427	68	52	0.7428	0.3914	**0.00287**
RBK93236.CR4	34	331	361	275	38	**0.04015**	0.1083	0.2597
RBK94229.CR1	46	333	333	194	85	0.856	0.5055	0.2063
RBK94230.CR1	22	102	103	280	32	0.6195	0.4201	0.6099
RBK94231.CR2	50	496	535	151	98	0.3574	0.4881	0.5767
RBK94234.CR1	22	224	226	267	31	0.06507	0.2169	0.7287
RBK94234.CR3	36	270	273	159	103	0.0808	0.3806	0.4725
RBK94235.CR1	71	546	632	136	84	0.06051	0.2365	0.5996
RBK95075.CRT	22	52	74	1	0	0.8837	0.9922	0.9942
RBK95077.CRT	21	49	73	1	0	0.5987	0.5596	0.5577
RBK95079.CRT	25	49	71	1	0	0.1844	0.9476	0.553
RBK95080.CRT	16	49	90	1	0	0.9243	0.9223	0.9471
RBK95081.CRT	15	33	154	7	18	0.8807	0.9214	0.02286
RBK95082.CRT	13	32	154	90	301	0.8927	0.6845	0.3281
RBK95083.CRT	17	39	161	10	26	0.8986	0.733	0.5536
RBK95087.SWT	21	9	123	1	0	**3.327e-05**	**5.361e-07**	0.1199
RBK95089.SWT	14	7	130	1	0	**1.72e-05**	**0.0001799**	0.02798
RBK95091.SWT	11	10	135	1	0	**5.67e-06**	**9.574e-09**	0.4287
RBK95093.CRT	26	50	68	4	15	0.509	0.907	0.3262
RBK95094.CRT	25	50	78	1	0	0.6372	0.4966	0.7139
RBK95095.CRT	21	49	93	5	22	0.9169	0.8825	0.4545
RBK95096.CRT	25	50	96	8	31	0.966	0.4922	0.7019
RBK95099.CRT	22	44	58	5	15	0.5552	0.4299	0.4396
RBK95105.CRT	20	50	60	6	24	0.869	0.4437	0.562
RBK95106.CRT	22	50	70	5	22	0.4993	0.1244	0.06543
RBK95119.CRT	36	50	67	1	0	0.9147	0.4167	0.395
RBK95121.CRT	21	50	84	1	0	0.5246	0.4578	0.8026
RBK95125.CRT	12	35	72	7	21	0.965	0.6304	0.8602
RNI94105.AR1	14	520	525	12	3	0.8804	0.7024	**0.04638**
SA93215.MC1	59	378	387	69	62	**0.008523**	0.6616	**0.0005155**
SA93215.MC2	64	410	416	59	63	**0.03102**	0.3718	**0.001663**
SA94214.MC1	32	383	383	57	46	0.7376	0.7605	0.1651
SA94214.MC3	22	178	180	62	51	0.3549	0.637	0.3534
SA94214.MC4	33	406	419	59	41	0.7305	0.9613	0.3174
TRW93256.GR1	29	144	144	181	77	**0.00545**	**0.01028**	0.5034
TRW93257.GR2	23	214	214	211	47	**0.012**	0.1596	0.5112
TRW93258.GR2	23	197	197	182	80	0.149	0.1307	0.1911
TRW93259.GR1	30	307	307	186	97	**0.007387**	**0.03121**	0.9803
TRW94255.CC3	35	130	130	83	67	**0.01769**	0.4692	0.3786
TRW94256.CC1	56	262	262	86	72	0.1415	0.4741	0.5429
TRW94256.CC2	57	165	165	84	56	0.1186	0.5387	0.4943
TRW94256.CC3	31	228	228	62	51	0.2776	0.3423	0.2124
TRW94257.GR3	24	161	164	92	81	**0.04089**	0.4656	**0.01467**
TRW94258.GR1	49	146	146	64	187	0.6009	0.5598	0.562
TRW94258.GR2	28	275	275	82	105	0.7051	0.6243	0.201
TRW94259.GR1	20	165	167	122	131	**0.03226**	0.1857	0.7514

Table A8 Hatchery spring chinook tests of influence of release length on recovery. Bold indicates a p value for the hypothesis test less that .05

Release file ID	Number of fish recovered	Actual number of release records available	Ostensible release size from PTAGIS	days (mean)	days (std.)	p(H1)	p(H2)	p(H3)
CSM94054.A1A	46	1999	2000	11	16	**0.02419**	**0.03118**	**0.02624**
CSM94055.A2A	21	848	850	17	16	0.6969	0.2183	**0.0006378**
CSM94055.A2B	26	709	713	12	17	0.3352	0.4046	0.3245
CSM94055.A3A	28	999	1000	14	18	0.7558	0.5115	0.281
CSM94055.A3B	28	997	1000	10	13	0.3256	0.9265	0.05356
DAC94263.07B	25	230	230	5	9	0.4266	0.04017	0.11
DAC94263.08B	27	326	327	8	12	0.6251	0.6174	0.2255
DAC94264.AD1	41	499	500	191	20	0.6614	0.2971	0.5668
DAC94264.CWT	36	500	500	199	28	0.7123	0.7291	0.6835
DAC94264.RV1	49	999	1000	193	34	**0.005934**	**0.01182**	0.764
DAC96064.C07	29	500	500	3	11	0.6278	0.09318	0.2835
DAC96074.R11	22	1698	1698	40	18	0.8437	0.3058	0.4942
DAC96074.R12	31	1698	1698	39	17	0.6943	0.9423	0.273
DAC96074.R14	32	2222	2223	42	15	0.6517	0.7258	0.4534
DAC96074.R21	30	1696	1698	37	14	**0.00859**	**0.0009018**	0.3023
DAC96074.R32	28	2351	2351	38	17	0.9388	0.5916	0.6813
DAC96074.R42	44	2553	2553	35	16	0.7687	0.9688	0.7428
EJL92281.CF2	20	16	32	3	4	**0.005371**	**0.0003921**	0.07923
HLB96073.RW6	91	3866	3866	29	12	0.1872	0.7147	0.05174
HLB96074.R10	60	4221	4245	25	8	0.4077	0.3594	0.6375
HLB96075.R10	69	5077	5081	28	12	0.5988	0.4198	0.6257
HLB96078.R10	51	5253	5255	22	12	0.828	0.9229	0.1059
HLB97029.RW9	22	4075	4075	38	9	0.2766	0.3045	0.9872
HLB97036.R10	25	4343	4359	37	10	0.1632	0.2125	0.9939
HLB97037.R10	21	2675	2683	36	6	0.9942	0.974	0.5858
HLB97043.R10	25	4577	4606	36	10	0.5094	0.9533	0.8736
HLB98040.R05	44	3989	3989	20	4	0.6757	0.2717	0.6467
HLB98042.R07	33	4017	4017	23	4	**0.017**	0.2448	0.4805
HLB98043.R08	59	4023	4023	22	5	0.9427	0.8731	0.08693
HLB98049.R09	54	4009	4009	21	5	0.925	0.6435	0.8749
HLB98050.R10	80	4005	4005	22	4	0.2591	0.4314	0.776
HLB98054.R11	60	4009	4009	23	4	0.9419	0.5405	0.7022
HLB98056.R12	73	4008	4008	22	4	0.4679	0.3987	0.1013
HLB98057.R16	97	4005	4005	20	4	0.3996	0.4086	0.3739
HLB98061.R17	90	3997	3997	20	5	0.1259	0.7289	0.05285
HLB98063.R18	87	3995	3995	20	5	0.08243	0.9815	**0.04368**
HLB98064.R19	101	3993	3993	20	4	0.0804	0.4733	0.06076
HLB98068.C20	74	2998	2998	19	4	0.1673	0.5488	0.2104
KEP96325.2RD	73	250	250	2	7	0.2673	0.4742	0.6138
KEP96325.RD1	73	250	250	1	0	0.3182	0.8745	0.8109
LRB95046.R3A	20	489	499	94	232	0.4225	0.6206	0.6742
LRB95046.R4A	21	495	500	189	373	0.7019	0.8177	0.08046
PMS96046.003	37	243	243	3	3	0.8299	0.2236	0.1071
PMS96046.004	34	249	249	4	6	0.1348	0.7706	**0.0009448**
PMS96046.02A	23	286	286	2	0	0.3537	0.8845	0.9763
PMS96046.03A	40	261	261	5	9	0.8999	0.8257	0.7104
PMS96046.04A	37	261	261	9	13	0.438	0.7047	0.4604
PMS96046.OO2	25	228	228	7	8	0.174	0.7665	**0.004307**
PMS96047.005	25	228	228	6	10	0.1218	0.2596	**0.002376**
PMS96047.007	29	230	231	4	5	0.2598	0.8179	0.07855
PMS96047.060	23	211	211	5	6	0.9248	0.4619	0.8113
PMS96047.06A	23	223	223	4	8	0.274	0.1501	0.0009559
PMS96047.07A	31	275	275	6	10	0.6402	0.5038	0.004022
PMS96071.007	32	301	303	5	8	0.6411	0.8732	0.1334
PMS96071.06A	21	206	209	7	11	0.4243	0.6897	0.9976
PMS97028.3	256	1209	1209	6	7	**0.02483**	0.3894	**0.0007976**
PMS97028.3B	336	1631	1631	4	4	**0.003122**	0.143	**3.117e-07**
PMS97029.3	59	305	305	5	6	0.8187	0.7035	0.4081
PMS97029.3B	55	301	301	5	8	0.313	0.7205	**0.02921**

Table A8 Hatchery spring chinook tests of influence of release length on recovery. Bold indicates a p value for the hypothesis test less that .05

Release file ID	Number of fish recovered	Actual number of release records available	Ostensible release size from PTAGIS	days (mean)	days (std.)	p(H1)	p(H2)	p(H3)
PMS97029.4	336	1841	1841	6	7	**4.197e-05**	0.3344	**0.0006899**
PMS97029.4B	127	782	782	5	6	**0.001989**	0.2336	**4.313e-06**
PMS97029.4C	59	331	331	6	8	**0.05037**	0.2495	**0.02825**
PMS97029.4D	83	426	426	5	7	0.3153	0.4388	0.9384
PMS97030.4	179	1108	1108	5	6	**2.002e-05**	0.2081	0.359
PMS97030.4B	168	899	899	6	7	**0.001309**	**0.01382**	**0.03231**
PMS97030.6	332	1497	1497	5	6	**0.003133**	0.8449	**1.286e-05**
PMS97030.6B	283	1275	1275	5	7	**0.01532**	0.6008	0.1411
PMS97031.7	161	744	744	5	7	**0.01138**	0.9641	0.004975
PMS97031.7B	240	1029	1029	6	8	**0.01984**	0.7997	0.4273
PMS97034.14	41	2586	2586	17	10	**3.306e-07**	**0.0002571**	0.1881
PMS97035.14A	37	1934	1934	10	9	**0.008455**	**0.02957**	0.1098
PMS97035.14B	40	2605	2605	13	11	**0.007513**	0.1125	0.06792
PMS97036.17B	60	3025	3025	12	9	**3.059e-07**	**6.655e-05**	0.9908
PMS97037.17	33	2198	2198	13	9	0.1152	0.05767	0.116
PMS97037.17B	42	2208	2208	13	9	**7.063e-05**	**0.01505**	**0.03796**
PMS97041.15	26	1663	1663	13	11	**0.0009054**	**0.09927**	0.2018
PMS97041.15B	54	2778	2778	15	12	0.3163	0.554	0.6869
PMS97041.15C	26	955	955	18	11	**0.003835**	**0.02807**	0.9259
PMS97042.15	28	1910	1910	15	9	0.08854	0.3127	**0.0003323**
PMS97043.16C	60	3127	3127	14	12	0.8287	0.9034	0.8141
PMS97044.16	51	2581	2582	13	12	0.1631	0.1192	0.06922
PMS97044.16C	28	1386	1386	8	7	**0.00532**	**0.008674**	0.7317
PMS98048.02A	337	1806	1806	4	4	**0.03754**	0.367	**0.03182**
PMS98048.02B	202	1206	1206	4	4	0.06284	0.8657	0.448
PMS98049.05A	338	2100	2100	5	4	**0.0241**	0.8636	**0.0003844**
PMS98049.05D	343	1873	1873	6	4	**0.006247**	0.2011	**1.634e-12**
PMS98050.04A	218	1183	1183	5	4	**0.01743**	0.9645	**9.349e-07**
PMS98051.07C	415	2607	2607	6	4	**3.109e-07**	**0.004141**	**3.457e-09**
PMS98051.07D	287	1615	1617	6	3	**2.25e-06**	0.0856	0.9
PMS98054.03A	322	1826	1826	4	4	**0.04869**	0.77	0.05442
PMS98056.15A	61	2631	2631	7	5	**0.001007**	**0.01244**	0.7013
PMS98056.15B	44	2910	2911	7	5	**0.003528**	**0.001996**	**0.02198**
PMS98057.15A	61	2872	2872	7	6	**0.01367**	**0.01117**	0.2769
PMS98057.15B	63	2985	2985	7	5	**0.0009517**	**0.004198**	**0.02766**
PMS98058.15A	46	2642	2642	7	5	0.2683	0.235	0.4197
PMS98058.15D	50	2564	2564	7	5	0.11	0.1092	**0.007982**
PMS98061.15B	52	3164	3164	6	5	0.06035	0.5947	0.6809
PMS98061.15C	50	3124	3124	8	5	**0.002252**	**0.04944**	**0.05619**
PMS98062.15A	38	2454	2454	5	4	**0.03697**	**0.04796**	0.8707
PMS98062.15D	56	2804	2804	8	6	**0.0159**	0.123	0.1185
PMS98063.15B	50	1785	1785	9	5	**0.004228**	**0.05449**	0.8035
PMS98064.16C	56	3806	3806	11	5	**0.01042**	**0.01652**	**0.001273**
RBK95081.CRT	15	100	154	7	18	**2.925e-07**	**1.042e-06**	**0.04693**
RBK95082.CRT	13	100	154	90	301	**1.735e-06**	**7.212e-05**	**0.001505**
RBK95083.CRT	17	100	161	10	26	**4.049e-07**	**1.654e-06**	**0.006394**
RBK95087.SWT	21	105	123	1	0	0.4001	**0.04539**	0.3869
RBK95089.SWT	14	98	130	1	0	0.1465	0.2593	0.2803
RBK95091.SWT	11	100	135	1	0	0.9889	0.7068	0.738
RNI93104.R1B	94	823	863	13	6	0.08441	0.07831	**5.707e-14**
RNI93106.R3B	87	984	1055	12	6	0.4827	0.6584	**0.001937**
RNI93108.R5B	58	835	902	12	5	0.8242	0.3845	0.3789
RNI93109.R6B	48	617	641	13	3	0.8746	0.3918	**0.02158**
RNI93110.R7A	44	865	880	12	3	0.8276	0.7694	0.5082
RNI94104.AA1	34	1204	1206	18	4	0.5957	0.3102	**1.104e-08**
RNI94106.AB1	24	1200	1200	17	6	0.7245	0.6628	0.6327
RNI94107.AC1	22	1200	1201	18	7	0.8334	0.5981	0.1206
RNI94110.AD1	24	1197	1201	17	6	0.413	0.6399	**0.02891**
RNI94110.DA1	25	742	744	9	4	0.7882	0.3953	0.2661
RNI94110.EA1	22	743	743	9	4	0.8308	0.4284	0.1336
RNI94110.FA1	44	1481	1481	8	5	0.2252	0.9562	**0.0008992**

Table A8 Hatchery spring chinook tests of influence of release length on recovery. Bold indicates a p value for the hypothesis test less that .05

Release file ID	Number of fish recovered	Actual number of release records available	Ostensible release size from PTAGIS	days (mean)	days (std.)	p(H1)	p(H2)	p(H3)
RNI94112.CA1	21	732	733	8	3	0.1599	0.3219	0.7322
RNI94112.OA1	22	729	731	10	3	0.9462	0.764	0.1955
RNI94115.FB1	36	1476	1480	11	4	0.07609	**0.03735**	**0.003564**
RNI94116.KA1	28	770	774	5	5	0.6982	0.8883	0.4913
RNI94116.MA1	47	1498	1500	4	3	0.7213	0.509	**0.01171**
RNI94117.CB1	26	743	743	10	3	**0.02677**	**0.02979**	0.4778
RNI94118.HA1	31	1438	1442	4	2	0.3656	0.08095	**0.008114**
RNI94118.JA1	35	1436	1439	5	3	0.2228	0.4045	0.8497
RNI94119.EC1	20	742	742	9	2	0.5077	0.1125	**0.004903**
RNI94119.FC1	24	1490	1491	10	6	0.2406	0.3475	0.2431
RNI94122.KB1	32	802	803	5	3	0.1294	0.6043	**0.003954**
RNI94122.LB1	31	792	794	5	2	0.6783	0.2584	0.286
RNI94122.MB1	58	1461	1463	4	3	0.6416	0.9173	0.5668
RNI94124.HB1	64	1341	1346	3	4	0.1553	0.2222	**0.02276**
RNI94124.JB1	66	1362	1364	3	3	0.4204	0.6969	0.4561
RNI94125.402	41	53	53	0	0	0.7979	0.7763	0.8433
RNI94126.KC1	21	665	667	3	1	0.5174	0.4423	0.9124
RNI94126.LC1	27	707	708	4	3	0.04537	0.2289	0.4067
RNI94126.MC1	44	1393	1397	4	4	0.5298	0.489	0.09426
RNI95098.AA1	38	1250	1250	59	169	0.2267	0.06628	**0.002262**
RNI95100.AB1	32	781	781	94	256	0.2669	0.2937	0.2084
RNI95104.AC1	37	1183	1183	57	170	0.9396	0.1491	**0.003061**
RNI95107.AD1	20	568	569	78	232	0.127	0.2956	0.09083
RNI95110.AE1	32	691	691	82	228	0.08252	0.3287	0.4019
RNI95112.AF1	51	1246	1246	19	4	0.9753	0.6433	0.4307
RNI95114.AG1	61	1260	1261	18	4	0.9471	0.3071	0.1974
RNI95116.AH1	44	1223	1225	111	302	0.6732	0.4664	0.6108
RNI95118.AJ1	51	1065	1066	39	145	0.4218	0.3499	0.8588
RNI95120.AK1	38	1210	1213	71	234	0.3163	0.6639	0.882
TRW95031.171	22	249	250	10	12	0.4598	0.2327	0.9775

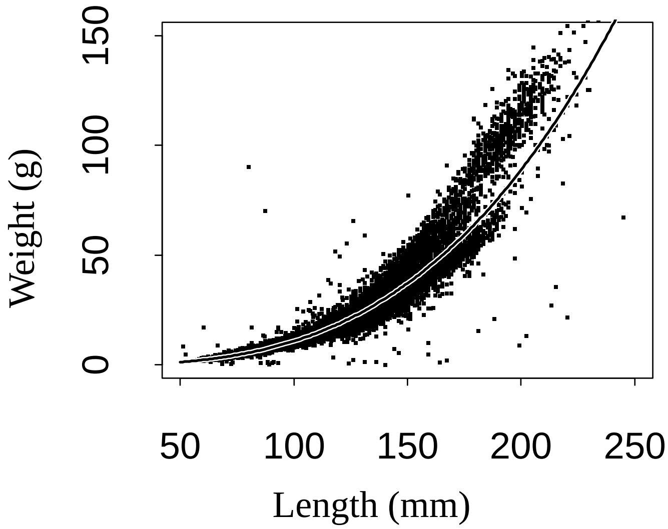


Figure 1 Length - weight relationship for all chinook, and plot of Eqn. (1).

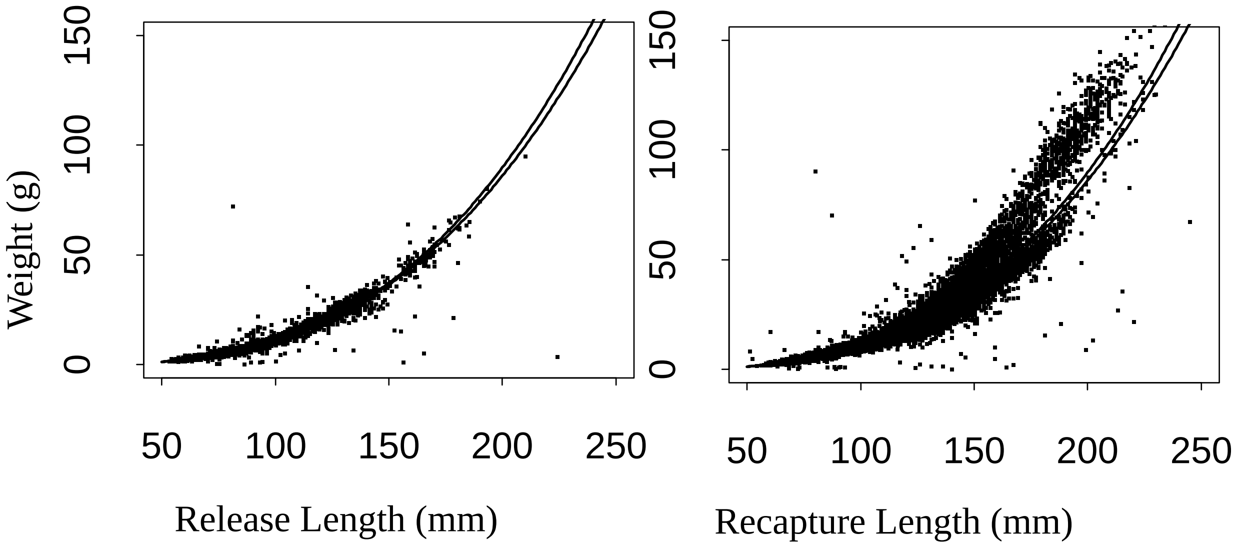


Figure 2 Weight / length relationship for released fish (left) and recaptured fish (right). The common regression for both the release and the recapture data are shown on both plots. They are significantly different in both slope and intercept ($p < .001$).

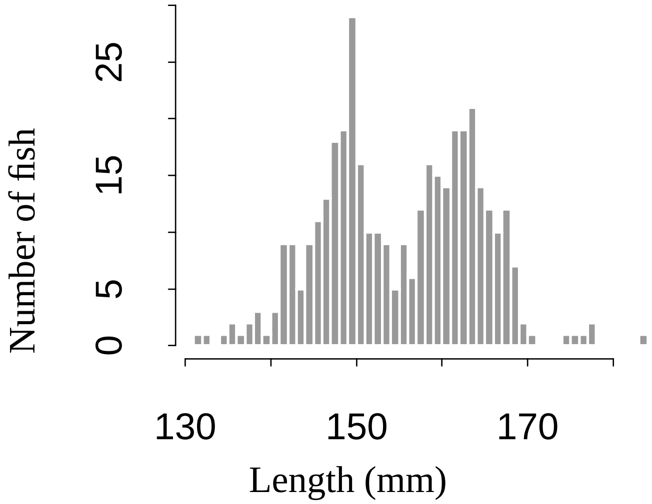


Figure 3 Example of the bi-modal distribution of lengths for recaptured fish weighing more than 40 grams and less than 44 grams.

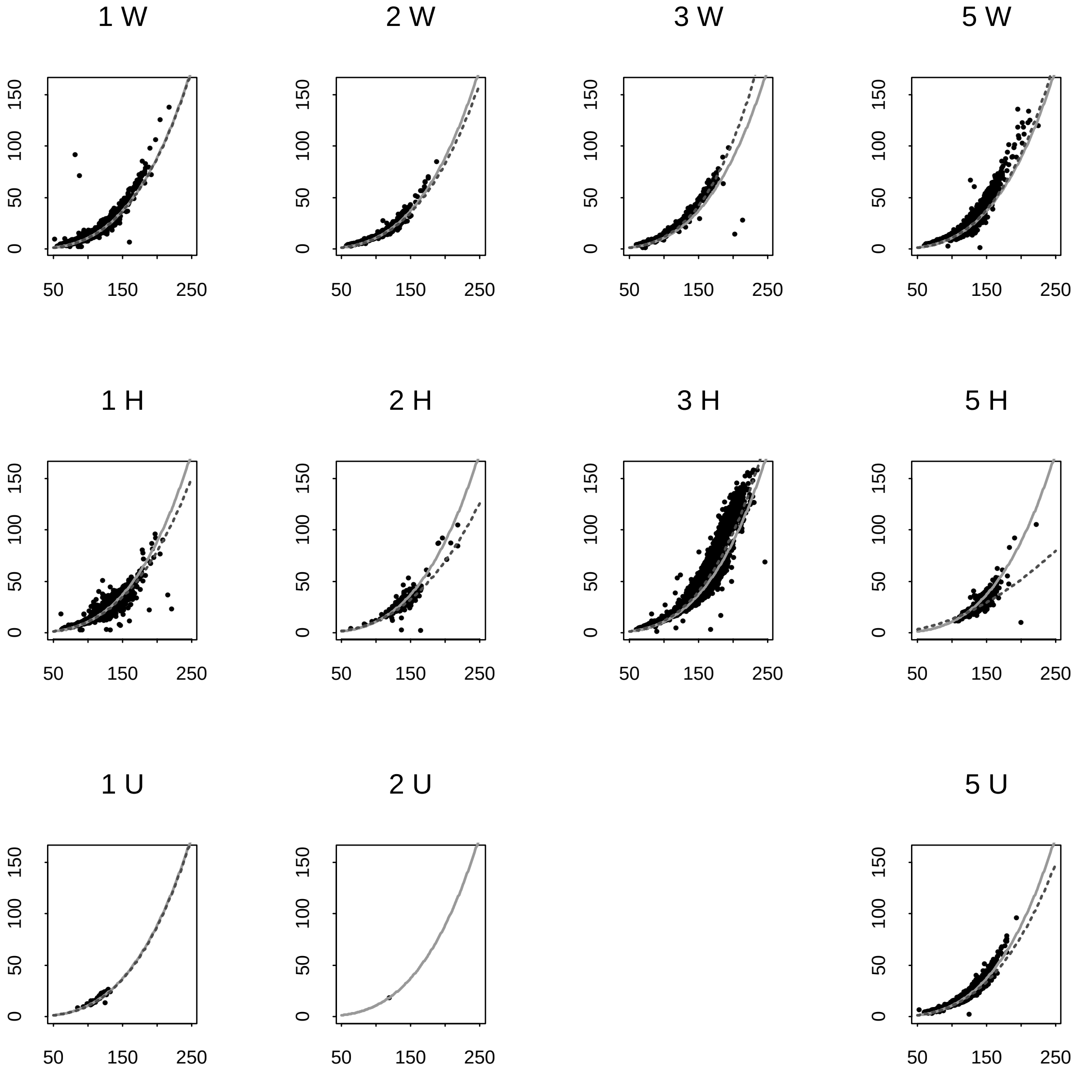


Figure 4 Weight (Y axis) vs. Length (X axis) plots for juvenile chinook salmon. Title show the runs: yearling (1, 2), subyearling (3), and unknown (5) and the rearing types: wild (W), hatchery (H) and unknown (U). Solid curve is the common regression curve for all releases and recoveries as in Figure 1. The dotted curves are local fits to individual run and rearing type recovery data (plotted points)

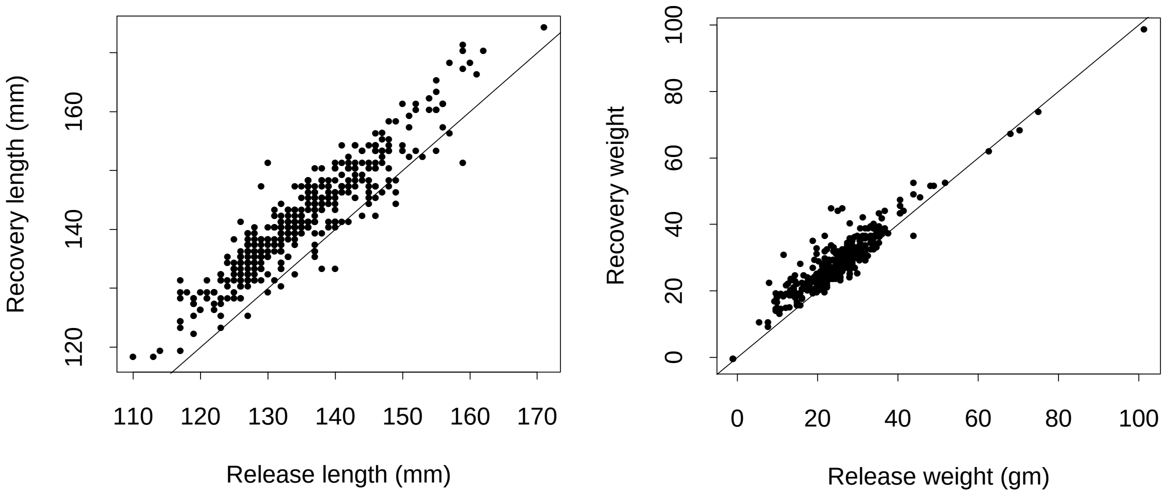


Figure 5 Release and recovery information for yearling hatchery chinook passing from LGR to LMO. The weights are modeled since no release weights are available and only one recovery weights is available.

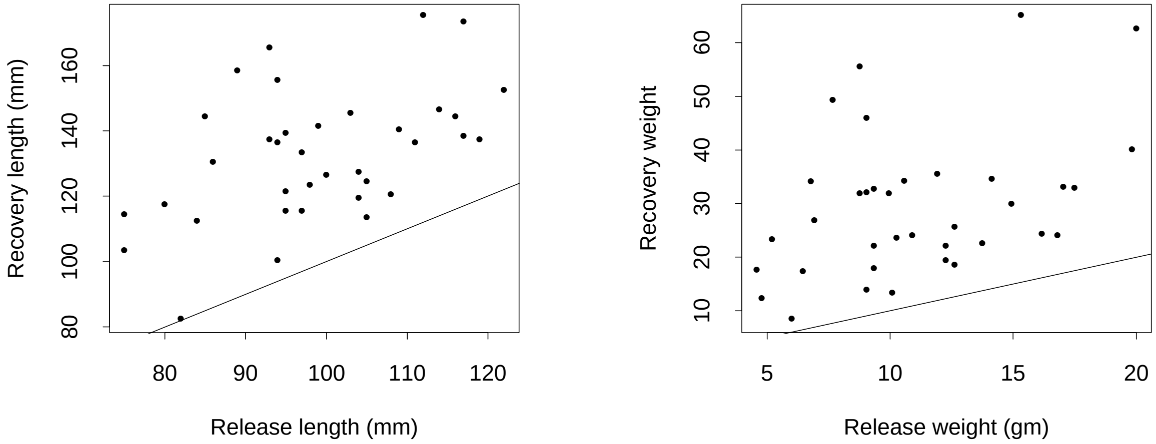


Figure 6 Release and recovery information for yearling wild chinook passing from GRANDR to LGR. Most of the release weights are modeled since only six fish were weighed on release. Recovery weights did exist and were used.

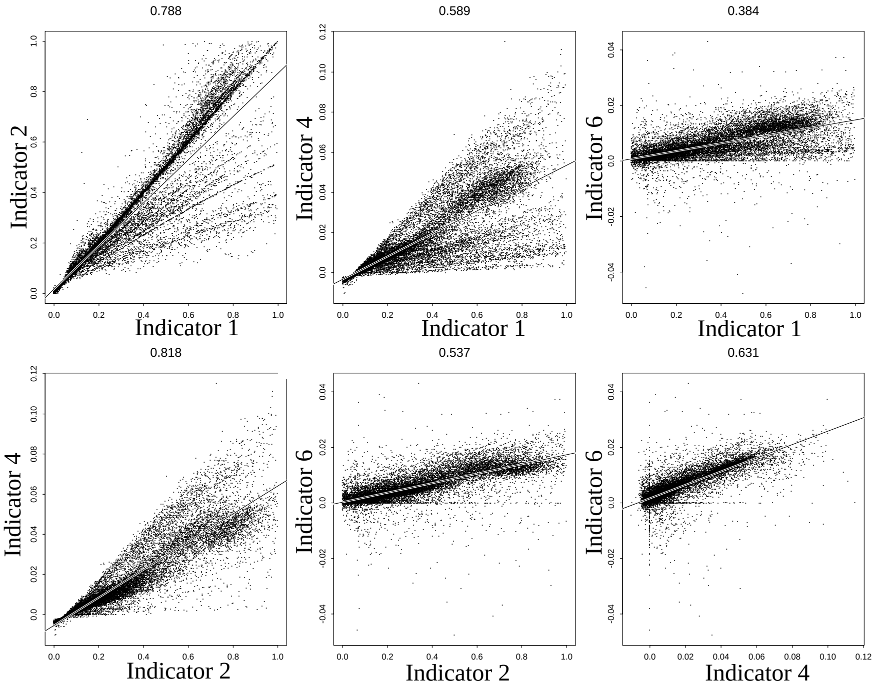
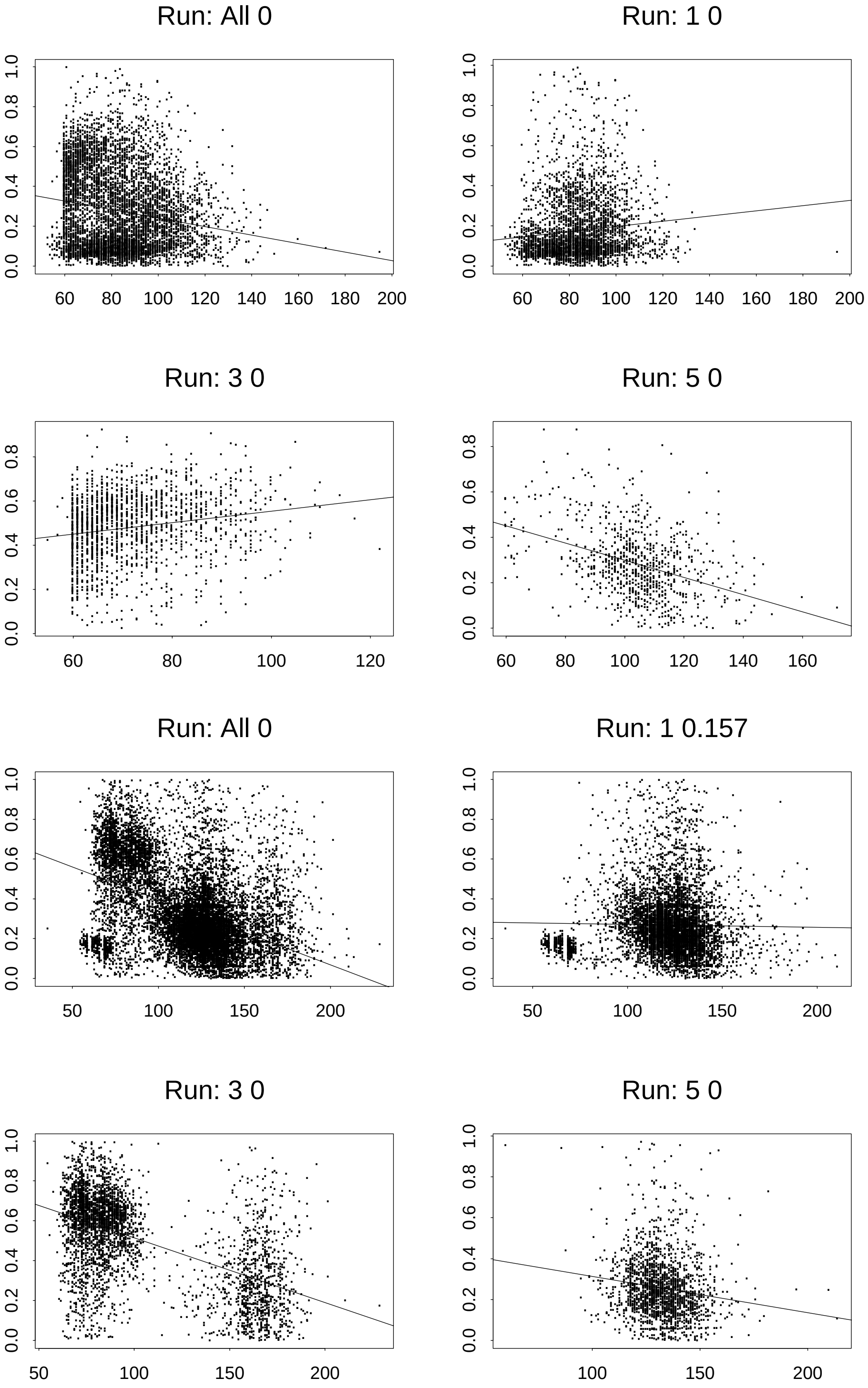


Figure 7 Comparison of the major indicators. The title of the graph show the R^2 for the regression line (drawn) between the two indicators. Indicators 1 and 2 are P-values by two different methods. Indicator 4 is the weight growth rate. Indicator 6 is the length growth rate.



Run: All 0

Run: 1 0

Run: 3 0

Run: 5 0

Run: All 0

Run: 1 0.157

Run: 3 0

Run: 5 0

Figure 8 Relationship of indicator 2 to release weights for wild chinook (above) and hatchery chinook (below). Title includes: run designator, and significance of the line (Run 3 above includes SNAKER 1,5,W fish).

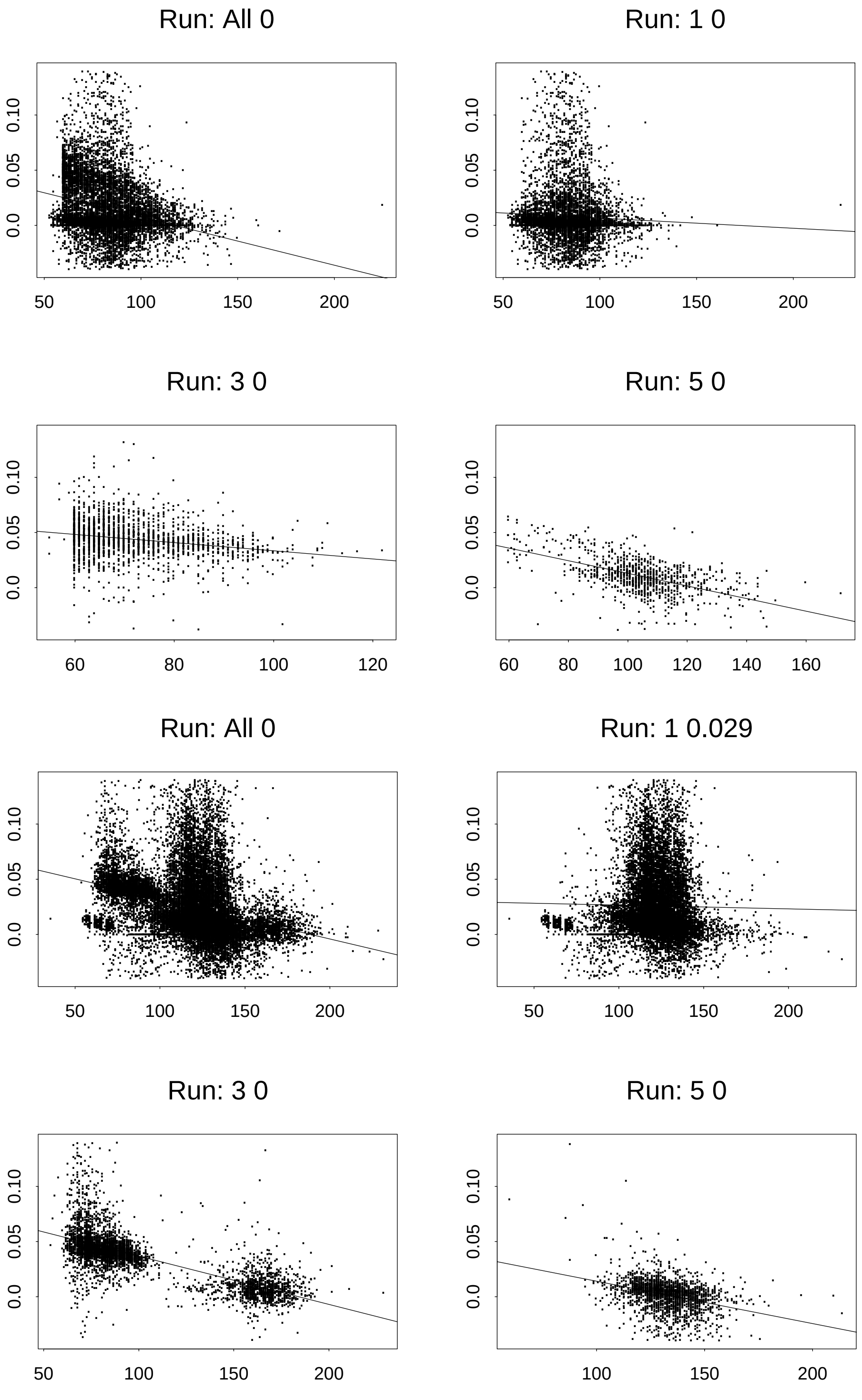


Figure 9 Relationship of indicator 4 to release length for wild chinook (above) and hatchery chinook (below). Title includes: “Run:”, run designator, and significance (p) for the line. Run 3 includes SNAKER 1,5,W fish.

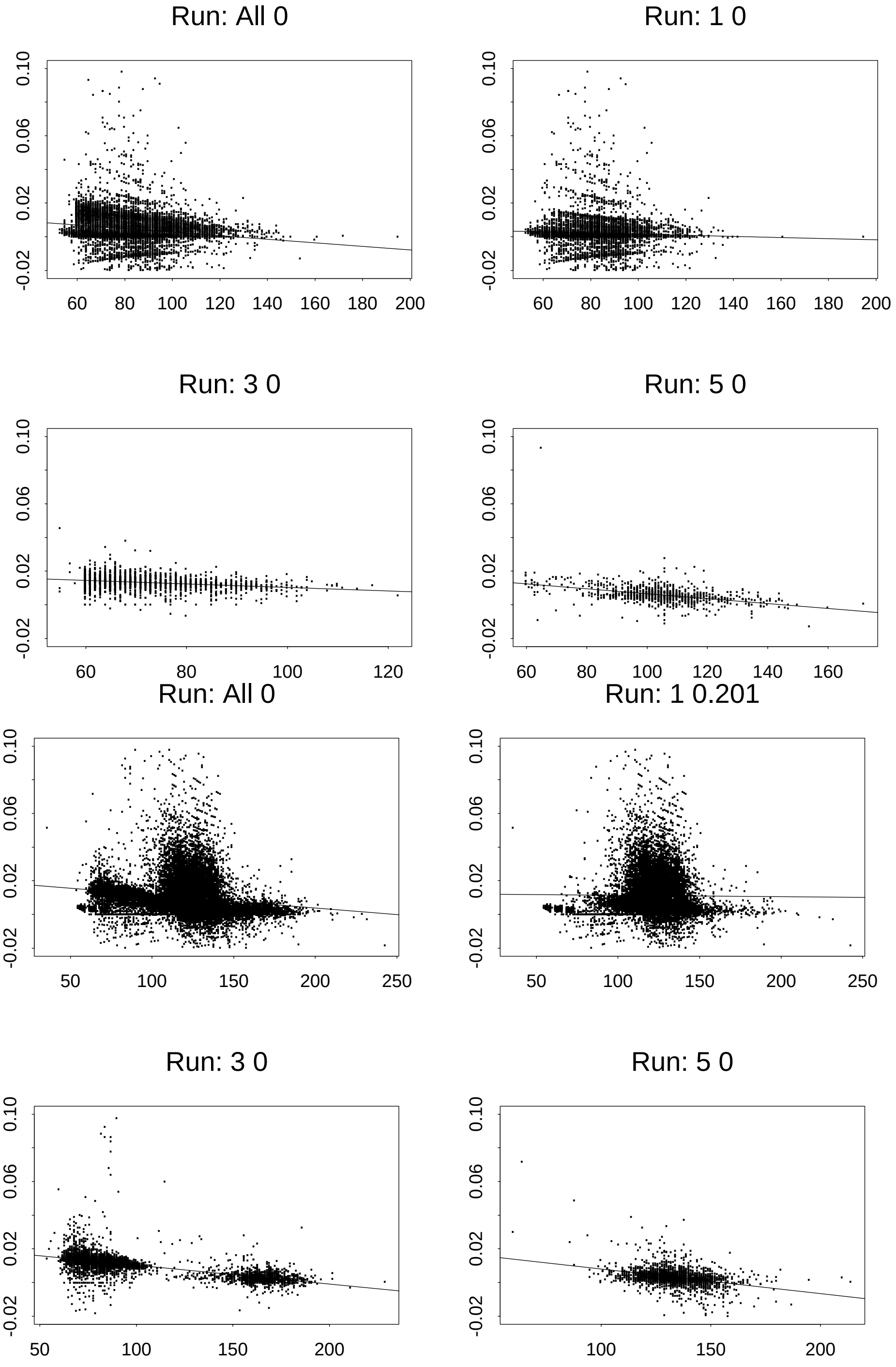


Figure 10 Relationship of indicator 6 to release length for wild (above) and hatchery chinook (below). Title includes: “Run:”, run designator, and significance of the line (1, W includes SNAKER 5,W fish).

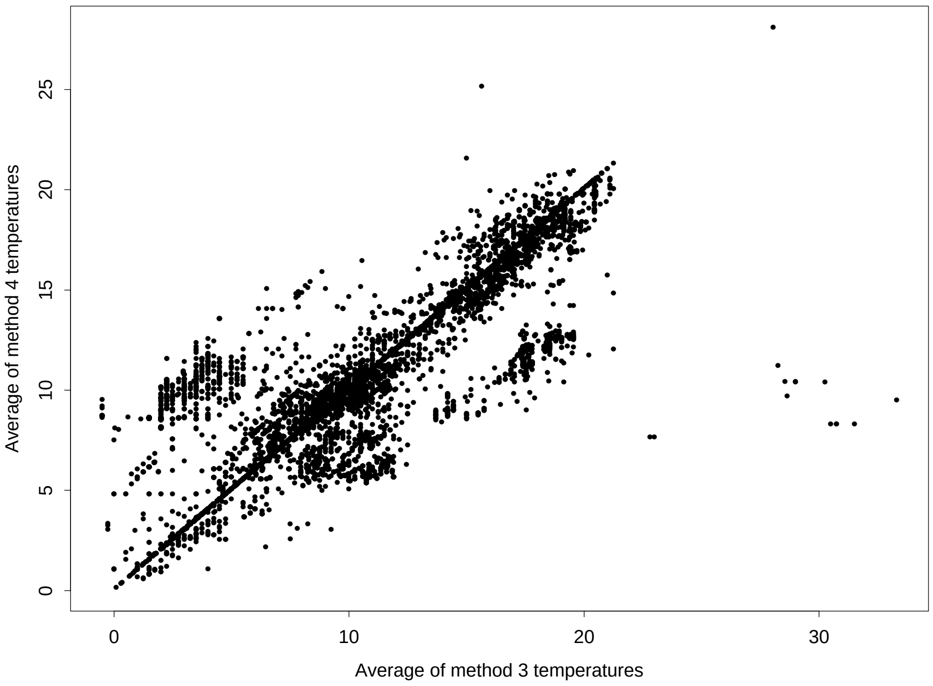


Figure 11 Comparison of average of method 3 temperatures to average of method 4 temperatures.

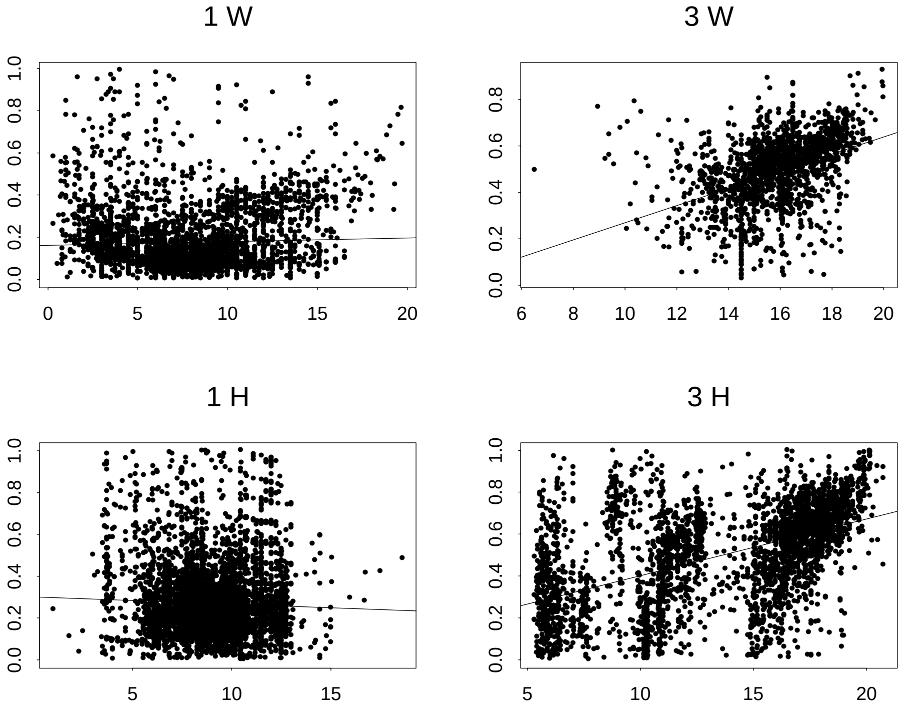


Figure 12 Relationship of indicator 2 to average method 4 temperatures Title shows run and type. Regression lines are shown.

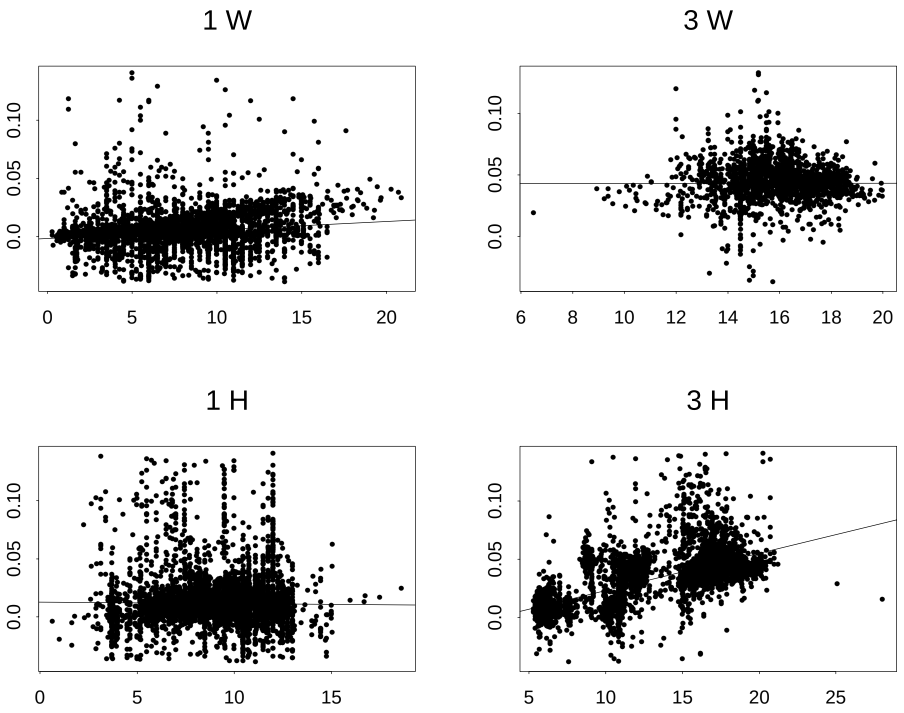


Figure 13 Relationship of growth indicator 4 to average method 4 temperatures. Regression lines shown.

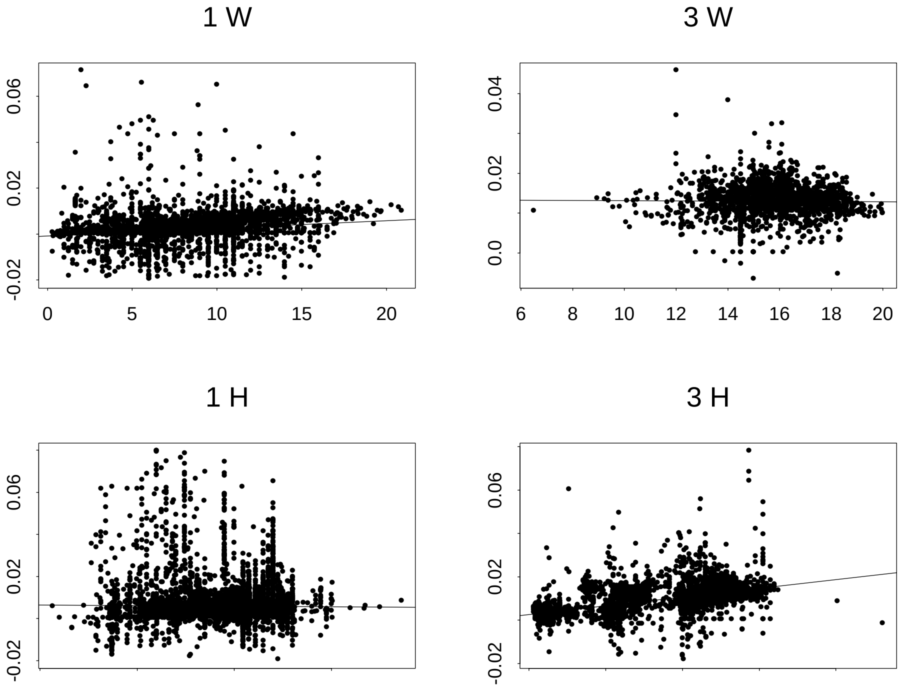


Figure 14 Relationship of growth indicator 6 to average method 4 temperatures. Regression lines shown.

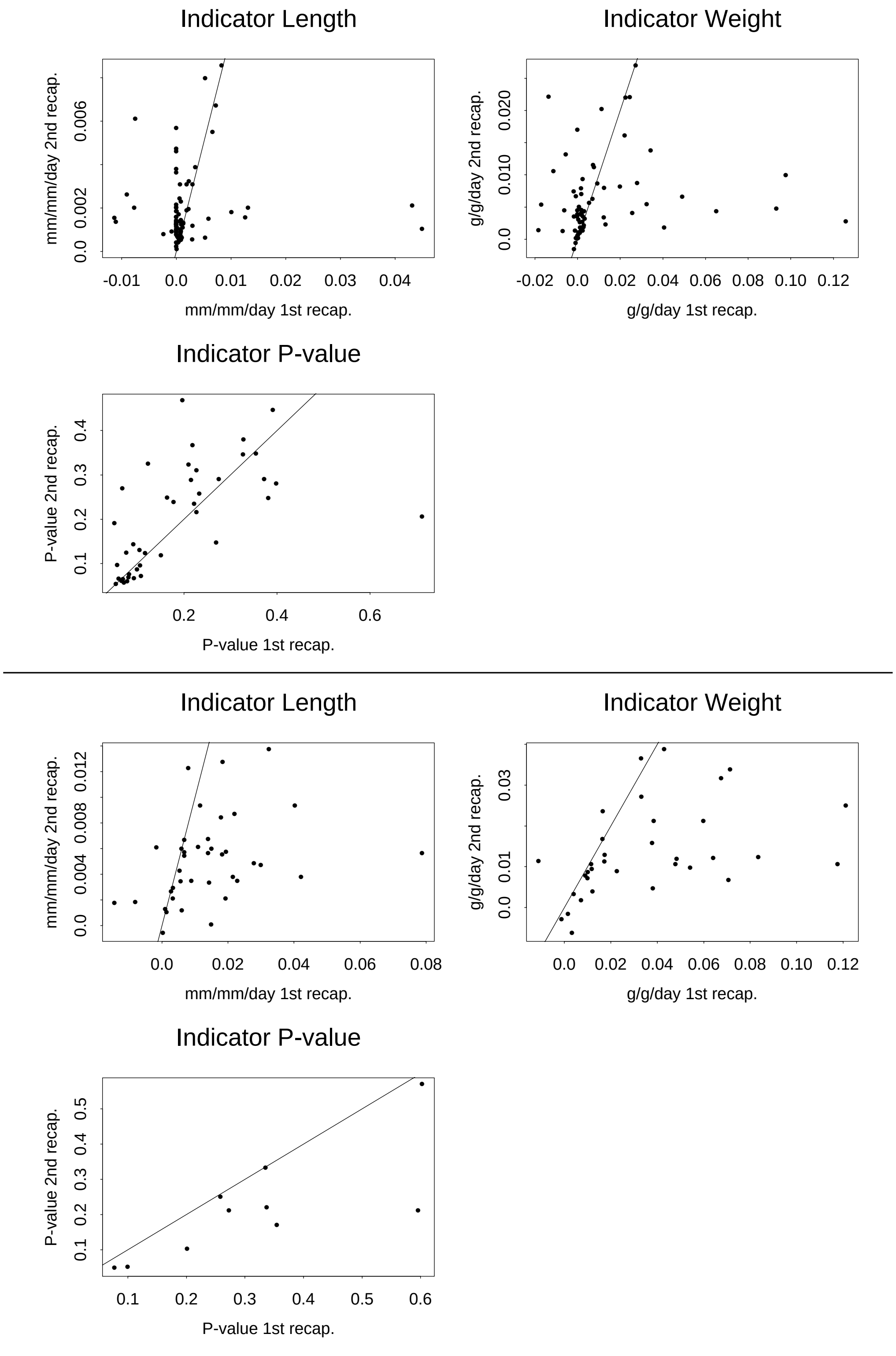


Figure 15 Differences in the three indicators for multiple recovery wild yearling (1, W) chinook above and hatchery yearling (1, H) chinook below. The second recovery was NOT at location of first recovery. X axis shows the indicator for the first recovery and the Y axis shows the indicator for the second recovery. Lines shown have intercept = 0 and slope = 1.

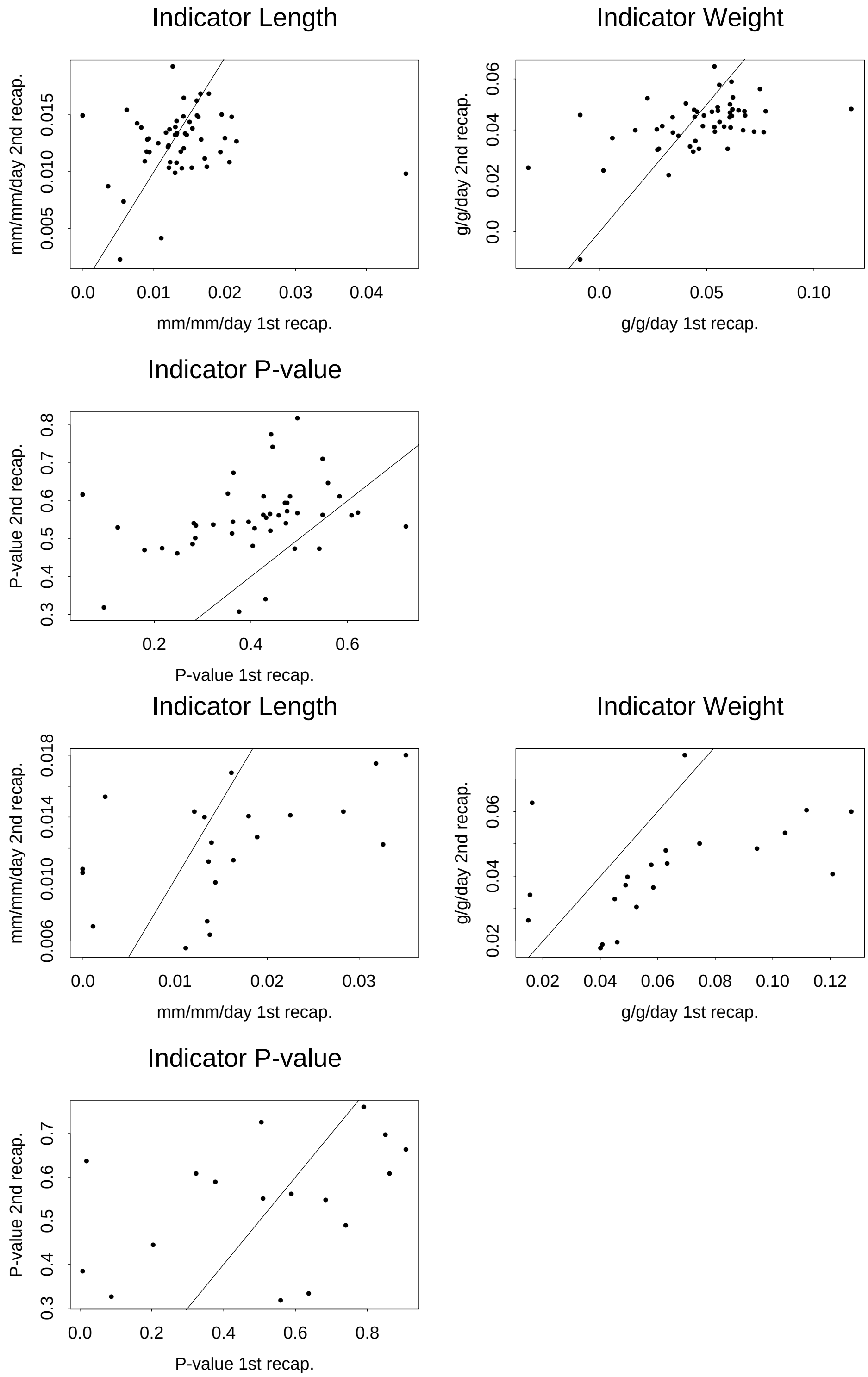


Figure 16 Differences in the three indicators for multiple recovery wild subyearling (3, W) chinook above and hatchery subyearling (3, H) chinook below. The second recovery was NOT at location of first recovery. X axis shows the indicator for the first recovery and the Y axis shows the indicator for the second recovery. Lines shown have intercept = 0 and slope = 1.

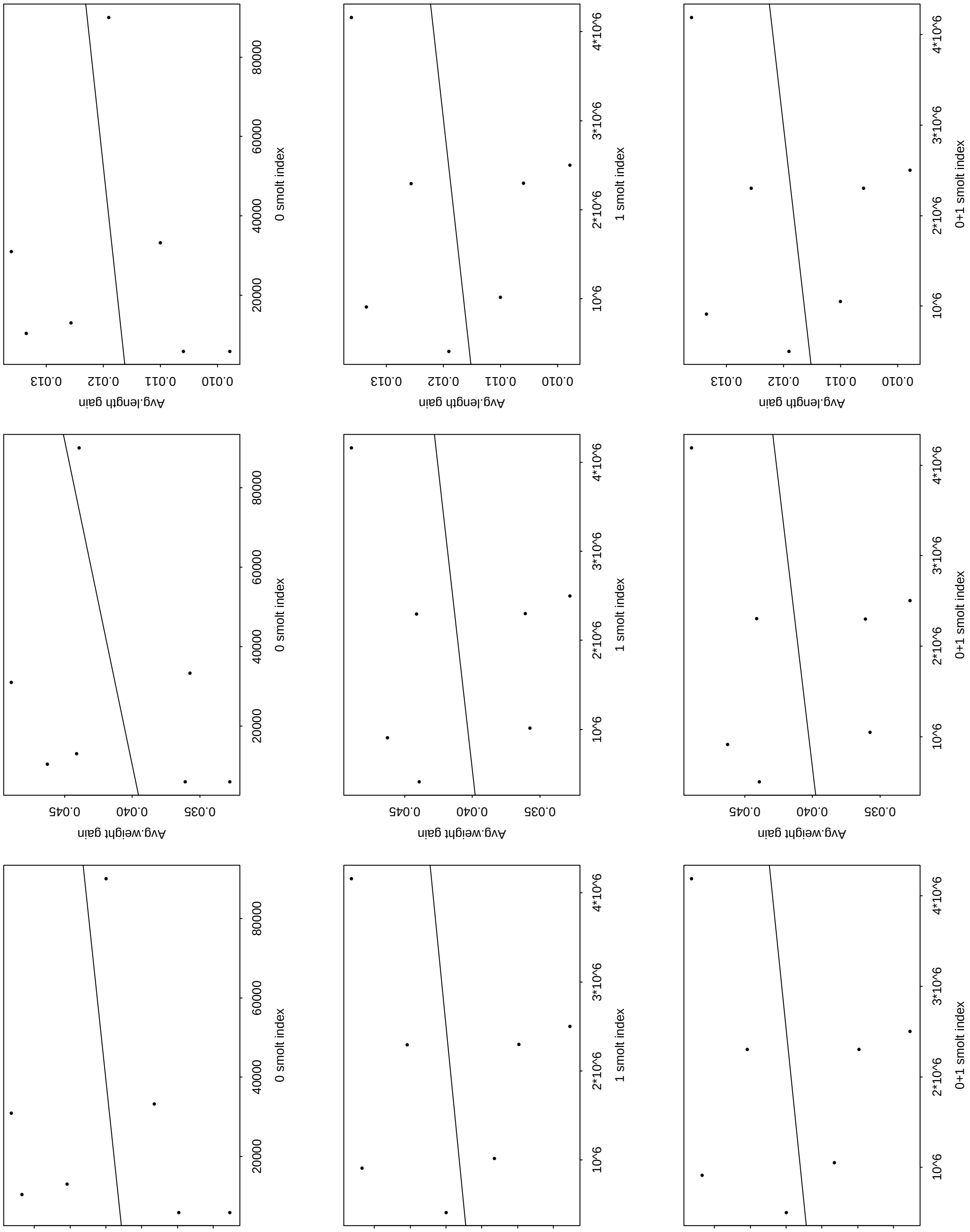


Figure 17 The **mean values** of the distribution of Wild, Snake River sub-yearling chinook growth measures from 1991 to 1997 plotted against smolt indices (total number of smolts passing Lower Granite dam). Column 1 is indicator 1 (p value), column 2 is indicator 4 (average weight growth rate) and column 3 is indicator 5 (average length growth rate)

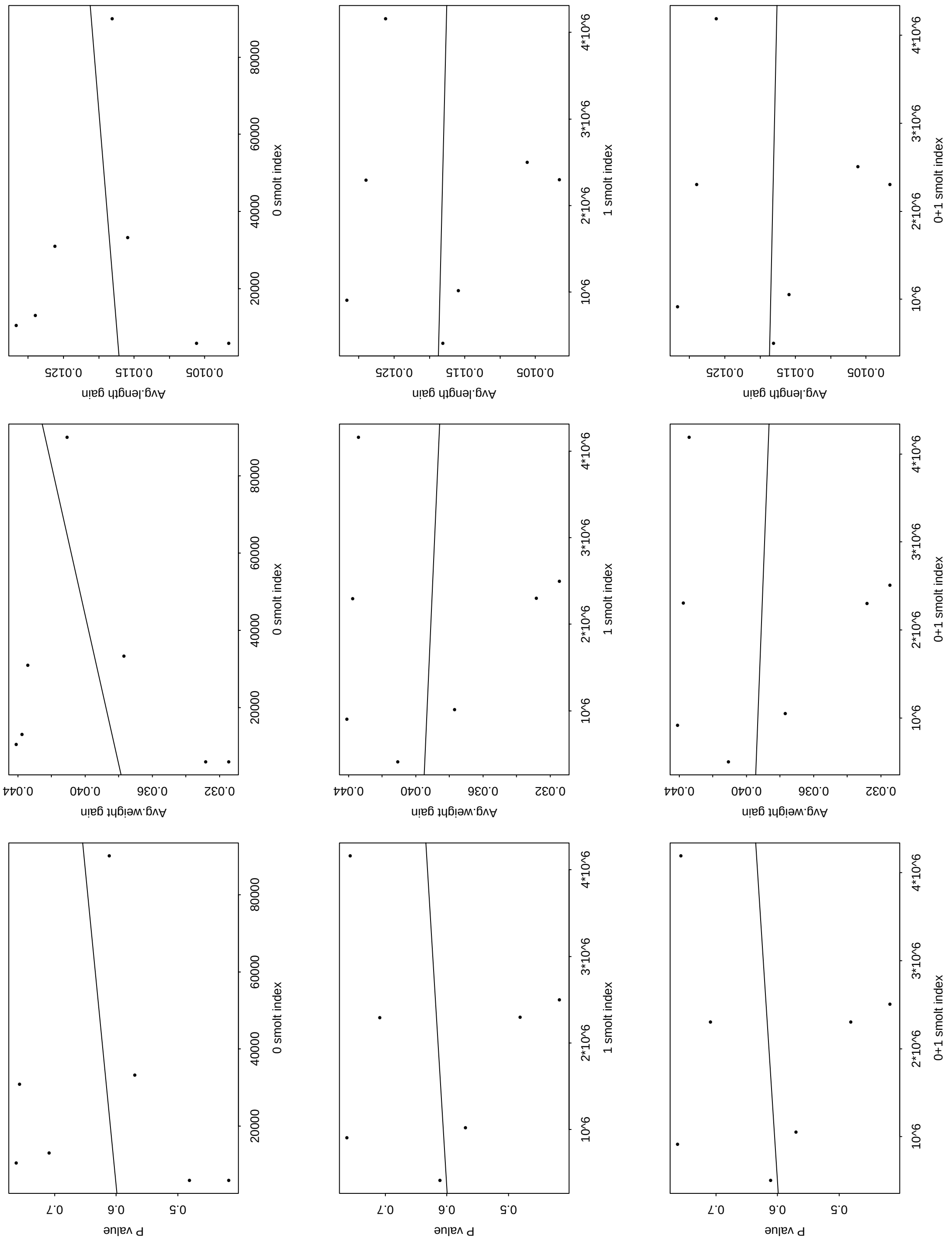


Figure 18 The **median values** of the distribution of Wild, Snake River sub-yearling chinook growth measures from 1991 to 1997 plotted against smolt indices (total number of smolts passing Lower Granite dam). Column 1 is indicator 1 (p value), column 2 is indicator 4 (instantaneous weight growth rate) and column 3 is indicator 6 (instantaneous length growth rate)

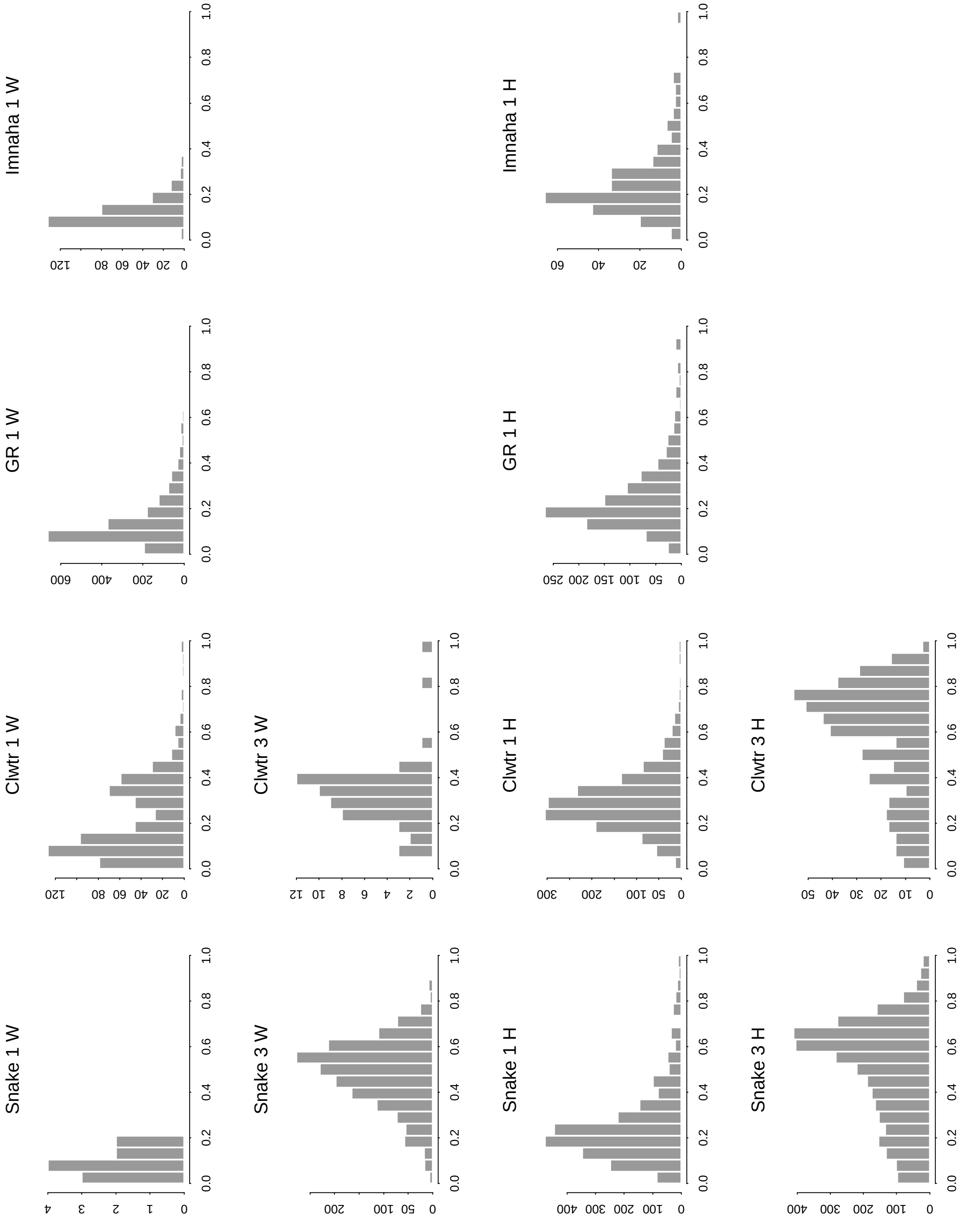


Figure 19 Distribution of indicator 2 by system, run, and rearing type

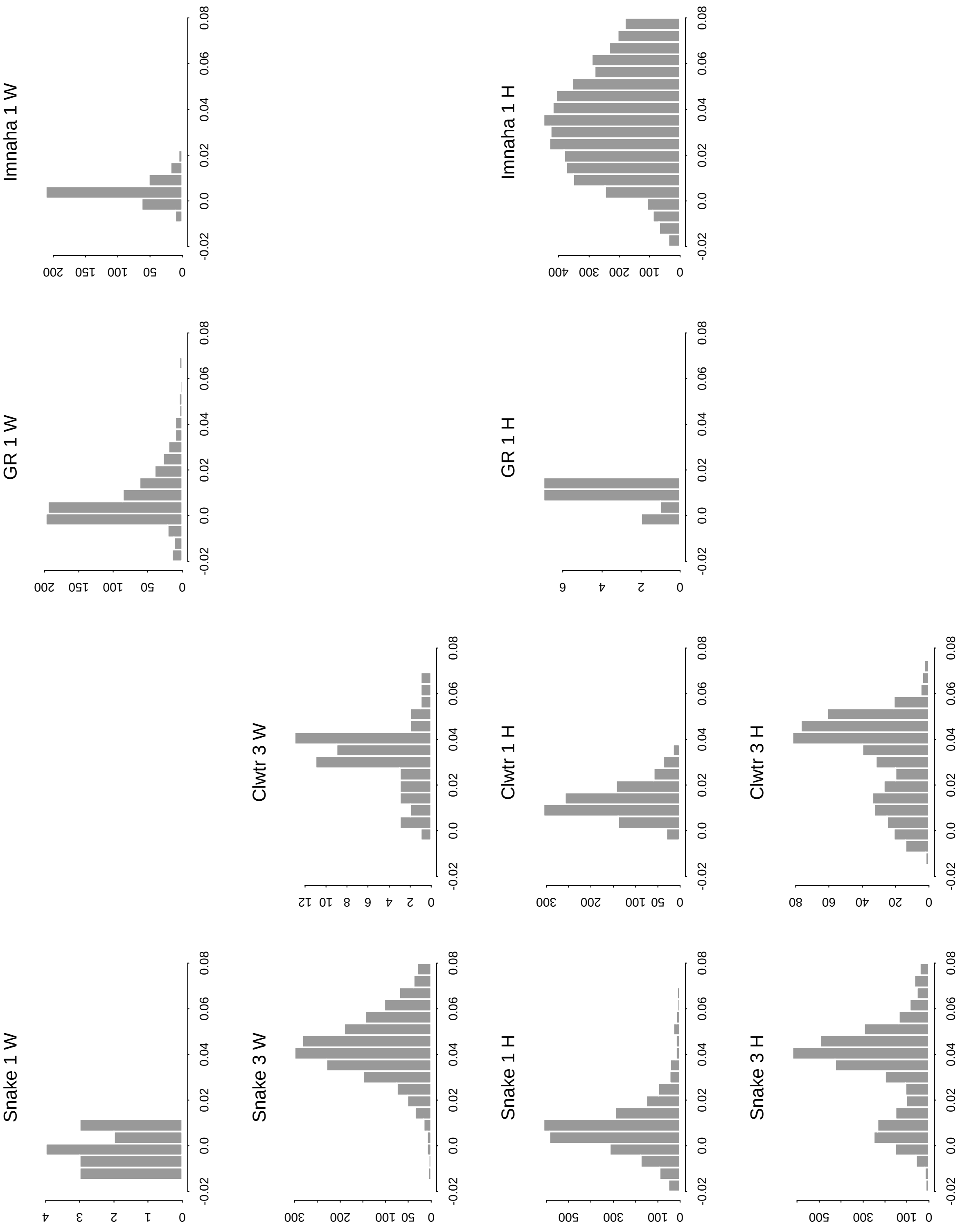


Figure 20 Distribution of indicator 4 by release system, run and rearing type.

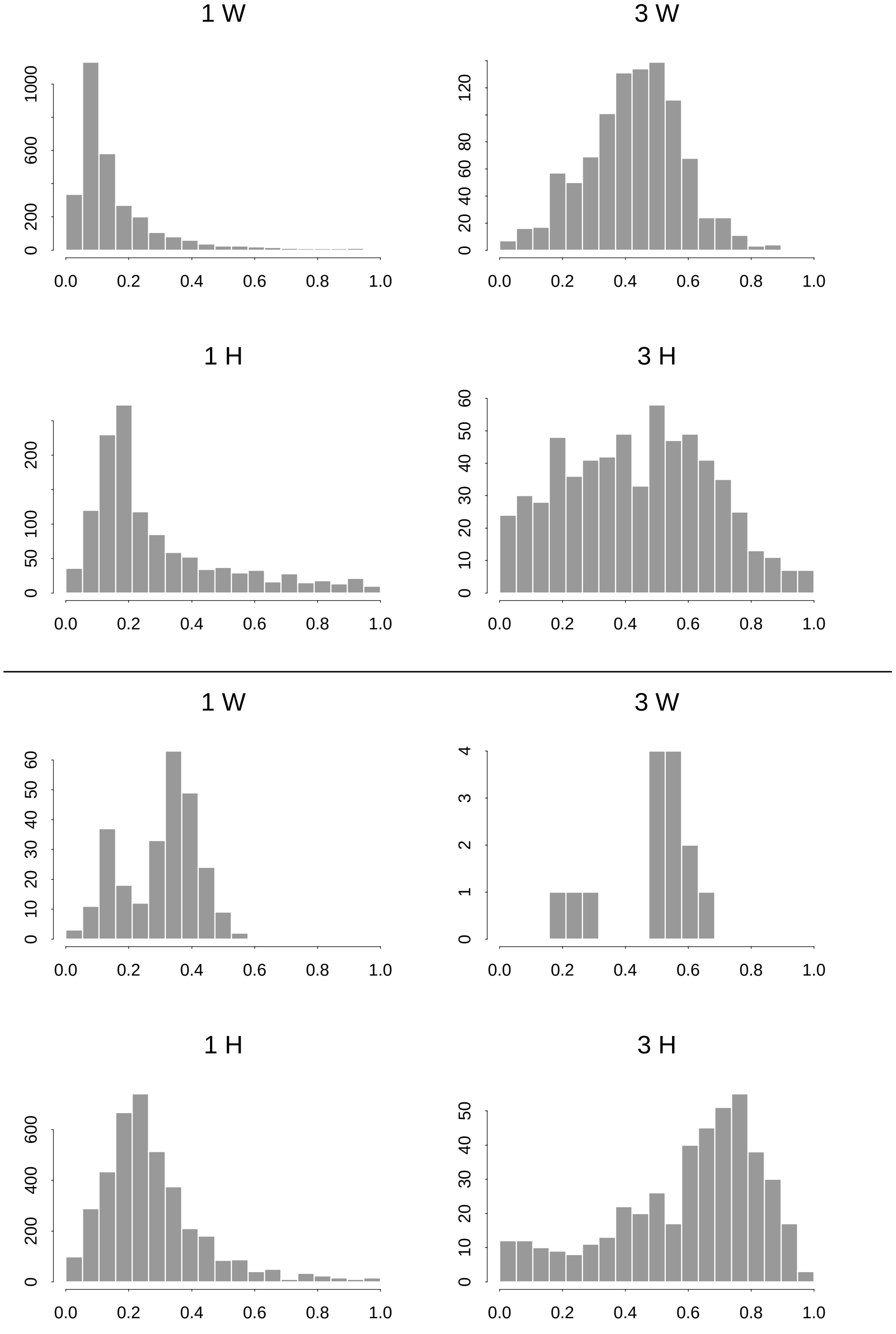


Figure 21 Distribution of indicator 2 by run and rearing type for fish exclusively above (upper panel) or below (lower panel) the Snake/Clearwater confluence. Histograms show the number of fish at each level of the indicator.

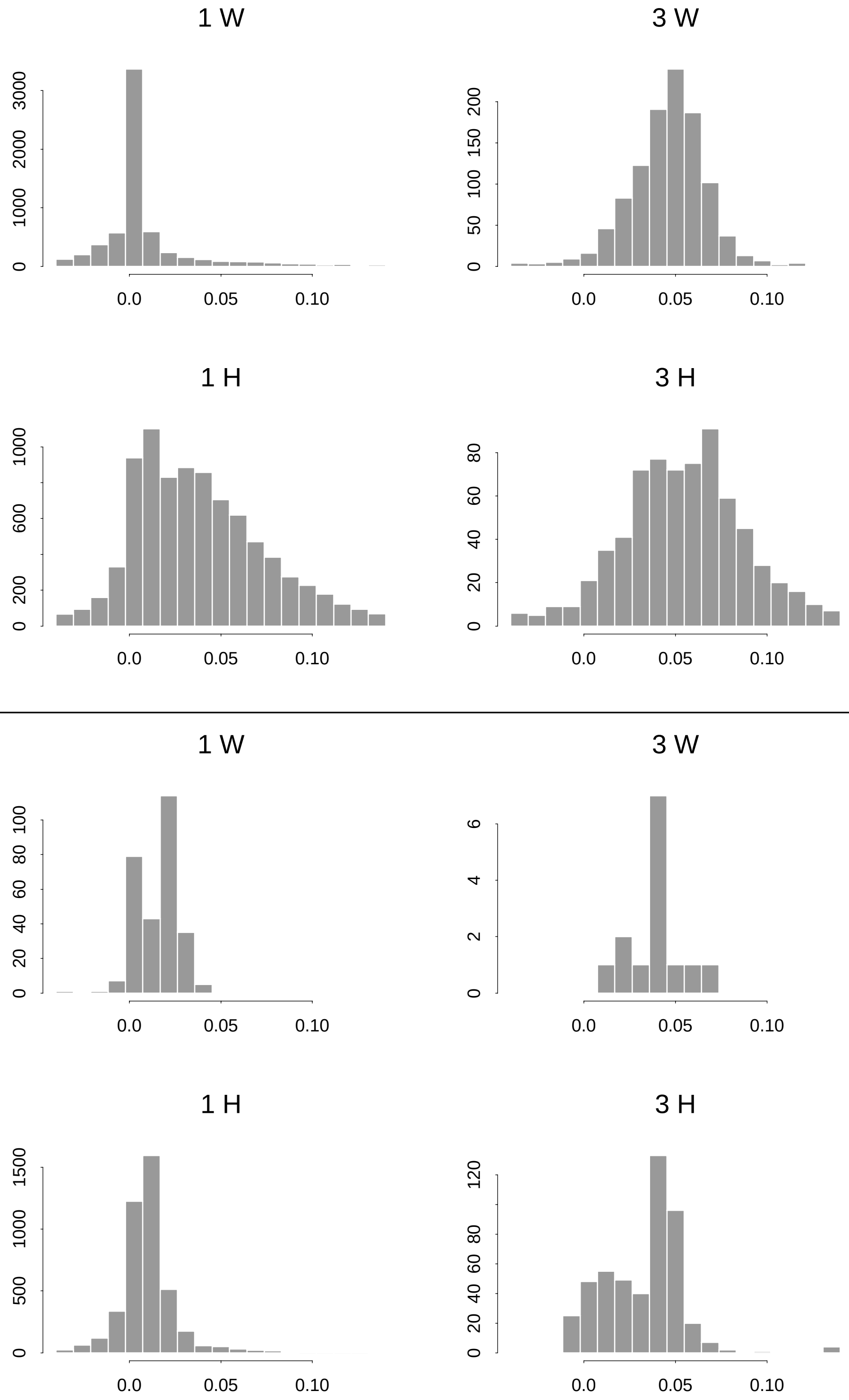


Figure 22 Distribution of indicator 4 for fish exclusively above (upper panel) and below (lower panel) the Snake/Clearwater confluence. Histograms show the numbers of fish at each level of the indicator.

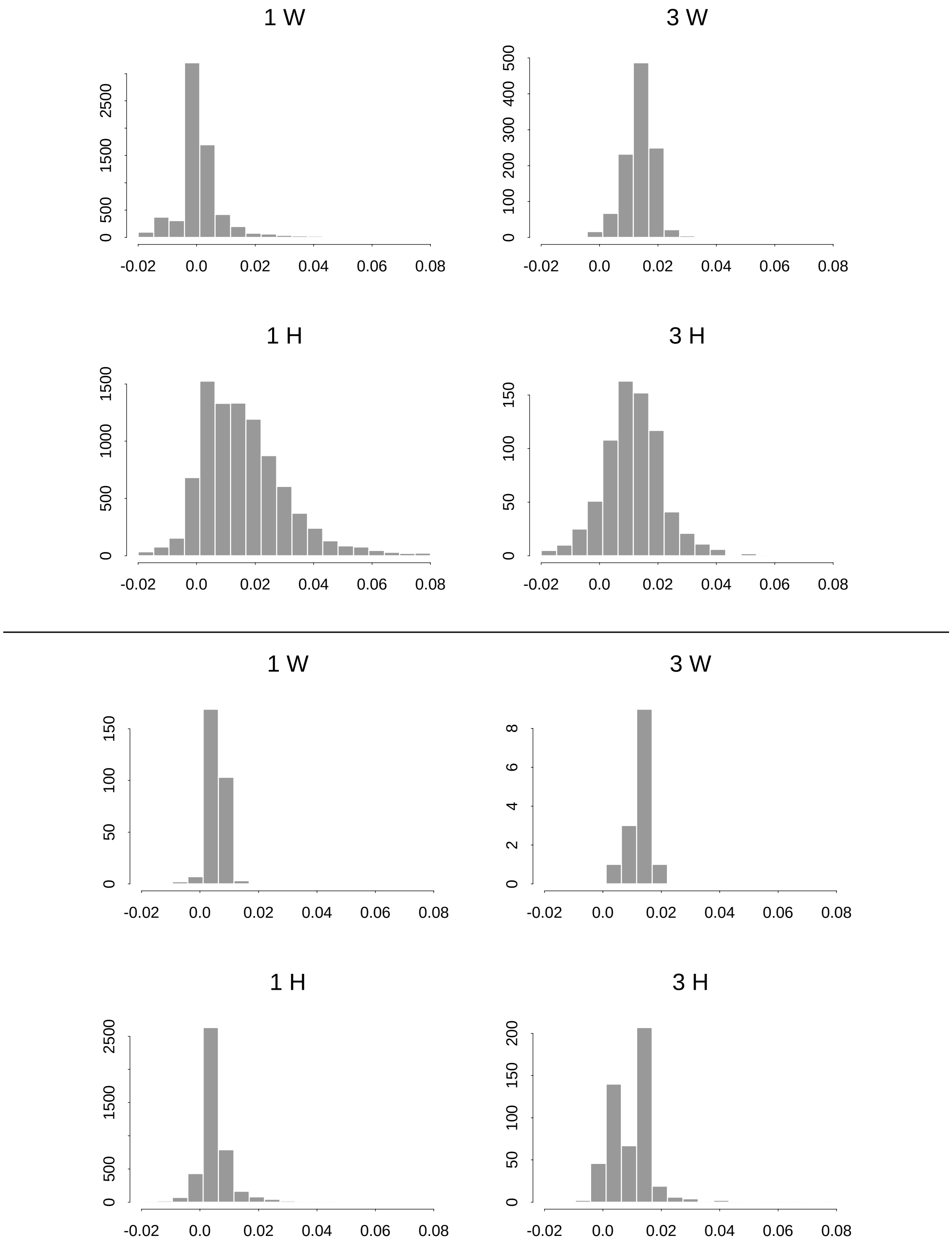


Figure 23 Distribution of indicator 6 for fish exclusively above (upper panel) and below (lower panel) the Snake/Clearwater confluence. Histograms show the numbers of fish at each level of the indicator.

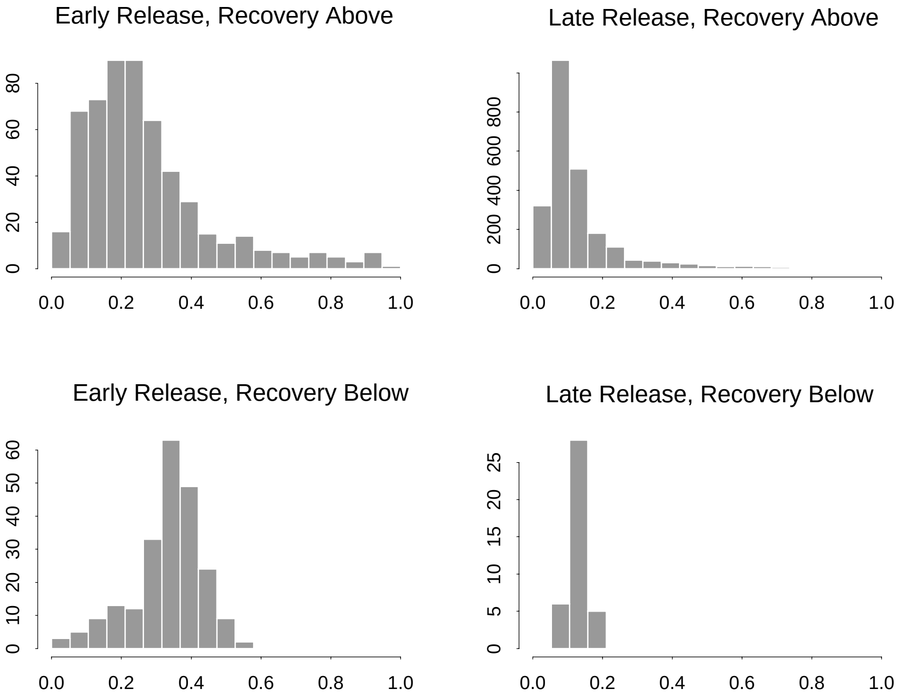


Figure 24 Distributions of indicator 2 for wild spring chinook released and recovered exclusively above (upper panel) or below (lower panel) the Snake/Clearwater confluence and released early (in the spring) or late (in the summer-autumn). Histograms show the numbers of fish at each level of the indicator.

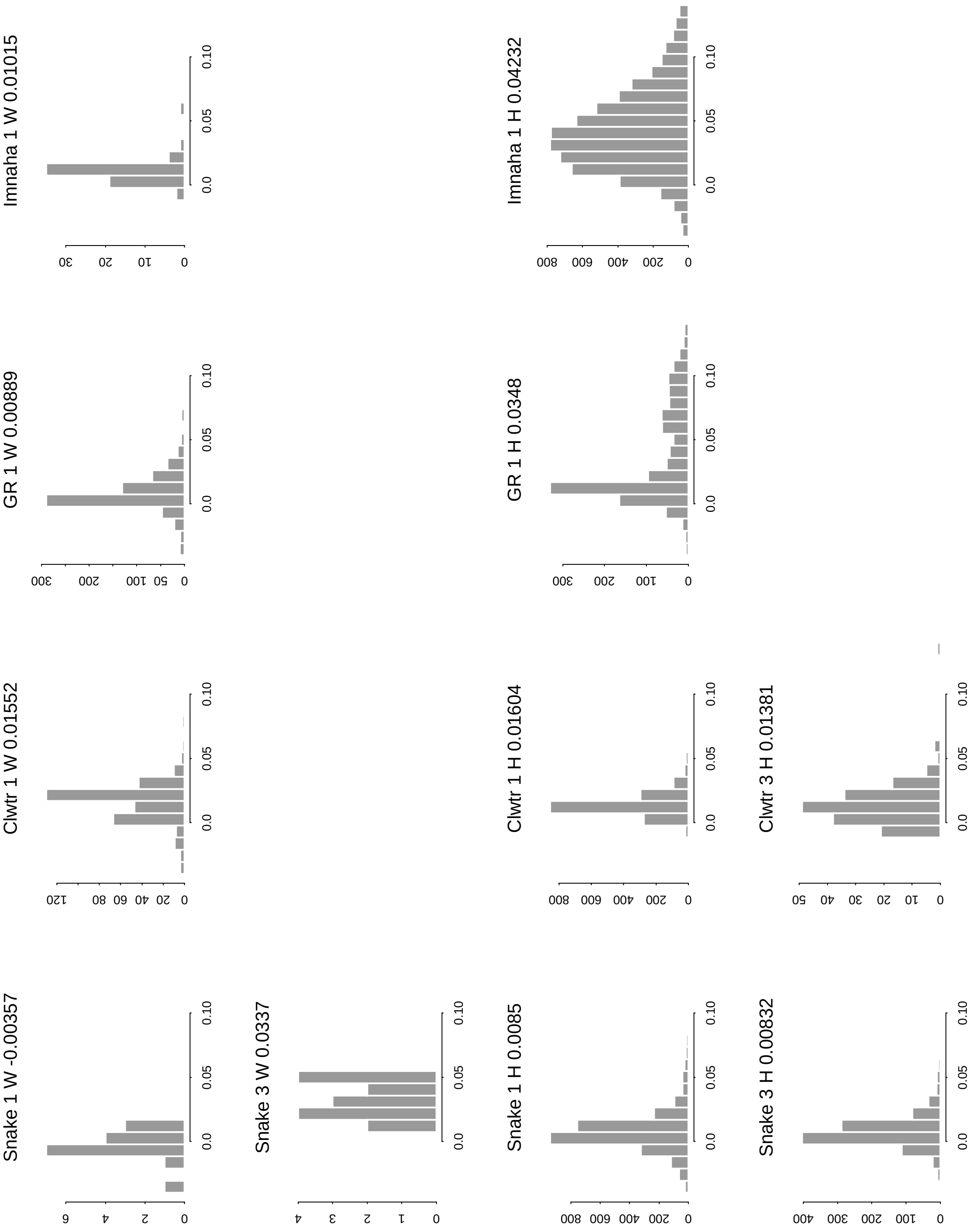


Figure 25 Distribution of indicator 4 for fish exclusively above the Snake/Clearwater confluence and released before the cutoff date. Histograms show the numbers of fish at each level of the indicator. Title shows: River system: Snake, Clearwater, Grand Ronde, or Imnaha; Run: 1 or 3; Type: Wild or Hatchery; and the mean of the distribution.

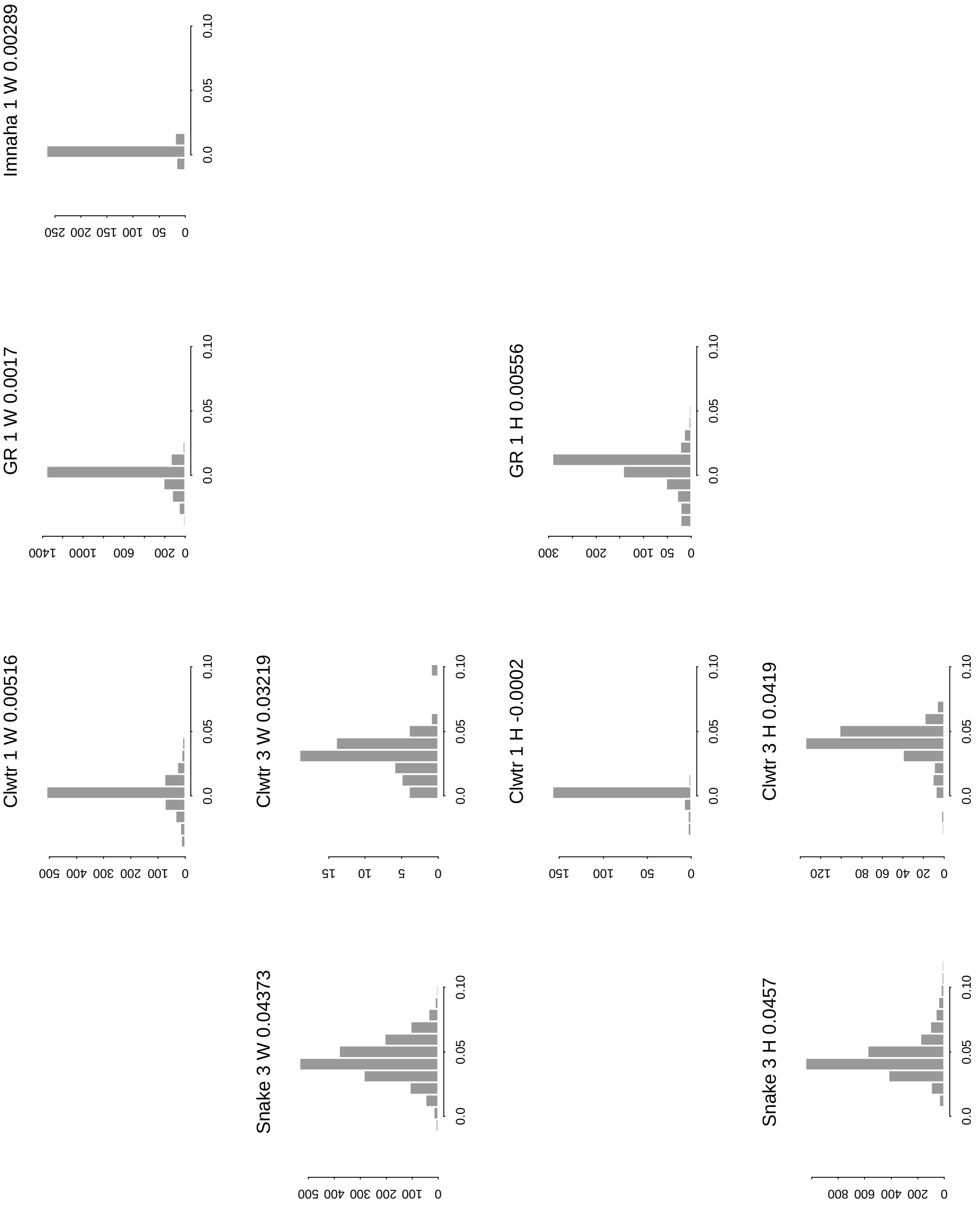


Figure 26 Distribution of indicator 4 for fish exclusively above the Snake/Clearwater confluence and released after the cutoff date. Histograms show the numbers of fish at each level of the indicator. Title shows: River system: Snake, Clearwater, Grand Ronde, or Imnaha; Run: 1 or 3; Type: Wild or Hatchery; and the mean of the distribution.

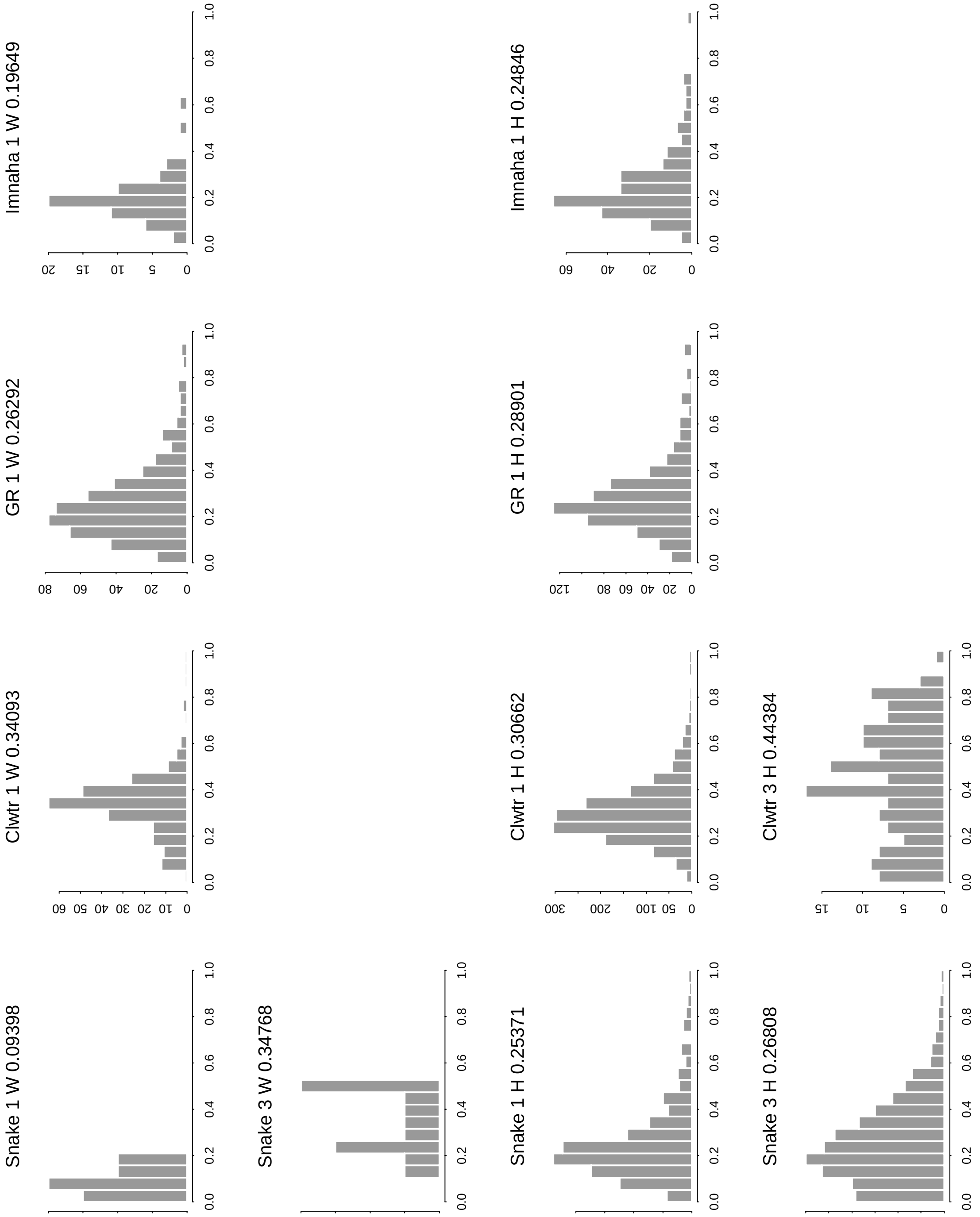


Figure 27 Distribution of indicator 2 for fish exclusively above the Snake/Clearwater confluence and released before the cutoff date. Histograms show the numbers of fish at each level of the indicator. Title shows: River system: Snake, Clearwater, Grand Ronde, or Imnaha; Run: 1 or 3; Type: Wild or Hatchery; and the mean of the distribution.

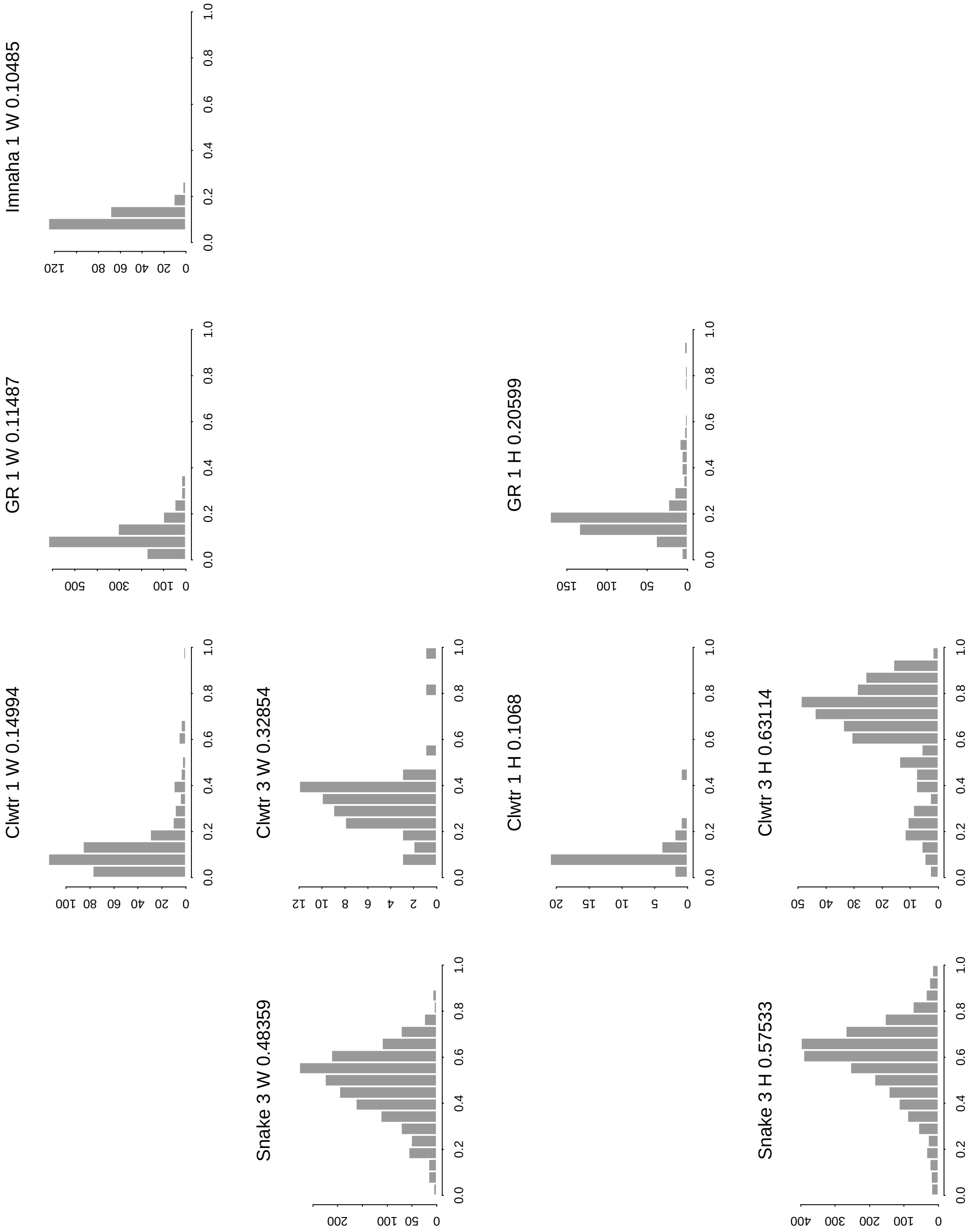


Figure 28 Distribution of indicator 2 for fish exclusively above the Snake/Clearwater confluence and released after the cutoff date. Histograms show the numbers of fish at each level of the indicator. Title shows: River system: Snake, Clearwater, Grand Ronde, or Imnaha; Run: 1 or 3; Type: Wild or Hatchery; and the mean of the distribution.