Evaluation of Juvenile Salmonid Condition (Descaling) Under Different Turbine Operating Conditions at McNary Dam, 2010

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EXECUTIVE SUMMARY

The objective of this study was to test for significant differences in descaling rates of steelhead and yearling and subyearling Chinook, coho, and sockeye salmon exposed to ESBSs (extended length bar screens) and gatewells during two turbine operations. The two turbine operations compared were a "target" operating range, which was higher than 1% of peak operating efficiency (>1%, or 13,300-15,000 ft^3/s) vs. the upper 1% of peak operational efficiency (1%, or 11,600-12,400 ft^3/s).

Descaling rates at dams can be influenced by a number of factors such as stock differences, smoltification levels, and previous migration history as well as by external or environmental factors such as turbine unit location, turbine operating condition, debris load, and experimental handling. To provide comparable conditions for comparison of descaling rates between two operational treatments, we measured descaling simultaneously in two turbine unit intake slots (4A and 5A). During testing, one unit was operated within the "target" operating range (> 1% of peak efficiency), while the other was operated within the upper 1% of peak efficiency. To account for a possible unit effect, we switched operational treatments between units every other night. Therefore, each 2-d, two-unit “block” resulted in a paired test of descaling rates between the two operating conditions.

With data from these tests, we modeled descaling through time using logistic regression. Factors included in the model were turbine unit, operational treatment, date, and head differential. We also examined two-way interactions between these four variables. We used quasi-likelihood Akaike information criterion (QAIC) to rank the models. Models differing by less than 2.0 from the best-fitting model were averaged across predicted values using the respective Akaike weights. Candidate models ranged from the most complex, with all factors and all two-way interactions, to the most simple, with only unit as a factor explaining differences in descaling. Since unit was essentially a nuisance factor in this analysis, we included it in all models.

From the model-averaged results, we estimated descaling rates through time for units 4A and 5A, with each operating at both operating conditions. Empirical values were visually compared with calculated model-averaged estimated descaling rates. Results from empirical and model-averaged data determined a 2.1-3.2 % higher descaling rate for yearling Chinook salmon (SE 1.0-1.3) and 3.8% higher descaling rate for subyearling Chinook salmon (SE 1.1) that entered the gatewell under the target operating range (>1% of peak efficiency). Descaling rates for sockeye salmon were similar under the two operational treatments. Sample sizes of steelhead and coho salmon were insufficient for analysis.

CONTENTS

INTRODUCTION

This study compared the condition of juvenile salmonids after passage through gatewells in the juvenile fish bypass and collection system (JBS) at McNary Dam during two different turbine operations. Turbine operations evaluated included a “target" operating range above 1% of peak efficiency (> 1%, or 13,300-15,000 ft^3/s) and a range at the upper end of the top 1% of turbine efficiency (1%, or 11,600-12,400 ft^3/s). This information will be used to assist in determining future operations for fish passage at McNary Dam, which may include increased flow through turbines or new turbine designs.

There are numerous components to contemporary fish bypass systems. At McNary Dam and similar hydroelectric projects, fish are guided upward and away from turbine intakes at the ESBSs (extended-length bar screens). Guided fish then enter gatewells, where a VBS (vertical barrier screen) confines them near submerged orifices. Fish pass through these orifices to enter a collection channel, which extends across the powerhouse. From the collection channel, fish can either be returned to the river below the dam, diverted to holding raceways to await transport, or diverted for tagging or examination within the JFF (juvenile fish facility). The condition of juvenile anadromous salmonids diverted from turbines at these hydroelectric projects is an ongoing concern because the manner in which turbines or the bypass system are operated may influence the degree of injury or mortality to fish passing through the system.

In accordance with section 7 of the U.S. Endangered Species Act, the National Marine Fisheries Service prepares a biological opinion (BiOp) on the effects of the Federal Columbia River Power System on endangered fish species (NMFS 2008). The 2008 BiOp calls for the operation of turbine units "to achieve best fish passage survival, currently within 1% of best efficiency at mainstem dams on the Lower Columbia and Lower Snake Rivers" (NMFS 2008, Reasonable and Prudent Alternatives 27 and 32). In addition, the 2008 BiOp stipulates continued evaluation of turbine operations, suggested modifications, and application of adaptive management for operation of units in their optimum configuration for safe fish passage (NMFS 2008, RPA 54). This study was conducted in part to address these BiOp directives.

Results from previous studies at McNary Dam indicate there may be a survival benefit to juvenile fish when turbines are operated within 1% of peak efficiency (Ferguson et al. 2006). However, peak efficiency flows can be high, and the consequences of these high flow levels on fish within the juvenile bypass system are relatively unknown. Trash racks, vertical barrier screens, and gatewell conditions have all been tested during turbine operations within 1% of peak efficiency. Higher flows associated with turbines operating above 1% of peak efficiency may create hydraulic conditions detrimental to fish and may also increase the debris load, creating conditions outside established operating criteria.

Absolon et al. (2003) examined descaling at McNary Dam in 2002 and found no significant differences in fish condition of juvenile yearling Chinook salmon *Oncorhynchus tshawytscha* exposed to turbine discharge rates of 11,200 vs. 16,400 ft^3/s. These results contrasted with an earlier evaluation of the effect of vertical barrier screens on river-run yearling Chinook salmon, where significantly higher descaling rates were noted for fish released at flows of 16,000 ft^3/s than for those released at flows of 12,000 ft^3/s (Brege et al. 1998). These results were seen with both the existing VBS and a prototype VBS.

In 2004, a study at McNary Dam examined the effects on fish condition of increasing turbine loads from 60 MW (~12,000 ft^3/s) to 80 MW (~6,400 ft^3/s; Absolon et al. 2005). While this study was interrupted, and therefore had few test replicates, results indicated the overall condition of PIT-tagged yearling Chinook salmon released into the gatewells of turbines operated at 80 MW was similar to that of smolts released into turbine units operated at approximately 60 MW. Absolon et al. (2005) also found that some degree of descaling and injury might have occurred before fish entered the gatewells of turbines operating at the higher loads. At times during the study, daily samples of smolts collected at the juvenile fish facility showed an increase in overall descaling that appeared to be related to the periods of higher turbine load.

A follow-up study conducted in 2005 included evaluation of a prototype rotating vertical barrier screen, which was installed in gatewell 4A. The new screen was intended to reduce rates of debris accumulation (Gessel et al. 2006). This study used PIT-tagged smolts released at two locations: just downstream from the trashrack in front of turbine unit 4A, and within the gatewell of turbine unit 4A. Results from this study again indicated somewhat higher rates of descaling when turbines were operated at higher loads, but the researchers were unable to isolate the cause.

In 2006, fish condition was evaluated in gatewells 4A and 5A at McNary Dam for river-run juvenile salmonids (Gessel et al. 2007). The test design included both 80- and 62-MW loads for turbine unit 4 and a 62-MW load for turbine unit 5. Additionally, a rotating vertical barrier screen and a flow-control device were used in gatewell 4A, while a standard vertical barrier screen was used in gatewell 5A. During the spring portion of the study, results with the flow-control device were inconclusive due to problems with the device. Descaling for all species was higher under test loads of 80 MW in turbine unit 4. Prior to summer tests, the flow-control device was modified, and problems were corrected. Results for subyearling Chinook salmon during summer showed no statistically significant difference in descaling between the two flow conditions (descaling rates were 2.8% at 80 MW and 2.5% at 62 MW; $P = 0.632$), although mortality was significantly higher at 80 than at 62 MW (1.9 and 0.6%, respectively; $P = 0.015$).

METHODS

Fish Collection and Descaling Evaluation

Our study was designed as a series of paired tests during the spring and summer juvenile migrations of 2010. River-run yearling and subyearling Chinook salmon and juvenile sockeye salmon *O. nerka*, coho salmon *O. kisutch*, and steelhead *O. mykiss* were captured using orifice traps and examined for descaling and obvious external injuries. The methodology for determining descaling was developed over a number of years, beginning in the mid–1970s (Ceballos et al. 1992). Briefly, the fish is visually divided into five equally sized partitions on each side of the body, with the partitions beginning near the operculum and extending to the caudal fin. The deeper parts of the body (near the head and dorsal fin) have narrower partitions (horizontally) than the body areas near the adipose and caudal fins. If 40% or more of the scales are missing from two adjacent partitions on one side of a fish, then the fish is considered to be descaled. For a given test, the descaling rate was the percent of fish considered descaled (i.e. if 6 out of 100 fish examined were descaled, then the descaling rate for that test would be 6%).

Two orifice traps attached to the A gatewells (south orifices) in turbine units 4 and 5 were used to collect river-run fish during the study period (3 May to 9 July). Both test gatewells were equipped with extended-length bar screens and standard vertical barrier screens. Turbine operation treatments included a "target" operating range, which was higher than 1% of peak operating efficiency (> 1%, or 13,300-15,000 ft^3/s) and an operating range within the upper end of the 1% efficiency rating curve (1%, or 11,600-12,400 ft^3/s). Turbine units 4 and 5 were operated with both treatments on an alternating daily schedule (Table 1). For each replicate, the turbines were adjusted to the predetermined operational treatment at noon. At 1600 h, residual juvenile fish were removed from gatewells 4A and 5A by dip-netting, so that each replicate was comprised only of fish that entered the gatewell during the test.

All salmonid species collected during each test period were examined, resulting in varying sample sizes that were dependent on the overall general availability of each species. Orifice traps in 4A and 5A were operated simultaneously from 1900-0100 PDT (the hours of highest passage) during each replicate. Fish collected in the orifice trap were anesthetized and examined for descaling and injury. After examination, all fish were allowed to recover from anesthesia and then returned directly to the collection channel within the JBS.

Table 1. Treatment schedule for turbine loading study at McNary Dam, 2010. This schedule was repeated throughout the study period, from 3 May to 9 July. The complete schedule with dates is shown in Appendix Table 1.

Day	Turbine unit 4	Turbine unit 5
Monday	> 1%	1%
Tuesday	1%	> 1%
Wednesday	> 1%	1%
Thursday	1%	> 1%
Friday	> 1%	1%
Monday	1%	> 1%
Tuesday	> 1%	1%
Wednesday	1%	> 1%
Thursday	> 1%	1%
Friday	1%	> 1%

Analytical Design

The objective of this study was to test for significant differences in descaling rates of steelhead, yearling and subyearling Chinook, coho, and sockeye salmon exposed to ESBSs and gatewells with turbines operated above 1% or within 1% of peak operating efficiency. Descaling rates at dams can be influenced by a number of factors, such as stock differences, smoltification levels, and previous migration history; as well as by external or environmental factors such as turbine unit location, turbine operating condition, debris load, and experimental handling.

In order to appropriately compare descaling rates between treatment groups, we used an experimental design that attempted to average across these factors and across temporal differences. Thus we measured descaling simultaneously in the two turbine unit slots (4A and 5A), with one unit operated under the higher load and the other under the 1% peak efficiency load. We alternated treatments between units every other night in an attempt to account for (or average across) a possible "unit effect." Therefore, we assumed that each 2-d block resulted in a two-unit paired difference in descaling rates between the two operating conditions that was unbiased by either time or unit. A paired series of these treatment blocks was then statistically compared using a *t*-test. However, for multiple reasons we concluded that a *t*-test was not appropriate because:

1) The test assumed no interaction between time and treatment effects, but initial empirical evidence suggested this may not have been the case (at least for some species).

2) The *t*-test did not account for sample sizes that varied between units and across the season, especially for some species and at some times.

3) We wanted to incorporate head differential as a covariate. Head differential is presumably an index of debris loading on the VBS, which is thought to impact descaling rates. Inclusion of this covariate could improve inference and reduce variability.

Therefore, we conducted further analysis using a logistic regression approach to model descaling through time.

We used logistic regression (Hosmer and Lemeshow; 2000) to determine statistical relationships between the probability of being descaled and a set of factors and two-way interactions. Individual fish within cohorts were classified (by species) as descaled or not (numerically 0 or 1), and the cohorts were summarized by the total number of fish examined and the total number descaled. A response variable *p* (the proportion of juveniles descaled) was modeled as a function of explanatory variables, x_i, ($i = 1,\ldots, i = $ n; where n was the number of terms in the model):

$$p(x_1,\cdots,x_n) = \frac{\exp(\beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n)}{1 + \exp(\beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n)} \quad (1)$$

Equation (1) can alternatively be viewed using the logit link (*g*) to obtain a linear response as:

$$g\left[p(x_1,\cdots,x_n)\right] = \ln\left[\frac{p(x_1,\cdots,x_n)}{1 - p(x_1,\cdots,x_n)}\right] = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n + \varepsilon \quad (2)$$

Unlike standard linear regression, where the error term is assumed to be distributed normally, the error term in the logistic regression model is assumed to be distributed binomially.

For this study, the factors included in the modeling process were unit (4A or 5A), treatment (>1% or 1%), day (day of year) and head differential (difference between water levels measured on either side of the VBS). We also included two-way interactions between these four variables.

We used quasi-likelihood Akaike Information Criterion (QAIC) to compare logistic regression models (Burnham and Anderson, 2002). For each candidate model in the set, this approach estimated QAIC as twice the log-likelihood from the logistic regression, adjusted for sample size (number of day/unit cohorts), number of model parameters, and estimated binomial over-dispersion (Ramsey and Schafer 1997). The models were then ranked by QAIC and compared using the difference from the best model (the model with minimum QAIC). To get a more robust predictive model, we model-averaged the models differing by less than 2.0 from the best model by constructing a weighted average across predicted values, where the weights were the respective Akaike weights (*w*; Burnham and Anderson, 2002). The candidate set of models for this study included all models: from the largest, with all factors and all two-way interactions, to the smallest, with only unit as a factor. Since unit was essentially a nuisance factor in this analysis, we included it in all models.

From the model-averaged results, we constructed plots with four estimated descaling rate "lines" through time: units 4A and 5A for both operating treatments (>1% and 1%). (Note that if day was not included in the models used for model-averaging, the line was horizontal). To compare to the empirical values calculated for each block (as described above for the original experimental design), we also constructed a similarly calculated model-averaged "line of values."

RESULTS

Project Operations

McNary Dam turbine units 4 and 5 were alternated between a higher "target" operating range and the range within the upper limit of 1% peak efficiency, according to the treatment schedule described above (Table 1; Appendix Table 1). Unit loads were set at 1200 PDT each day and remained constant until enough fish were collected for each replicate, at which time the operator was instructed to reset unit operations back to fish-passage plan requirements until the next treatment block. Mean turbine loads throughout the spring and summer are provided in Figure 1. Mean turbine load was 13,800 ft^3/s (range 13,200-15,100 ft^3/s) during the "target" (>1%) treatments and 12,100 ft^3/s (range 11,500-12,400 ft^3/s) during treatments of operation within the upper limit of 1% of peak efficiency. We omitted the first 24 h test of operation within 1% of peak efficiency in turbine unit 5 due to lower-than-expected turbine discharge. For the remainder of the study, treatments followed the study design until 1 July, when unit 4 was pulled offline for maintenance for the entire month. All further tests were conducted in unit 5.

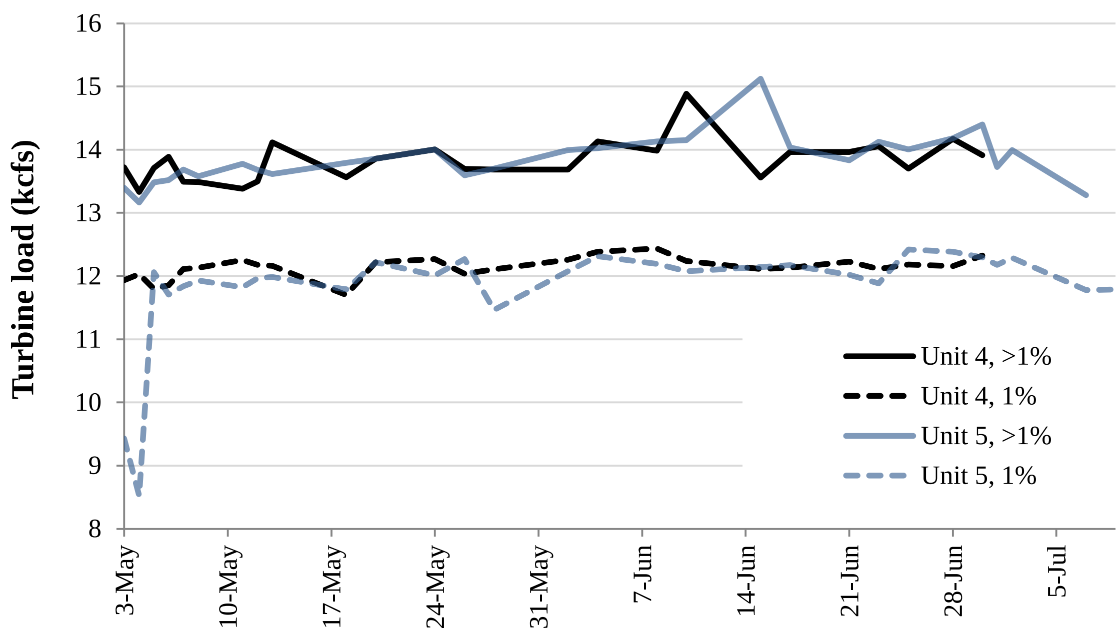

Figure 1. Mean turbine unit loads experienced by juvenile salmonids collected from orifice traps at McNary Dam during the 2010 field season to determine associated descaling effects within the gatewell.

Yearling Chinook Salmon

Fish were present in adequate numbers for most of the season through May, but began to decline near the end of the month and into June (Table 2). From 3 May through 11 June, we collected and examined 8,574 yearling Chinook salmon. Due to very low collection numbers after 4 June, fish collected after this date were omitted from analysis. Empirical descaling rates were reported only from tests within individual gatewells where the sample size met or exceeded 30 fish examined.

Table 2. Total number of yearling Chinook salmon examined for descaling and the measured difference between the two turbine loading treatments. Percent descaling was recorded only for replicates of ≥ 30 fish.

Date	Day	Block	Unit	Test	Head differential	Examined (n)	Descaled (n)	Descaled (%)
3 May	123	1	4	>1%	0.5	202	20	9.9
3 May	123	1	5	1%	0.6	220	8	3.6
4 May	124	1	4	1%	0.1	253	22	8.7
4 May	124	1	5	>1%	0.1	296	18	6.1
5 May	125	2	4	>1%	0.1	247	13	5.3
5 May	125	2	5	1%	0.1	229	14	6.1
6 May	126	2	4	1%	0.1	274	21	7.7
6 May	126	2	5	>1%	0.1	273	28	10.3
7 May	127	3	4	>1%	0.1	254	12	4.7
7 May	127	3	5	1%	0.1	225	23	10.2
10 May	130	3	4	1%	0.6	239	14	5.9
10 May	130	3	5	>1%	0.6	305	27	8.8
11 May	131	4	4	>1%	0.6	374	16	4.3
11 May	131	4	5	1%	0.7	198	20	10.1
12 May	132	4	4	1%	0.8	242	6	2.5
12 May	132	4	5	>1%	0.1	285	33	11.6
13 May	133	5	4	>1%	0.5	336	7	2.1
13 May	133	5	5	1%	0.6	313	19	6.1
14 May	134	5	4	1%	0.1	130	5	3.8
14 May	134	5	5	>1%	0.1	239	16	6.7
17 May	137	6	4	1%	0.1	175	10	5.7
17 May	137	6	5	>1%	0.1	315	25	7.9
18 May	138	6	4	>1%	0.1	273	47	17.2
18 May	138	6	5	1%	0.1	269	17	6.3
19 May	139	7	4	1%	0.1	249	12	4.8
19 May	139	7	5	>1%	0.1	315	22	7.0
20 May	140	7	4	>1%	0.6	227	53	23.3
20 May	140	7	5	1%	0.6	295	19	6.4
21 May	141	8	4	1%	0.6	58	5	8.6
21 May	141	8	5	>1%	0.7	265	25	9.4
24 May	144	8	4	>1%	0.8	215	24	11.2
24 May	144	8	5	1%	0.1	111	6	5.4

Table 2. Continued.

Date	Day	Block	Unit	Test	Head differential	Examined (n)	Descaled (n)	Descaled (%)
25 May	145	9	4	1%	0.8	45	0	0.0
25 May	145	9	5	>1%	0.8	131	9	6.9
26 May	146	9	4	>1%	1.0	13	1	
26 May	146	9	5	1%	0.5	34	2	5.9
27 May	147	10	4	1%	0.6	2	0	
27 May	147	10	5	>1%	0.4	4	0	
28 May	148	10	4	>1%	0.1	30	3	10.0
28 May	148	10	5	1%	0.1	21	0	
1 Jun	152	11	4	1%	0.1	11	2	
1 Jun	152	11	5	>1%	0.1	32	1	3.1
2 Jun	153	11	4	>1%	1.2	43	3	7.0
2 Jun	153	11	5	1%	0.8	32	1	3.1
3 Jun	154	12	4	1%	0.1	52	3	5.8
3 Jun	154	12	5	>1%	0.1	85	3	3.6
4 Jun	155	12	4	>1%	0.8	22	3	
4 Jun	155	12	5	1%	0.9	61	1	1.6
8 Jun	159		4	>1%	0.1	5	0	
8 Jun	159		5	1%	0.1	23	0	
9 Jun	160		4	1%	0.1	2	0	
9 Jun	160		5	>1%	0.1	10	0	
10 Jun	161		4	>1%	0.9	0	0	
10 Jun	161		5	1%	0.8	7	0	
11 Jun	162		4	1%	0.9	2	0	
11 Jun	162		5	>1%	0.1	6	0	

Empirical descaling rates collected for yearling Chinook salmon were highly variable throughout the study (Figure 2). This may have been related to debris problems, which we attempted to quantify in the analysis by modeling head differential within the gatewell. Another aspect that may have contributed to variability in descaling results for all species was the smaller sample sizes that passed via gatewell 4A than 5A. Coincidentally, descaling values were more variable and in general higher for gatewell 4A than 5A. Results indicated higher descaling during operating conditions above 1% (>1%) for both turbine units (Figure 2; Appendix Table 2), as all models included both factors without their interaction. We also observed a temporal trend where descaling increased in Unit 4A while decreasing in Unit 5A.

Visual comparison of the empirical differential values of descaling calculated for each block indicated general agreement with the model-averaged “line of values” except for two blocks in mid-May when empirical estimates were much higher (Figure 2). The weight of evidence suggested a consistent 2.1-3.4% higher rate of descaling for the higher turbine load (SE 1.0-1.3%). All but one of the empirical differential values showed a higher rate of descaling for the operational treatment above 1% of peak efficiency.

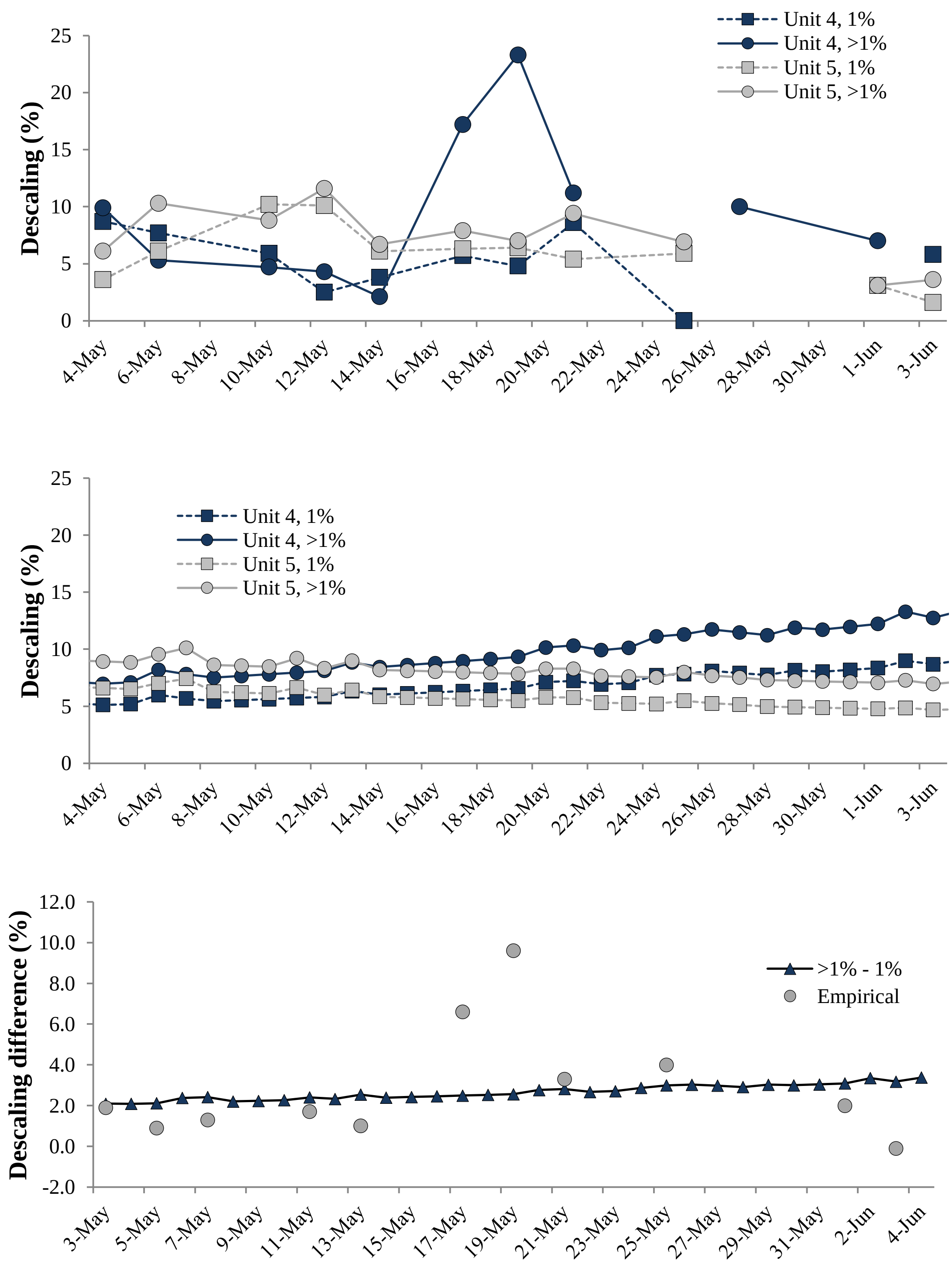

Figure 2. Descaling estimates for yearling Chinook juvenile salmon collected from orifice traps at McNary Dam during the 2010 field season. Upper panel shows empirical data, middle panel shows model-average descaling estimates, and lower panel shows the difference between test conditions in model-averaged descaling rates (>1% – 1%).

Steelhead

Steelhead were present in sufficient numbers only for the first week in May and then sample sizes were generally below the 30 fish minimum criteria (Table 3). From 3 May through 11 June, we collected and examined 1,521 juvenile steelhead. Due to the small sample sizes, differences in descaling between operational treatments (>1 vs. 1% of peak efficiency) were calculated for only four blocks. There was no significant difference in descaling between operational treatments for steelhead. However, the test was weak with little power due to the limited number of blocks examined over the brief temporal period (Figure 3; Appendix Table 3).

Table 3. Total number of juvenile steelhead examined for descaling and the measured difference between the two turbine loading treatments. Percent descaling was only recorded for replicates with >30 fish sampled.

Date	Day	Block	Unit	Test	Examined (n)	Descaled (n)	Descaled (%)
3 May	123	1	4	>1%	69	7	10.1
3 May	123	1	5	1%	90	5	5.5
4 May	124	1	4	1%	94	3	3.2
4 May	124	1	5	>1%	23	3	13.0
5 May	125	2	4	>1%	55	0	0.0
5 May	125	2	5	1%	84	6	7.1
6 May	126	2	4	1%	76	5	6.6
6 May	126	2	5	>1%	109	15	13.8
7 May	127	3	4	>1%	155	9	5.8
7 May	127	3	5	1%	120	12	10.0
10 May	130	3	4	1%	31	2	6.5
10 May	130	3	5	>1%	40	4	10.0
11 May	131	4	4	>1%	57	5	8.8
11 May	131	4	5	1%	33	3	10.1
12 May	132	4	4	1%	9	0	
12 May	132	4	5	>1%	5	3	
13 May	133	5	4	>1%	20	0	
13 May	133	5	5	1%	8	0	
14 May	134	5	4	1%	22	1	
14 May	134	5	5	>1%	8	0	
17 May	137	6	4	1%	18	1	
17 May	137	6	5	>1%	12	0	
18 May	138	6	4	>1%	1	0	
18 May	138	6	5	1%	1	0	
19 May	139	7	4	1%	8	0	
19 May	139	7	5	>1%	0	0	
20 May	140	7	4	>1%	4	0	
20 May	140	7	5	1%	5	0	
21 May	141	8	4	1%	7	0	
21 May	141	8	5	>1%	11	1	
24 May	144	8	4	>1%	26	1	

Table 3. Continued.

Date	Day	Block	Unit	Test	Examined (n)	Descaled (n)	Descaled (%)
24 May	144	8	5	1%	84	4	4.8
25 May	145	9	4	1%	15	0	
25 May	145	9	5	>1%	29	1	
26 May	146	9	4	>1%	5	0	
26 May	146	9	5	1%	2	0	
27 May	147	10	4	1%	0	0	
27 May	147	10	5	>1%	0	0	
28 May	148	10	4	>1%	0	0	
28 May	148	10	5	1%	0	0	
1 Jun	152	11	4	1%	1	0	
1 Jun	152	11	5	>1%	1	0	
2 Jun	153	11	4	>1%	4	0	
2 Jun	153	11	5	1%	11	0	
3 Jun	154	12	4	1%	14	0	
3 Jun	154	12	5	>1%	35	1	2.9
4 Jun	155	12	4	>1%	22	0	
4 Jun	155	12	5	1%	28	1	
8 Jun	159		4	>1%	20	0	
8 Jun	159		5	1%	22	1	
9 Jun	160		4	1%	4	0	
9 Jun	160		5	>1%	7	0	
10 Jun	161		4	>1%	0	0	
10 Jun	161		5	1%	10	0	
11 Jun	162		4	1%	2	0	
11 Jun	162		5	>1%	4	0	

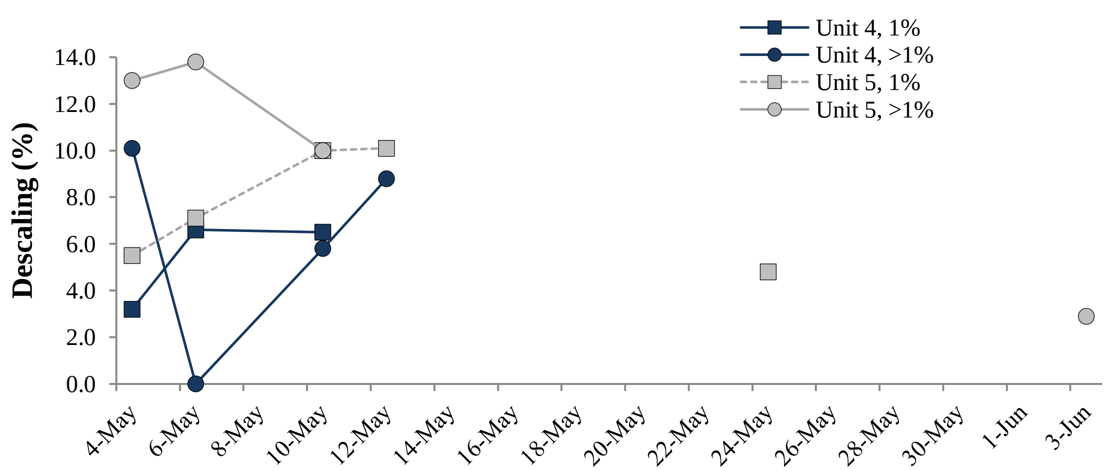

Figure 3. Empirical descaling estimates for juvenile steelhead collected from orifice traps at McNary Dam during the 2010 field season.

Coho Salmon

From 3 May through11 June, we collected and examined 246 coho salmon. No analyses were conducted on coho salmon due to limited sample sizes.

Sockeye Salmon

Throughout the study, sockeye salmon were present in sufficient numbers for analysis with some variation (Table 4). From 3 May through 11 June, we collected and examined 7,374 sockeye salmon. Due to low numbers, we omitted from analysis data from fish collected after 4 June. We did not find a significant difference in descaling between >1% and 1% operations for sockeye salmon. Although "test" was a factor included in one of the three models strongly supported by the data, the estimated model-averaged differences were small (0.5-1.0%) with large standard errors (SE 0.6-1.0%). Therefore, we observed a small effect, and the tests had insufficient statistical power with large variability (Figure 4; Appendix Table 4). Descaling was higher for sockeye than for other species sampled as a result of windstorms in the area, especially during periods of high debris loading. Descaling declined dramatically after the trash racks were raked on 19 May (Appendix Figure A1). Empirical descaling data for sockeye showed that six out of the nine comparisons resulted in a higher descaling rate for the >1% operational treatment.

Table 4. Total number of sockeye salmon examined for descaling and the measured difference between the two turbine loading treatments. Percent descaling was only recorded for replicates with >30 fish sampled.

Date	Day	Block	Unit	Test	Examined (n)	Descaled (n)	Descaled (%)
3 May	123	1	4	>1%	39	5	16.6
3 May	123	1	5	1%	75	9	13.1
4 May	124	1	4	1%	51	18	23.7
4 May	124	1	5	>1%	23	0	14.7
5 May	125	2	4	>1%	27	6	
5 May	125	2	5	1%	9	2	
6 May	126	2	4	1%	88	15	
6 May	126	2	5	>1%	21	6	
7 May	127	3	4	>1%	184	41	22.2
7 May	127	3	5	1%	69	7	10.1
10 May	130	3	4	1%	265	27	10.2
10 May	130	3	5	>1%	141	16	11.3
11 May	131	4	4	>1%	202	9	4.5
11 May	131	4	5	1%	203	33	16.3

Table 4. Continued.

Date	Day	Block	Unit	Test	Examined (n)	Descaled (n)	Descaled (%)
12 May	132	4	4	1%	243	14	5.8
12 May	132	4	5	>1%	235	24	10.2
13 May	133	5	4	>1%	254	19	7.5
13 May	133	5	5	1%	226	12	5.4
14 May	134	5	4	1%	356	32	8.9
14 May	134	5	5	>1%	202	19	9.4
17 May	137	6	4	1%	295	44	14.9
17 May	137	6	5	>1%	440	46	10.4
18 May	138	6	4	>1%	26	11	
18 May	138	6	5	1%	42	5	11.9
19 May	139	7	4	1%	36	4	11.1
19 May	139	7	5	>1%	66	11	16.6
20 May	140	7	4	>1%	12	9	
20 May	140	7	5	1%	34	9	26.5
21 May	141	8	4	1%	24	1	
21 May	141	8	5	>1%	50	11	22.2
24 May	144	8	4	>1%	84	29	34.5
24 May	144	8	5	1%	71	11	15.5
25 May	145	9	4	1%	248	21	8.5
25 May	145	9	5	>1%	408	68	16.7
26 May	146	9	4	>1%	201	37	18.4
26 May	146	9	5	1%	249	39	15.7
27 May	147	10	4	1%	200	30	14.8
27 May	147	10	5	>1%	247	43	17.4
28 May	148	10	4	>1%	260	42	16.2
28 May	148	10	5	1%	258	47	18.2
1 Jun	152	11	4	1%	262	57	21.8
1 Jun	152	11	5	>1%	240	63	26.3
2 Jun	153	11	4	>1%	206	41	19.9
2 Jun	153	11	5	1%	169	29	17.2
3 Jun	154	12	4	1%	28	4	12.8
3 Jun	154	12	5	>1%	40	21	37.7
4 Jun	155	12	4	>1%	37	12	20.5
4 Jun	155	12	5	1%	52	7	14.8
8 Jun	159		4	>1%	39	1	
8 Jun	159		5	1%	77	11	
9 Jun	160		4	1%	5	0	
9 Jun	160		5	>1%	7	0	
10 Jun	161		4	>1%	7	4	
10 Jun	161		5	1%	13	3	
11 Jun	162		4	1%	6	1	
11 Jun	162		5	>1%	22	5	

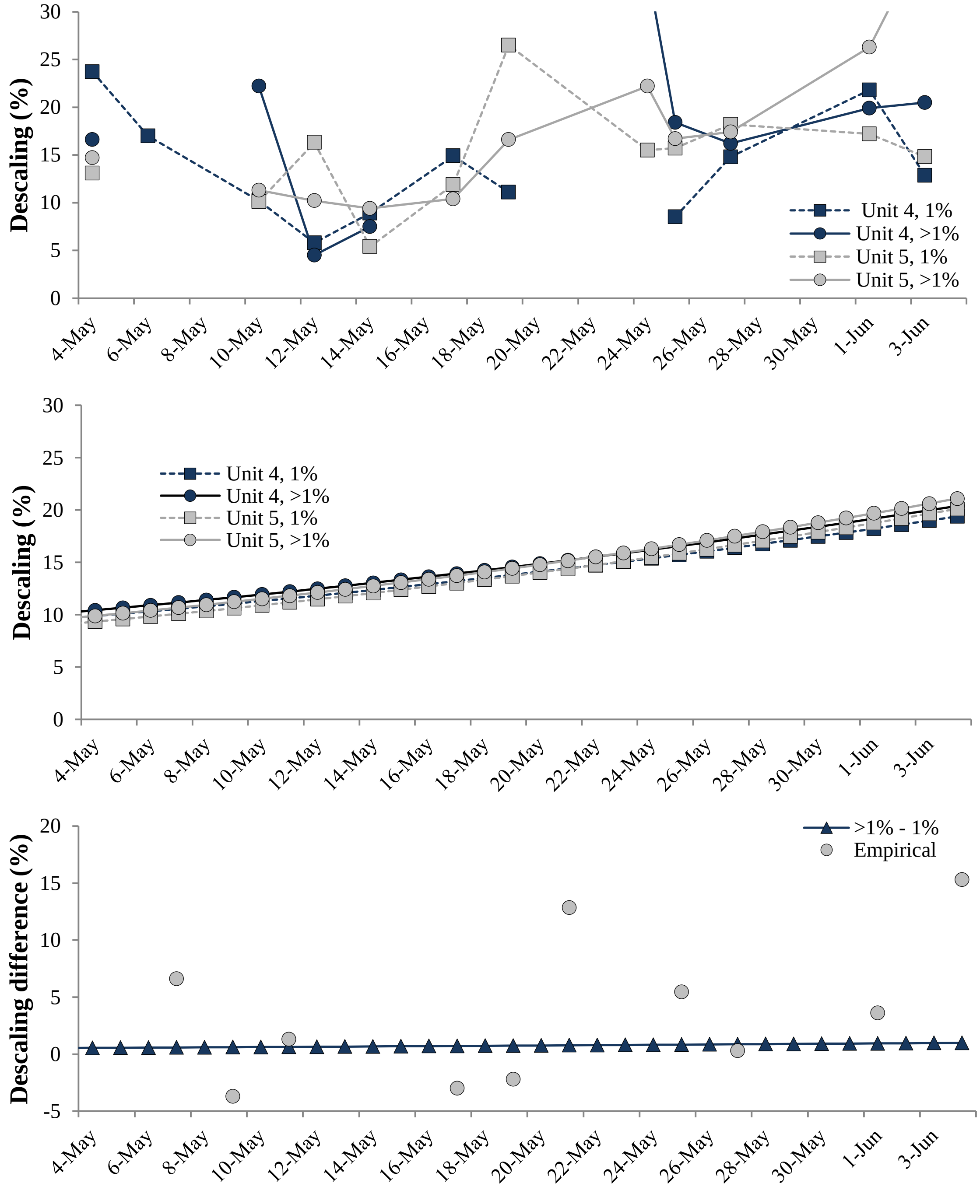

Figure 4. Descaling estimates for migrating juvenile sockeye salmon collected from orifice traps at McNary Dam, 2010. Upper panel shows data from empirical observation, middle panel shows the model average, and lower panel shows the difference between model-average descaling estimates (>1% – 1%).

Subyearling Chinook Salmon

In the summer, sufficient numbers of these fish were present after 8 June through the end of the study in early July (Table 5). From 1 June through 9 July, we collected and examined 7,268 subyearling Chinook salmon. There was a significant difference in descaling between >1% and 1%, but the magnitude varied between units. Logistic regression models showed higher descaling under >1% treatments for both turbine units, though there was sufficient evidence to suggest a unit effect with higher descaling consistently occurring in turbine unit 4 during >1% treatments for subyearling Chinook salmon. However, descaling through time was highly variable (Figure 5; Appendix Table 5), perhaps due to the issues discussed above with yearling Chinook salmon.

Averaging across the estimated unit differences, empirical differential descaling values were higher for >1% treatments in eleven of thirteen test blocks (Figure 5), with the model-averaged result determining a consistent 3.8% (SE 1.1%) difference in descaling.

Table 5. Total number of subyearling Chinook salmon examined for descaling and the measured difference between the two turbine loading treatments. Percent descaling was recorded only for replicates with >30 fish sampled.

					Descaled	
Date	Day	Unit	Test	Examined	(n)	(%)
1 June	152	4	1%	5	0	
1 June	152	5	>1%	4	0	
2 June	153	4	>1%	31	4	12.9
2 June	153	5	1%	13	1	
3 June	154	4	1%	10	0	
3 June	154	5	>1%	19	0	
4 June	155	4	>1%	29	3	
4 June	155	5	1%	30	0	0.0
8 June	159	4	>1%	53	3	5.7
8 June	159	5	1%	105	1	1.0
9 June	160	4	1%	20	0	
9 June	160	5	>1%	74	1	1.4
10 June	161	4	>1%	16	3	
10 June	161	5	1%	70	2	2.9
11 June	162	4	1%	53	5	9.4
11 June	162	5	>1%	202	6	3.0
14 June	165	4	1%	78	1	1.3
14 June	165	5	>1%	334	8	2.4
15 June	166	4	>1%	10	0	
15 June	166	5	1%	202	4	2.0
16 June	167	4	1%	47	2	4.3
16 June	167	5	>1%	152	6	3.9

Table 5. Continued.

Date	Day	Unit	Test	Examined	Descaled (n)	Descaled (%)
17 June	168	4	>1%	57	10	17.5
17 June	168	5	1%	278	6	2.2
18 June	169	4	1%	32	2	6.3
18 June	169	5	>1%	68	2	2.9
21 June	172	4	>1%	426	35	8.2
21 June	172	5	1%	410	37	9.0
22 June	173	4	1%	403	20	5.0
22 June	173	5	>1%	654	27	4.1
23 June	174	4	>1%	223	21	9.4
23 June	174	5	1%	204	1	0.5
24 June	175	4	1%	117	3	2.6
24 June	175	5	>1%	255	7	2.7
25 June	176	4	>1%	105	18	17.1
25 June	176	5	1%	225	3	1.3
28 June	179	4	>1%	71	22	31.0
28 June	179	5	1%	232	2	0.9
29 June	180	4	1%	76	1	1.3
29 June	180	5	>1%	250	12	4.8
30 June	181	4	>1%	101	8	7.9
30 June	181	5	1%	234	1	0.4
1 July	182	5	1%	239	6	2.5
2 July	183	5	>1%	102	4	3.9
6 July	187	5	>1%	219	10	4.6
7 July	188	5	1%	237	4	1.7
8 July	189	5	>1%	213	8	3.8
9 July	190	5	1%	280	6	2.1

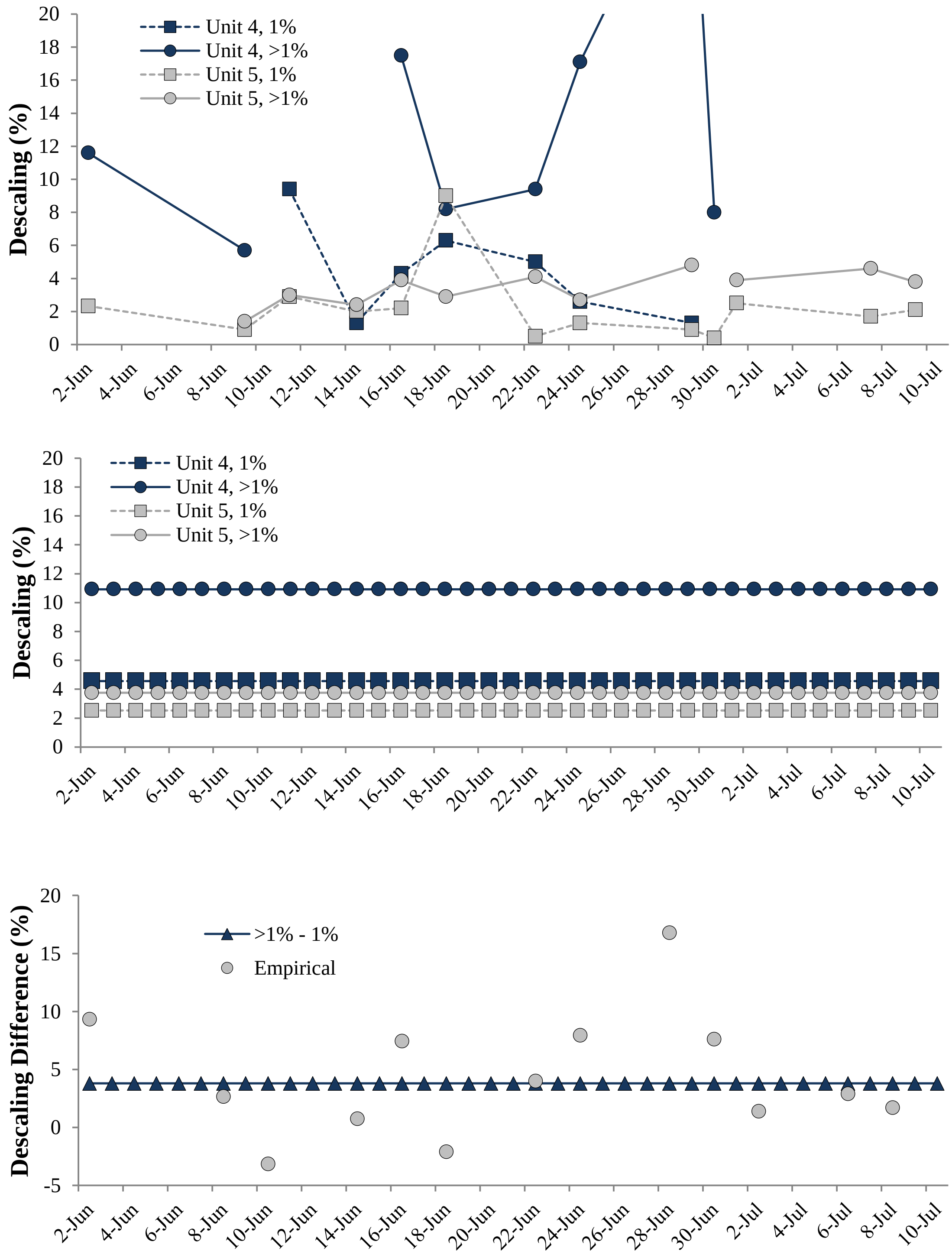

Figure 5. Descaling estimates for juvenile subyearling Chinook salmon collected from orifice traps at McNary Dam, 2010. Upper panel shows empirical data, middle panel shows model-averaged estimates, and lower panel shows the difference between model-averaged descaling (>1% – 1%) estimates.

DISCUSSION

At McNary Dam, operation of turbines at higher discharge loads may require modification of some juvenile bypass system components to abate descaling rates, which have been observed to increase in juvenile salmonids exposed to more turbulent gatewell conditions. Studies conducted at McNary Dam during 2004-2006 showed that descaling and injury rates were somewhat higher for collected smolts when turbines were operated at higher discharge levels (Absolon et al. 2005; Gessel et al. 2006, 2007). In some of these studies it was not evident where the descaling problem occurred; however, turbulence related to the higher flows was a probable cause.

Further, it is known that debris accumulates on the face of the vertical barrier screens, which can lead to higher descaling and injury rates to fish. In the 2008 Biological Opinion for the FCRPS (NMFS 2008), RPA 21 calls for the U.S. Army Corps of Engineers (USACE) to investigate and implement reasonable and effective measures to increase survival of fish passing through the forebay and McNary Dam by improving debris management to reduce injury of bypass and turbine-passed fish. While head-differential measurements collected by USACE personnel did not seem to relate directly to higher descaling, there was a considerable amount of debris within the test gatewells during the study (personal comm. Robert Johnson, Assistant Project Biologist McNary Dam).

Large volumes of windswept debris (tumbleweeds in this case) accumulated in the forebay at McNary Dam during the juvenile migration of spring 2010. Turbine intake flows drew this debris onto the trashracks, where it accumulated until becoming sufficiently waterlogged to sink to the lower ends of the trashracks. With time, this type of debris can partially block complete sections of the trashrack, from the surface to the river bottom. When this occurs, descaling rates for migrating juvenile salmonid can be very high. Evidence of this is displayed primarily as superficial abrasions on fish, particularly on sockeye salmon.

When project maintenance crews rake debris off the trash racks, descaling rates drop considerably, more so than when vertical barrier screens are cleaned. Therefore, it is intuitive that as debris accumulates, higher turbine loading may create a harsher environment through which migrating juvenile salmonids must pass. The unit effect observed in our study may be a result of differential debris loading across the powerhouse.

This study evaluated descaling in only 2 of 84 orifices within the juvenile fish bypass system at McNary Dam, consisting of 2 of the 14 turbine units. The effect of higher turbine loads across the powerhouse may be different from results obtained in units 4 and 5, and in other gate slots as well (this test only examined the A-slots).

Evaluations to monitor the condition of juvenile salmonids during higher turbine discharges at McNary Dam present a difficult problem. Variable flow conditions are combined with a continually changing river environment (i.e., variability in water temperature, debris loads, and debris types), as well as rates of descaling that vary among species of juvenile salmonid. These conditions require data sets that are more robust to provide conclusive information on descaling. Such data will be necessary if we are to continue the use of descaling and injury measurements as the primary methodology to evaluate the effects of various juvenile salmonid passage conditions at dams. Descaling evaluations with river-run fish do provide a cursory assessment of passage effects. However, if future investigations are to provide more definitive information, improvements to the study design are needed. For example, non-descaled fish should be released into test units in order to remove the possibility of previous descaling injuries from upstream projects.

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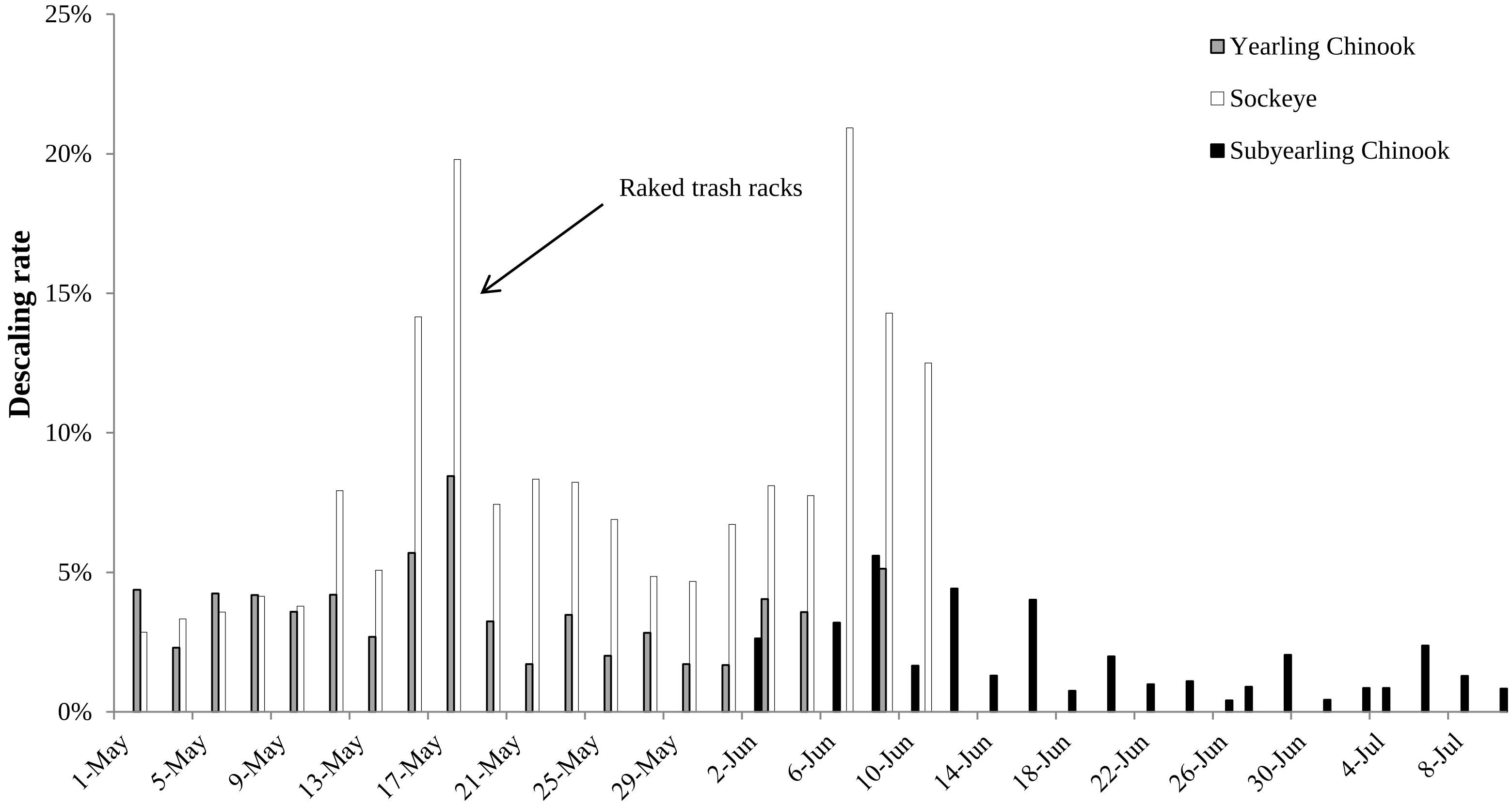
APPENDIX A



Appendix Figure A1. Percent descaling for yearling Chinook, sockeye, and subyearling Chinook salmon sampled at the smolt monitoring facility at McNary Dam during the 2010 juvenile migration season.

Appendix Table 1. Treatment schedule for turbine loading study at McNary Dam, 3 May-9 July 2010.

Date	**Day**	**Turbine unit 4**	**Turbine unit 5**
3-May	Monday	>1%	1%
4-May	Tuesday	1%	>1%
5-May	Wednesday	>1%	1%
6-May	Thursday	1%	>1%
7-May	Friday	>1%	1%
10-May	Monday	1%	>1%
11-May	Tuesday	>1%	1%
12-May	Wednesday	1%	>1%
13-May	Thursday	>1%	1%
14-May	Friday	1%	>1%
17-May	Monday	1%	>1%
18-May	Tuesday	>1%	1%
19-May	Wednesday	1%	>1%
20-May	Thursday	>1%	1%
21-May	Friday	1%	>1%
24-May	Monday	>1%	1%
25-May	Tuesday	1%	>1%
26-May	Wednesday	>1%	1%
27-May	Thursday	1%	>1%
28-May	Friday	>1%	1%
31-May	Monday	>1%	1%
1-Jun	Tuesday	1%	>1%
2-Jun	Wednesday	>1%	1%
3-Jun	Thursday	1%	>1%
4-Jun	Friday	>1%	1%
7-Jun	Monday	1%	>1%
8-Jun	Tuesday	>1%	1%
9-Jun	Wednesday	1%	>1%
10-Jun	Thursday	>1%	1%
11-Jun	Friday	1%	>1%
14-Jun	Monday	1%	>1%
15-Jun	Tuesday	>1%	1%
16-Jun	Wednesday	1%	>1%
17-Jun	Thursday	>1%	1%
18-Jun	Friday	1%	>1%
21 Jun	Monday	>1%	1%
22 Jun	Tuesday	1%	>1%
23 Jun	Wednesday	>1%	1%
24 Jun	Thursday	1%	>1%
25 Jun	Friday	>1%	1%
28 Jun	Monday	1%	>1%
29 Jun	Tuesday	>1%	1%
30 Jun	Wednesday	1%	>1%
1 Jul	Thursday	>1%	1%
2 Jul	Friday	1%	>1%
5 Jul	Monday	>1%	1%
6 Jul	Tuesday	1%	>1%
7 Jul	Wednesday	>1%	1%
8 Jul	Thursday	1%	>1%
9 Jul	Friday	>1%	1%

Appendix Table 2. Model selection process statistics for yearling Chinook salmon based on Akaike's Information Criterion adjusted for sample size and over-dispersion (*QAICc*). Data was modeled using logistic regression. Model in the first row has the lowest *QAICc*. Delta *QAICc* is the difference in a model's *QAICc* from the lowest one. Weight is the relative value of the model versus the others. Abbreviations: U, *unit;* D, *day*; T, *test*; H, *head*.

Model components	Log likelihood	Parameters	*QAICc*	*Δ QAICc*	Weight
Unit + Day + (U×D) + Test	-2252.03	5	1340.1	0.0	0.15
Unit + Test	-2260.59	3	1340.2	0.2	0.14
Unit + Day + (U×D) + Test Head	-2249.09	6	1340.9	0.9	0.10
Unit + Day + (U×D) + Test + Head + (D×H)	-2245.41	7	1341.5	1.5	0.07
Unit + Day + (U×D) + Test + Head + (D×T)	-2245.88	7	1341.8	1.7	0.06
Unit + Day + (U×D) + Test Head + (D×T) + (D×H)	-2241.66	8	1342.2	2.1	0.05
Unit + Day + Test	-2260.06	4	1342.3	2.2	0.05
Unit + Day + Test + Head	-2256.11	5	1342.5	2.4	0.05
Unit + Day + (U×D)	-2260.63	4	1342.6	2.6	0.04
Unit	-2269.45	2	1343.2	3.1	0.03
Unit + Day + (U×D) + Test + Head + (D×T) + (T×H)	-2244.04	8	1343.6	3.5	0.03
Unit + Day + (U×D) + Head	-2258.19	5	1343.7	3.6	0.02
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T)	-2244.27	8	1343.7	3.7	0.02
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H)	-2245.13	8	1344.2	4.2	0.02
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H)	-2245.22	8	1344.3	4.2	0.02
Unit + Day + (U×D) + Test + Head + (D×H) + (T×H)	-2245.34	8	1344.4	4.3	0.02
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T)	-2245.76	8	1344.6	4.6	0.02
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H)	-2240.81	9	1344.8	4.7	0.01
Unit + Day	-2268.71	3	1345.0	5.0	0.01
Unit + Day + (U×D) + Test + Head + (D×T) + (D×H) + (T×H)	-2241.37	9	1345.1	5.0	0.01
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H)	-2241.48	9	1345.1	5.1	0.01
Unit + Day + Head	-2265.59	4	1345.6	5.5	0.01
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (T×H)	-2242.60	9	1345.8	5.7	0.01
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (T×H)	-2244.00	9	1346.6	6.6	0.01
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T)	-2244.17	9	1346.7	6.7	0.01
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H)	-2244.96	9	1347.2	7.1	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H) + (T×H)	-2245.06	9	1347.3	7.2	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H) + (T×H)	-2245.18	9	1347.3	7.3	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H) + (T×H)	-2240.50	10	1347.8	7.7	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H)	-2240.68	10	1347.9	7.8	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H) + (T×H)	-2241.24	10	1348.2	8.1	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (T×H)	-2242.59	10	1349.0	8.9	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H) + (T×H)	-2244.93	10	1350.4	10.3	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H + (T×H)	-2240.43	11	1351.1	11.1	0.00

Appendix Table 3. Model selection process statistics for juvenile steelhead based on Akaike's Information Criterion adjusted for sample size and over-dispersion (*QAICc*). Data was modeled using logistic regression. Model in the first row has the lowest *QAICc*. Delta *QAICc* is the difference in a model's *QAICc* from the lowest one. Weight is the relative value of the model versus the others. Abbreviations: U, *unit;* D, *day*; T, *test*; H, *head*.

Model components	Log likelihood	Para-meters	*QAICc*	*ΔQAICc*	Weight
Unit + Day + Test	-338.33	4	577.9	0.0	0.35
Unit + Day	-340.14	3	578.4	0.5	0.27
Unit + Day + (U×D) + Test	-338.13	5	580.3	2.4	0.11
Unit + Day + (U×D)	-339.91	4	580.6	2.7	0.09
Unit + Day + (U×D) + Test + Head	-337.55	6	582.2	4.3	0.04
Unit + Day + (U×D) + Head	-339.39	5	582.4	4.5	0.04
Unit + Day + (U×D) + Test + Head + (D×H)	-336.53	7	583.6	5.7	0.02
Unit + Day + (U×D) + Test + Head + (D×T)	-337.01	7	584.4	6.5	0.01
Unit + Day + (U×D) + Test + Head + (U×T)	-337.36	7	585.0	7.1	0.01
Unit + Day + (U×D) + Test + Head + (T×H)	-337.40	7	585.1	7.2	0.01
Unit + Day + (U×D) + Test + Head + (U×H)	-337.54	7	585.3	7.4	0.01
Unit + Test	-344.42	3	585.6	7.7	0.01
Unit	-345.94	2	585.8	7.9	0.01
Unit + Day + (U×D) + Test + Head + (D×T) + (D×H)	-336.07	8	586.2	8.2	0.01
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H)	-336.39	8	586.7	8.8	0.00
Unit + Day + (U×D) + Test + Head + (D×H) + (T×H)	-336.53	8	586.9	9.0	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H)	-336.53	8	586.9	9.0	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T)	-336.72	8	587.2	9.3	0.00
Unit + Day + (U×D) + Test + Head + (D×T) + (T×H)	-336.93	8	587.6	9.7	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T)	-337.00	8	587.7	9.8	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H)	-335.84	9	589.4	11.4	0.00
Unit + Day + (U×D) + Test + Head + (D×T) + (D×H) + (T×H)	-336.06	9	589.7	11.8	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H)	-336.07	9	589.7	11.8	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H) + (T×H)	-336.37	9	590.2	12.3	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H)	-336.39	9	590.3	12.4	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H) + (T×H)	-336.52	9	590.5	12.6	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (T×H)	-336.59	9	590.6	12.7	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T)	-336.71	9	590.8	12.9	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (T×H)	-336.91	9	591.2	13.2	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H) + (T×H)	-335.80	10	593.2	15.3	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H)	-335.84	10	593.2	15.3	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H) + (T×H)	-336.05	10	593.6	15.7	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H) + (T×H)	-336.37	10	594.1	16.2	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (T×H)	-336.58	10	594.5	16.6	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H) + (T×H)	-335.80	11	597.4	19.5	0.00

Appendix Table 4. Model selection process statistics for sockeye salmon based on Akaike's Information Criterion adjusted for sample size and over-dispersion (*QAICc*). Data was modeled using logistic regression. Model in the first row has the lowest *QAICc*. Delta *QAICc* is the difference in a model's *QAICc* from the lowest one. Weight is the relative value of the model versus the others. Abbreviations: U, *unit;* D, *day*; T, *test*; H, *head*.

Model components	Log likelihood	Para-meters	*QAICc*	*ΔQAICc*	Weight
Unit + Day	-3031.8	3	1119.1	0.0	0.30
Unit + Day + Test	-3027.56	4	1119.9	0.8	0.20
Unit + Day + (U×D)	-3029.64	4	1120.7	1.6	0.14
Unit + Day + (U×D) + Test	-3024.44	5	1121.2	2.1	0.10
Unit + Day + Head	-3031.47	4	1121.4	2.2	0.10
Unit + Day + (U×D) + Head	-3028.96	5	1122.9	3.8	0.05
Unit + Day + (U×D) + Test + Head	-3024.06	6	1123.7	4.6	0.03
Unit + Day + (U×D) + Test + Head + (D×H	-3020.61	7	1125.1	6.0	0.01
Unit + Day + (U×D) + Test + Head + (T×H)	-3021.13	7	1125.3	6.2	0.01
Unit + Day + (U×D) + Test + Head + (D×H) + (T×H)	-3016.10	8	1126.3	7.2	0.01
Unit	-3058.08	2	1126.5	7.4	0.01
Unit + Day + (U×D) + Test + Head + (D×T) + (D×H)	-3018.28	8	1127.1	8.0	0.01
Unit + Day + (U×D) + Test + Head + (D×T) + (T×H)	-3019.59	8	1127.6	8.5	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H)	-3019.64	8	1127.6	8.5	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H)	-3020.54	8	1128.0	8.9	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (T×H)	-3020.67	8	1128.0	8.9	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (T×H)	-3020.80	8	1128.1	8.9	0.00
Unit + Day + (U×D) + Test + Head + (D×T) + (D×H) + (T×H)	-3014.88	9	1128.9	9.8	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H) + (T×H)	-3015.20	9	1129.0	9.9	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H) + (T×H)	-3016.00	9	1129.3	10.2	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H)	-3017.10	9	1129.7	10.6	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H)	-3017.95	9	1130.0	10.9	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (T×H)	-3018.92	9	1130.4	11.2	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (T×H)	-3018.98	9	1130.4	11.3	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H)	-3019.60	9	1130.6	11.5	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (T×H)	-3020.42	9	1130.9	11.8	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H) + (T×H)	-3013.80	10	1131.6	12.5	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H) + (T×H)	-3014.59	10	1131.9	12.8	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H) + (T×H)	-3015.16	10	1132.1	13.0	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H)	-3016.84	10	1132.7	13.6	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (T×H)	-3018.42	10	1133.3	14.2	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H) + (T×H)	-3013.62	11	1134.9	15.7	0.00

Appendix Table 5. Model selection process statistics for subyearling Chinook salmon based on Akaike's Information Criterion adjusted for sample size and over-dispersion (*QAICc*). Data was modeled using logistic regression. Model in the first row has the lowest *QAICc*. Delta *QAICc* is the difference in a model's *QAICc* from the lowest one. Weight is the relative value of the model versus the others. Abbreviations: U, *unit;* D, *day*; T, *test*; H, *head*.

Model components	Log likelihood	Para-meters	*QAICc*	*ΔQAICc*	Weight
Unit + Day + Test	-338.33	4	577.9	0.0	0.35
Unit + Day	-340.14	3	578.4	0.5	0.27
Unit + Day + (U×D) + Test	-338.13	5	580.3	2.4	0.11
Unit + Day + (U×D)	-339.91	4	580.6	2.7	0.09
Unit + Day + (U×D) + Test + Head	-337.55	6	582.2	4.3	0.04
Unit + Day + (U×D) + Head	-339.39	5	582.4	4.5	0.04
Unit + Day + (U×D) + Test + Head + (D×H)	-336.53	7	583.6	5.7	0.02
Unit + Day + (U×D) + Test + Head + (D×T)	-337.01	7	584.4	6.5	0.01
Unit + Day + (U×D) + Test + Head + (U×T)	-337.36	7	585.0	7.1	0.01
Unit + Day + (U×D) + Test + Head + (T×H)	-337.40	7	585.1	7.2	0.01
Unit + Day + (U×D) + Test + Head + (U×H)	-337.54	7	585.3	7.4	0.01
Unit + Test	-344.42	3	585.6	7.7	0.01
Unit	-345.94	2	585.8	7.9	0.01
Unit + Day + (U×D) + Test + Head + (D×T) + (D×H)	-336.07	8	586.2	8.2	0.01
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H)	-336.39	8	586.7	8.8	0.00
Unit + Day + (U×D) + Test + Head + (D×H) + (T×H)	-336.53	8	586.9	9.0	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H)	-336.53	8	586.9	9.0	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T)	-336.72	8	587.2	9.3	0.00
Unit + Day + (U×D) + Test + Head + (D×T) + (T×H)	-336.93	8	587.6	9.7	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T)	-337.00	8	587.7	9.8	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H)	-335.84	9	589.4	11.4	0.00
Unit + Day + (U×D) + Test + Head + (D×T) + (D×H) + (T×H)	-336.06	9	589.7	11.8	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H)	-336.07	9	589.7	11.8	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×H) + (T×H)	-336.37	9	590.2	12.3	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H)	-336.39	9	590.3	12.4	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×H) + (T×H)	-336.52	9	590.5	12.6	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (T×H)	-336.59	9	590.6	12.7	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T)	-336.71	9	590.8	12.9	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (T×H)	-336.91	9	591.2	13.2	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (D×T) + (D×H) + (T×H)	-335.80	10	593.2	15.3	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H)	-335.84	10	593.2	15.3	0.00
Unit + Day + (U×D) + Test + Head + (U×H) + (D×T) + (D×H) + (T×H)	-336.05	10	593.6	15.7	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×H) + (T×H)	-336.37	10	594.1	16.2	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (T×H)	-336.58	10	594.5	16.6	0.00
Unit + Day + (U×D) + Test + Head + (U×T) + (U×H) + (D×T) + (D×H) + (T×H)	-335.80	11	597.4	19.5	0.00