Technical Report 2024-10

Statistical analysis of court-ordered dam operation measures to improve passage of juvenile Chinook salmon at US Army Corps operated projects in the Willamette Valley System

Phase 1 Report

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The authors currently live and work on unceded territories of the Coast Salish peoples–Sḵwx̱wú7mesh (Squamish), Stó:lō and Səl̓ílwətaʔ/Selilwitulh (Tsleil-Waututh) and xʷməθkʷəy̓əm (Musqueam) Nations and Ts’elxwéyeqw Tribe, and within the Treaty and traditional territory of the Mississaugas of Scugog Island First Nation and Williams Treaties signatories of the Mississauga and Chippewa Nations.

Executive summary

The aim of the analyses detailed in this Phase 1 Report was to statistically test hypotheses about effects of measures implemented under the current injunction on Willamette Valley System (WVS) dam project operations on Upper Willamette River (UWR) spring Chinook salmon (*Oncorhynchus tshawytscha*) passage metrics. The injunction measures were hypothesized to improve survival, condition and passage efficiency of juvenile Chinook salmon. The main type of data used in the analyses in this Phase 1 Report are records from rotary screw traps (RSTs) sited above and below dams in the WVS that have been operated in periods both pre- and post-implementation of injunction measures. A substantial amount of effort was required to clean up the RST records for the purposes of statistical analysis. This involved, for example, consolidating records from four different trap operators and removing records of fish recaptured in trap efficiency trials from the data set to be used for testing of hypotheses on potential effects of injunction measures on fish passage metrics. We could confidently perform statistical tests where several years of RST data were available and there were no less than two years of RST data post injunction. However, there were significant limitations to the available RST records for testing hypotheses about injunction effects. Not all projects have paired RSTs above and below dams during the pre-and post-injunction periods. In addition, even at the data-rich sites there were only two full years of RST data available following the implementation of injunction measures. Additional years of data collection would allow for a broader range of hydrological variability known to occur at WVS projects to be incorporated in future analysis, which may influence results.

In this document we report an analysis of results from trap efficiency (TE) trials at RST sites with the goal of developing improved understanding of the adjustments to observed capture numbers needed to account for TE. There were sufficient flow data and TE trials to test whether TE was related to mean flow at 16 of the 20 RST sites. In four of these instances, TE was found to be negatively associated with mean flow, but at the other sites no relationship of TE with mean flow was found. Following adjustment of the RST records using results from this TE analysis, statistical tests were carried out to test for potential effects of injunction measures on fish passage metrics. Tests could only be carried out where there were RST records from both the pre-injunction and post injunction periods for a given WVS dam. The availability of covariate information further limited dams where tests could be conducted. For the two dams (Big Cliff and Cougar) where total dissolved gas (TDG) records were available in relation to RSTs in both pre- and post-injunction periods, a positive association was found between the incidence of gas bubble disease (GBD) and the maximum recorded values for TDG and there was a significant reduction in the incidence of GBD in juvenile Chinook salmon in the post injunction period. Measures to reduce TDG exceedances to below 130% through modification of dam spill operations appear to have reduced the risks to these threatened Chinook salmon populations. The incidence of mortality and all barotrauma-related injuries in juvenile Chinook salmon were also found to be lower in the post-injunction period at these two dams. In contrast, analysis of other injury categories at below-dam RST sites indicated an overall increase in injuries reported during the post-injunction period. However, injury analysis considered both wild and hatchery fish, and hatchery fish may experience injury during rearing and release. Additionally, because there was turnover in RST operators between pre- and post-injunction periods at all RST sites, it is unclear whether the increase in injury reporting is directly related to dam operations in the post-injunction period. Where both injunction period and operator effects were tested, RST operator often also had a significant effect on the rate of injury reporting.

When relatively simple models were fitted to test for injunction effects on project passage efficiency, i.e., the ratio of juvenile salmon abundance between dam tailrace and head of reservoir for a given cohort and juvenile migrant stage, a statistically significant positive effect was found for fry and subyearlings passing Cougar Dam where the largest amount of RST data were available. However, for all other dams, no statistically significant effect of injunction measure implementation was found. This is likely due to very low statistical power from the highly variable and sparse RST data available at these other locations (given RST records from 2024 and beyond, analysis of passage efficiency could potentially be conducted at some of the other locations). There were similar challenges in testing for an injunction effect on growth as there were too few data post-injunction at both above- and below dam sites to perform statistical analysis; additional years of RST may improve our ability to statistically detect any changes to growth patterns that may arise from injunction measures. For most projects where growth curves could be parameterized for both pre- and post-injunction periods, confidence intervals on key growth parameters often overlapped. While there appear to be some site-specific differences in run timing between the two periods, due to there being only two years of data post-injunction we cannot conclude these differences are due to the injunction measures and not hydrological or other sources of variability.

Future analysis may include further refinements to the TE analysis, e.g., testing additional covariates such as mean trap rotation and mean size of fish used in the experiment. As data are made available, we may also analyze active tag data and additional RST records to test for injunction effects on fish passage metrics. We may also perform a statistical power analysis to better show the strengths and limitations in the data's ability to be used in testing for effects of dam operations on juvenile fish passage.

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Table of abbreviations

Abbreviation	Definition
AIC	Akaike Information Criterion
cfs	Cubic feet per second
DOY	Day of year
EAS	Environmental Assessment Services
ESA	Endangered Species Act
GBD	Gas bubble disease
HOR	Head of reservoir
IM	Interim measure
Inj	Injunction period
IPA	UBC's Integrated Passage Assessment team
ODFW	Oregon Department of Fish and Wildlife
PH	Powerhouse
PIT	Passive integrated transceiver
PPE	Project passage efficiency
RM&E	Research, evaluation, and monitoring
RO	Regulating outlet
RPM	Revolutions per minute
RST	Rotary screw trap
TDG	Total dissolved gas
TE	Trap efficiency
TR	Tailrace
UBC	University of British Columbia
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UWR	Upper Willamette River
Wk	Week
WVS	Willamette Valley System

Table of site codes

Site code	Full site name
BCL	Big Cliff
BRE	Breitenbush
CGR	Cougar
DET	Detroit
DEX	Dexter
FCR	Fall Creek
FOS	Foster
GPR	Green Peter
HCR	Hills Creek
LOP	Lookout Point
NFMF	North Fork Middle Fork
MF	Middle Fork
NS	North Santiam

Introduction

Purpose of this report

This report presents results from Phase 1 of analyses of rotary screw trap (RST) data records from traps placed above and below US Army Corps-operated projects to evaluate the effectiveness of injunction measures implemented in the Willamette Valley System (WVS). Specifically, the report provides an assessment of whether these measures have had the intended positive impacts on downstream passage through dams for wild juvenile Chinook salmon (*Oncorhynchus tshawytscha*), focusing on metrics of fish size, body condition, migration timing, and project passage efficiency. We use RST records from as early as 2005 to 2023 to compare pre- and post-injunction conditions.

Injunction measures at Willamette Valley Projects

On September 1, 2021, the United States District Court for the District of Oregon issued an interim injunction mandating specific actions to improve water quality and downstream fish passage at several dams operated by the US Army Corps of Engineers (USACE) in the WVS (see Figure 1). These measures aim to benefit ESA-listed populations of spring Chinook salmon and winter steelhead (*O. mykiss*) in the Upper Willamette River. The injunction includes measures to modify dam operations and structures to improve the downstream passage of target fish populations and to improve conditions related to temperature and dissolved gas levels below the dams. A summary of the measures related to downstream passage operations is presented in Table 1.

Monitoring and evaluation: RST record availability

To evaluate the effectiveness of injunction measures on populations of interest, the Corps has been carrying out research, monitoring, and evaluation (RM&E) efforts, including the use of RSTs above and below USACE-operated projects. RST records are a primary source of comprehensive data on fish species, run timing, size, and body condition. In the WVS, RST records are a primary source of data and one of a few sources of information about the dam passage of naturally spawned and reared fish. RST records also provide the most spatially and temporally comprehensive set of records on fish dam passage as of August 2024.

Biological goals of injunction measures for Chinook salmon passing WVS dams

One of the biological goals of the court-ordered injunction measures is to increase the diversity of juvenile migrants that pass through the dams. Spring measures are motivated in part by improving fry passage, and fall measures typically seek to pass subyearlings and any yearlings (to the extent they are present in the reservoirs at these times). It has been observed that smaller fish generally experience higher survival rates during dam passage. Some injunction measures involve significant drawdowns of reservoir pool elevations and/or delays in reservoir refilling, which are expected to increase the likelihood that juvenile migrants entering WVS reservoirs will continue downstream and pass-through dams at younger age classes rather than rearing in the reservoir. Fall drawdowns shorten reservoir length and are hypothesized to enhance the downstream flow signal used by juvenile migrants for navigation. Drawdowns also allow migrants in the dam’s forebay to more easily find and dive to dam outlets that provide safe passage (e.g., by reducing the depth to an RO or other non-turbine outlet). Consequently, it is anticipated that injunction measures will reduce reservoir residence times and increase the proportion of downstream migrants passing the dam as fry and surviving. For example, at Cougar Dam, injunction measure 15a—delayed spring refill—is partly aimed at maintaining optimal passage conditions for fry and yearling migrants in the spring. Similar goals apply to dam operations in the autumn, aligning with observed juvenile Chinook migration periods in the fall.

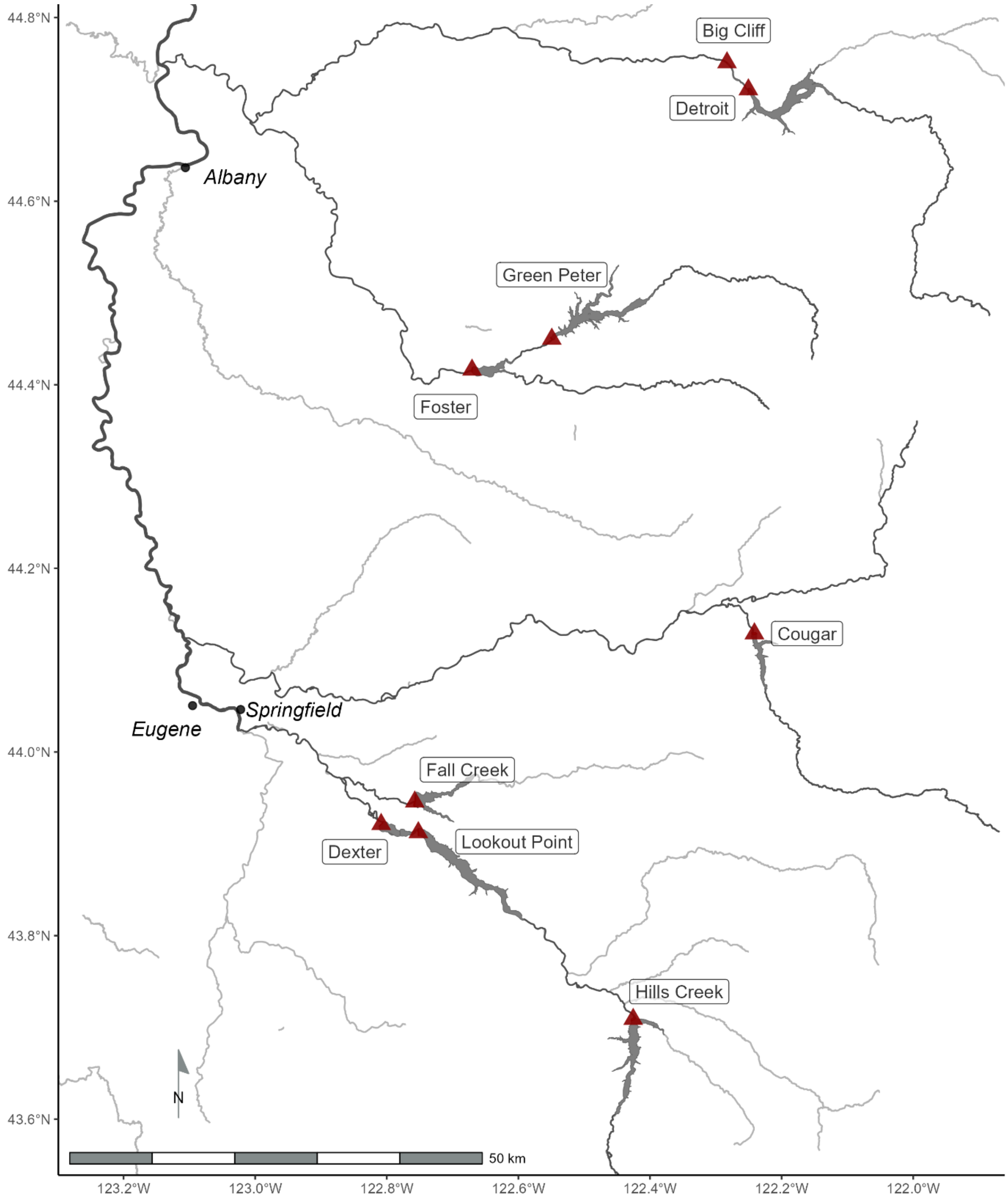

Figure 1. Map of the Upper Willamette River, Oregon, highlighting major cities and USACE-operated projects (red triangles). Spatial data downloaded from Open Street Map (OpenStreetMap contributors 2017) via the 'osmdata' R package (Padgham et al. 2017) and projected with the UTM 10 coordinate system.

Table 1. Summary of injunction measures related to dam operations and improving downstream fish passage and below-dam water quality (including total dissolved gas and temperature augmentation). Measures are project specific. Some measures were adapted from interim measures and are named with an "IM" prefix. This is not an exhaustive list of all injunction measures, which also include outplanting of fish above Green Peter Reservoir and resurfacing of the Cougar RO outlet. Full details are available on the injunction webpage: https://www.nwp.usace.army.mil/Locations/Willamette-Valley/Injunction/. Table continues on the following page.

Project	**Measure**	**Measure description**
Detroit	IM 5	Once the elevation of Detroit Reservoir is less than 100 ft over the turbine intakes during the fall drawdown and winter months, generally only operate the turbines at Detroit Dam during the day and prioritize a non-turbine outlet to pass flow at night (from dusk until dawn), generally with no turbine operation during that time.
Detroit	10a	Draft reservoir to pool elevation 1,465 feet or less by Oct 15, then use the dam's lower ROs for temperature control purposes.
Detroit and Big Cliff	IM 7	Through strategic use of the spillway, turbines, and regulating outlets at Detroit Dam, provide downstream fish passage in the spring and water temperature management throughout late spring and summer at Detroit and Big Cliff dams.
Big Cliff	IM 6	When operating the spillway at Big Cliff Dam, operate multiple spillway gates to spread total flow across the spillway.
Foster	13a	Draw down reservoir to elevation 620-625 feet by October 1 and operate the Foster Dam spillway with limited turbine operation from one hour before sunset to one-half hour after sunrise Oct 1-Dec 15.
Foster	13b	Hold Foster Reservoir at minimum conservation pool (613ft) and operate the Foster Dam spillway with limited turbine operation from one hour before sunset to one-half hour after sunrise, Feb 1-May 15. Beginning May 16, refill reservoir with a target of full pool by Memorial Day weekend (the last Monday in May) and operate the Foster Dam spillway with limited turbine operation from one hour before sunset to one-half hour after sunrise until June 15. Beginning June 16 through mid- to late-July, operate the Foster fish weir for downstream water temperature management.
Green Peter	12a	Release water from the spillway once the Green Peter Reservoir reaches 971 ft. Spill will be carried out continuously until May 1 or for at least 30 days, whichever is longer. At least two different spill strategies will be tested in a block study: (1) continuous (24/7) spill through a minimum gate opening of 1.5 ft. and (2) nighttime spill through a 3–4 ft gate opening one hour before sunset to one hour after sunrise. Operations in spring 2023 are summarized in the respective Green Peter Dam implementation plan and may be modified by mutual agreement of the Corps and NMFS as warranted.[1]
Green Peter	12b	Conduct a fall drawdown of Green Peter Reservoir to a target elevation of 780 ft. (approximately 35 feet over the regulating outlets, ROs) by Nov 15 and hold

[1] In 2023 the implementation of measure 12a at Green Peter was influenced by poor health of surrogate fish to be released during paired releases. This caused the Corps and NMFS to decide to continue operating 24/7 spill operations in 2023 versus testing continuous spill versus nighttime-only spill (as was planned with surrogate fish).

		at that elevation until Dec 15. Generally, use the ROs exclusively to pass flow once the reservoir is below minimum power pool (887 ft.).
Cougar	14	Conduct a fall drawdown of Cougar Reservoir to a target elevation of 1,505 feet by Nov 15 until Dec 15. Generally, use the ROs exclusively during that time to pass flow.
Cougar	15a	On Dec 16, initiate the refill of Cougar Reservoir to minimum conservation pool (1,532 feet) and hold until Mar 1. On Mar 1, begin drafting Cougar Reservoir to reach elevation 1,520 feet by Apr 1. Using adaptive management to determine the refill starting date, delay the refill of Cougar Reservoir from elevation 1,520 feet as long as possible while maintaining a high likelihood of reaching elevation 1,571 feet by July 1 to enable use of the water temperature control tower in late summer and fall. From Dec 16 through Jun 1, prioritize the regulating outlets at night to pass flows. In Sept, transition to the fall drawdown operation.
Hills Creek	IM 20 (aka. 8)	Once Hills Creek Reservoir is drawn down below El. 1460 ft., operate the ROs daily from 6:00 PM to 10:00 PM. This operation is expected to be implemented from approximately December 1 through March 1.
Lookout Point and Dexter	17	Use storage from Hills Creek Reservoir to begin refilling Lookout Point Reservoir in early March. Once Lookout Point Reservoir reaches elevation 890 ft., spill water over the spillways 24/7 for at least 30 days at both Lookout Point and Dexter dams while maintaining the elevation of Lookout Point Reservoir between 890-893 ft. During that time, generally do not operate the turbines at both projects, with limited exceptions. After that initial 30-day period, spill at night at both projects, with generation during the day, for as long as water is available and downstream conditions allow. Then manage Lookout Point Reservoir to achieve elevation 887.5 ft. by July 15, 2022 and operate the regulating outlets as needed to reduce downstream water temperatures when water temperatures downstream of Dexter Dam near 60 degrees.
Lookout Point	16	Annual Lookout Point Reservoir deep drawdown operation from November 15 through December 15.
Fall Creek	19	Annual Fall Creek Reservoir deep drawdown operation similar to prior years but extend the dates from Dec 1 through Jan 15.
Fall Creek	20	On Jan 16, begin the refill of Fall Creek Reservoir to elevation 700 feet and hold at that elevation through Mar 15. On Mar 16, initiate the refill to reach elevation 728 feet by Apr 15 and maintain that elevation through May 15 unless additional refill is necessary to ensure operation of the Fall Creek Adult Fish Collection Facility through Sept 30. After May 15, refill the reservoir to the extent possible.

Chinook salmon juvenile migrant types

Wild juvenile Chinook salmon exhibit migratory diversity during downstream migration. In the Upper Willamette River, juvenile migrant types are categorized as fry, subyearlings, and yearlings according to run timing and body size attributes, both of which are captured in RST records. Following other Willamette research groups (e.g., Zabel et al. 2015; Romer et al. 2017), previous research by the UBC IPA team has used a simple categorization to define juvenile migrants as fry if they are less than 60mm in size, subyearlings if they are larger than 60mm in summer to late fall, and yearlings if they are larger than 60mm and have not yet passed the dam in the spring (see Figure 2 for an example and section "Juvenile stage categorization" for details on further development of this categorization). Migrant types may also be determined using logistic growth functions parameterized from RST records.

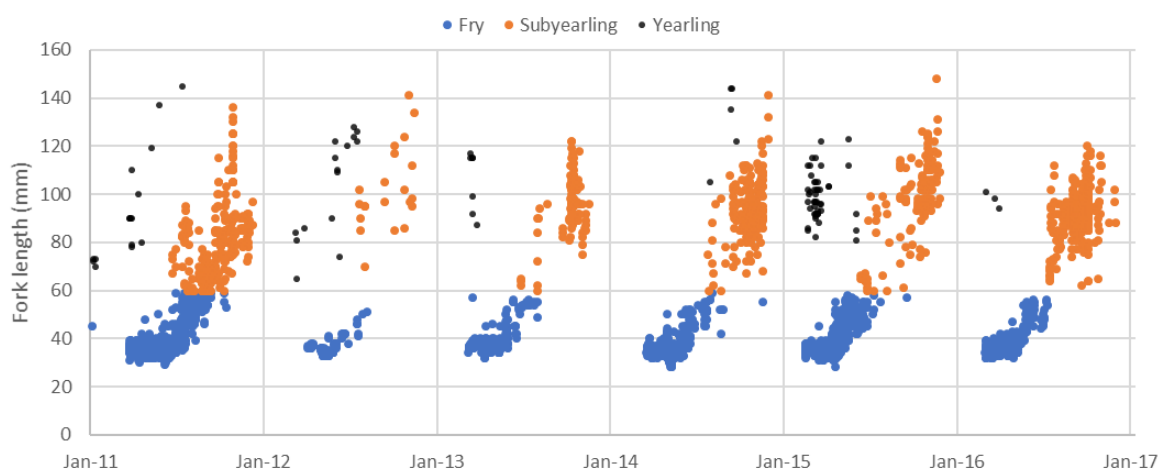

Figure 2. Size versus date of capture of juvenile Chinook salmon migrants captured in RST traps below Detroit dam from 2011 to 2017. Migrant types are identified from a combination of timing and body size. Fry are fish below 60mm in length who are captured below dams in their first spring. Yearlings are fish which are larger than 60mm who pass dams after their first year of rearing. The final category, subyearlings, are fish which are larger than 60mm but pass in the first summer or fall of life.

Migrant behaviour once in the forebay can vary; fish may either attempt to pass through the dam or remain in the reservoir. Thus, a cohort of juvenile Chinook salmon that enters the reservoir as fry may exit at the fry, subyearling, or yearling stage (see Figure 3).

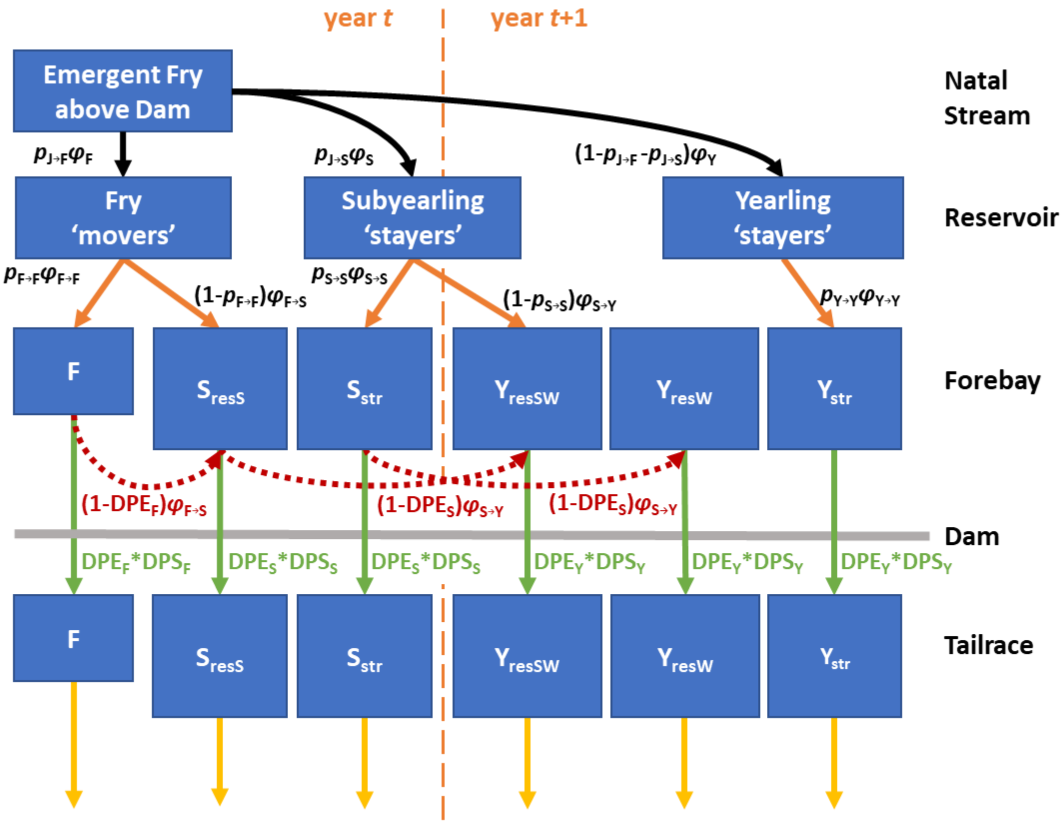

Figure 3. Schematic representation of how distinct migrant groups of juvenile salmonids emerge from different life history processes. Equations by each arrow describes the survival and splitting of migrant groups into subtypes. First, emergent fry above the dam may begin migration as fry, subyearlings, or yearlings. When moving as fry, migrants are called "movers", indicating movement from the natal grounds; if they rear longer on natal grounds, they are termed "stayers". Then, in the reservoir, fish may rear or continue to the dam and attempt passage (orange arrows). Those attempting dam passage may successfully pass the dam immediately (green lines, indicating successful passage), or they may rear in the reservoir longer to a larger adult stage (red dashed lines). DPE: dam passage efficiency; DPS: dam passage survival; F: fry type, S: subyearling type, Y: yearling type.

Methods

The approach applied in this section was to test hypotheses about effects of injunction measures in each WVS project on juvenile Chinook salmon passage metrics using RST data collected before and after injunction measure implementation. This required compiling and cleaning the RST data provided, analyzing data from multiple trap efficiency (TE) experiments, and then adjusting the RST capture records from each RST based on results from the TE experiment data analyses. Relatively simple models that represented potential injunction effects on project passage efficiency, migration timing, growth, and injury rates on different juvenile migrant types were formulated and fitted to the cleaned and, where appropriate, adjusted according to TE. In addition to an injunction measure effect, the effects of flow, reservoir elevation, total dissolved gas and other covariates were examined where appropriate. The range and complexity of models considered was quite limited due to the relatively few years of, and large amount of variability in, the RST data. The direction, magnitude and statistical significance of estimated effects were examined to test hypotheses about effects of injunction measures on fish passage metrics. It is expected that the statistical power of the hypothesis tests performed was mostly quite low due to the noted limitations in the data.

Definitions of calculated metrics used to assess injunction measures with RST data

The use of data collected via RSTs allowed us to assess several fish passage metrics associated with WVS dam operations. Each metric is hypothesized to be affected by injunction measures at some or all USACE-operated projects; below, we define each metric and the hypothesized effect of injunction measures on that metric.

Migration timing and growth analysis

In this Phase 1 report, we assessed two aspects of fish size and migration timing. First, we assessed the timing and size of migrants to identify an injunction effect. Second, we estimated growth curves of different migrant types at each site to identify if growth rates, maximum body size, or other attributes of juvenile growth have changed as a result of injunction measures.

Migration analysis focused on two core questions; 1) is the run timing different between the pre and post injunction, and 2) does the distribution of juvenile migrant types, using fork lengths as a proxy, change between the pre and post injunction time periods? Three metrics were used to evaluate run timing: weekly catch rate, fork length, and the distribution of raw observations each week.

- **Definition:** Fork Length at time at passage is defined as the median fork length of fish passing a dam in a given trapping event. Fish collected in the trap were measured by RST operators and their fork length recorded at the time of trap processing. The percent of fish assessed individually depends on the total number of fish captured in a given trap event –when many fish were captured in the trap, such that it was infeasible for trap processors to measure all fish, up to fifty fish may be measured. We use length and timing of passage records in combination used to infer age group or life history stage (e.g. fry, subyearling, or yearling juvenile migrant types).
- **Hypothesized impact(s) of injunction measures on size at time of dam passage:** If injunction measures have their intended effect on reservoir residence and travel time, there will be an observable decrease in the length of fish at time of dam passage. Compared to before injunction measures were implemented, it is hypothesized that fish passing the dam will represent younger and thus smaller migrant types.

Fish condition

- **Definition**: Fish condition is defined as external signs of injury and health of the fish. Injuries reported in RSTs typically include descaling, discoloration, trauma, wounds, hematoma, hemorrhaging, and body deformations. Health indicators reported at RSTs include the presence of parasites, external growths, gill condition, fin deterioration, and bloating. We also explicitly assessed evidence of gas bubble disease (GBD) that can occur due to excess total dissolved gas (TDG) caused by dam operations.
- **Hypothesized impact(s) of injunction measures on fish condition below dams:** Several measures seek to reduce the risk of poor health and injury of fish during reservoir and dam passage via at least three mechanisms: 1) by reducing in-reservoir residence time, expected to reduce the exposure of juvenile migrants to copepod parasitism and other sources of mortality in the reservoir, 2) by encouraging the passage of younger age class fish which are less likely to experience injury and trauma during passage due to their smaller size, and 3) by prioritizing the use of safer dam outlets to pass water through the dam during times of peak passage. As a result of the implementation of injunction measures, there will be less incidence of injury and trauma.

Project passage efficiency (PPE)

- **Definition:** Ratio of fish abundance at a dam's tailrace compared to that at the head of reservoir, for a given migrant type within a given season. For example, in this Phase 1 report, project passage efficiency (PPE) is defined for fry and subyearlings which pass within a single season (i.e., spring or autumn). PPE for yearling migrants will be considered in future analysis.
- **Hypothesized impact(s) of injunction measures on PPE:** Measures to reduce reservoir residency, increase fish attraction to dams, and reduce mortality during passage are hypothesized to improve the survival of juvenile migrants, particularly smaller life stages like fry (see hypotheses about body size described above). If dam operations increase the proportion of fry which, after having entered a reservoir, pass the dam while still fry, there may be an observable increase in the relative abundance of fry at the tailrace compared to before the injunction. It is hypothesized that if injunction measures perform as expected, PPE will increase for fry and subyearling migrants.

Data sources: RST data

Accurate calculation of fish passage and condition metrics, and estimation of any changes to these metrics in response to injunction measures requires careful study design and multiple years of data collection. RSTs must be operated in similar ways before and after the injunction to improve the likelihood that any observed differences in fish passage are attributable to dam operations, not changes in sampling methods. In addition to changing dam operations, RST records may also reflect changing hydrological and ecological conditions, and changes to the abundance of adult spawners which produce the juveniles captured and migrating past RSTs. Adult Chinook salmon are regularly outplanted above several dams in the WVS; varying numbers outplanted in each year will also influence observed juvenile passage metrics independently of dam operations. The extent to which RST data can inform whether changes to fish passage metrics have occurred as a result of injunction measures depends on the measure being assessed and the amount, quality, and representativeness of data available.

Low RST trap efficiency—typical at Willamette Valley System RST traps both before and after injunction measures (Monzyk et al. 2011; Romer et al. 2013, 2015; Cramer Fish Sciences 2023; EAS 2024a)—limits confidence that RST records are representative of the overall population of fish which pass the trap. Influenced by river morphology, flow, fish behaviour, trap location, and other attributes, trap efficiency is defined as the proportion of migrating fish caught in an RST.

RST records are available both before and after injunction measures at most projects, but at some WVS locations RSTs have only been operated during one of the before- or after-injunction periods (Table 2; see Figure 4 to Figure 7 for maps of RST locations in each of the four subbasins where WVS dams are located).

Table 2. Summary of RST locations and data availability as of August 2024. Specific trap locations may vary between years, but cases where traps were put in the same general area or just downstream of a given dam outlet, they are assumed to represent the same location. TR: tailrace; HOR: head of reservoir; RO: regulating outlet; PH: powerhouse/turbine outlet. Table continues on following page.

	Before injunction period		*After injunction period*	
RST location	**Year(s) operating**	**Trap type(s)**	**Year(s) operating**	**Trap type(s)**
RSTs in the North Santiam				
Big Cliff TR (-122.305, 44.756)	2014-2016	5ft	2021-2023	8ft
Breitenbush (-122.131, 44.751)	2010-2011, 2015-2016	5ft	2023	5ft
Detroit HOR (-122.050, 44.692)	2010-2016	5ft	2023	5ft
Detroit TR: BRZ bridge (-122.255, 44.725)	2011-2013	8ft, 5ft	-	-
Detroit TR: PH outlet (-122.252, 44.722)	2013-2014	8ft	-	-
RSTs in the South Santiam				
Foster HOR (-122.499, 44.391)	2010-2016	5ft	2022-2023	5ft
Foster TR (-122.671, 44.414)	2011-2016	8ft, 1x8ft, 1x5ft	-	-
Green Peter HOR (-122.373, 44.514)	-	-	2023	5ft
Green Peter TR (-122.55, 44.448)	-	-	2022-2023	8ft
RSTs in the South Fork McKenzie				
Cougar HOR (-122.217, 44.048)	2010-2016	5ft	2022-2023	5ft
Cougar TR: RO and PH (-122.243, 44.132)	2011-2016	2x8ft (PH), 2x5ft (RO), 1x5ft (RO)	2021-2023	2x8ft (PH), 1x5ft (RO)
RSTs in the Middle Fork Willamette				

	Before injunction period		*After injunction period*	
RST location	**Year(s) operating**	**Trap type(s)**	**Year(s) operating**	**Trap type(s)**
Fall Creek HOR (-122.666, 43.975)	2005-2008	8ft	2021-2023	8ft
Fall Creek TR (-122.760, 43.945)	2006-2020	8ft	2021-2023	8ft
Hills Creek HOR (-122.456, 43.603)	2013, 2015	5ft	2023	5ft
Hills Creek TR: PH outlet (-122.424, 43.711)	2003-2005, 2011-2017	8ft	2021-2023	8ft
Hills Creek TR: RO outlet (-122.423, 43.712)	2012-2013	5ft	2021-2023[1]	5ft
Lookout Point HOR (-122.531, 43.766)	2010-2014	8ft, 2x8ft, 5ft	2022-2023	5ft
Lookout Point TR: PH and spillway (-122.756, 43.914)	2007-2019	1x8ft, 2x8ft, 3x8ft	2021-2023	3x8ft
Dexter TR (-122.811, 43.925)	-	-	2022-2023	5ft
North Fork Middle Fork (-122.490, 43.767)	2007-2008, 2015-2016	8ft, 5ft	-	-

[1] Location was moved downstream of confluence with PH channel so captures both RO and PH passed fish.

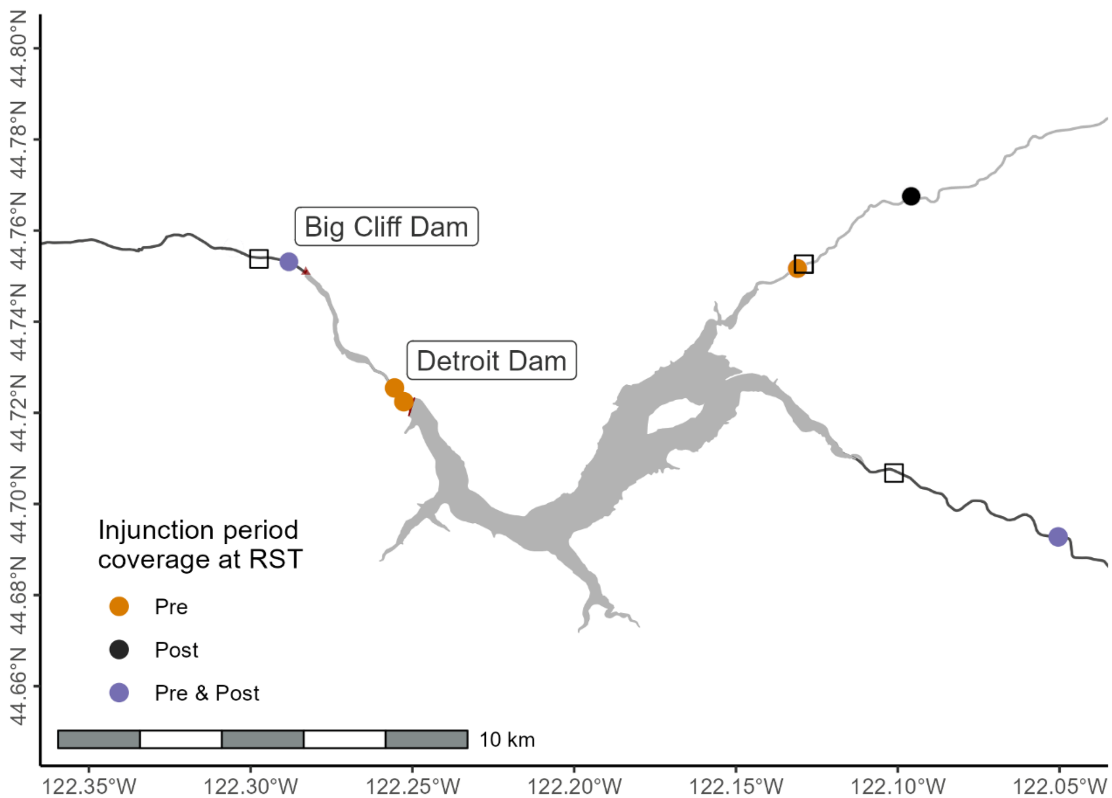

Figure 4. RST and USGS water gage station locations in the North Santiam subbasin used in this report. RST sites are coloured points, with the color representing data availability over time; squares show the location of USGS gages. Note that at Breitenbush, the RST was moved to be further upstream in the post-injunction period; we treat the two locations as though they are a single RST site in our analysis.

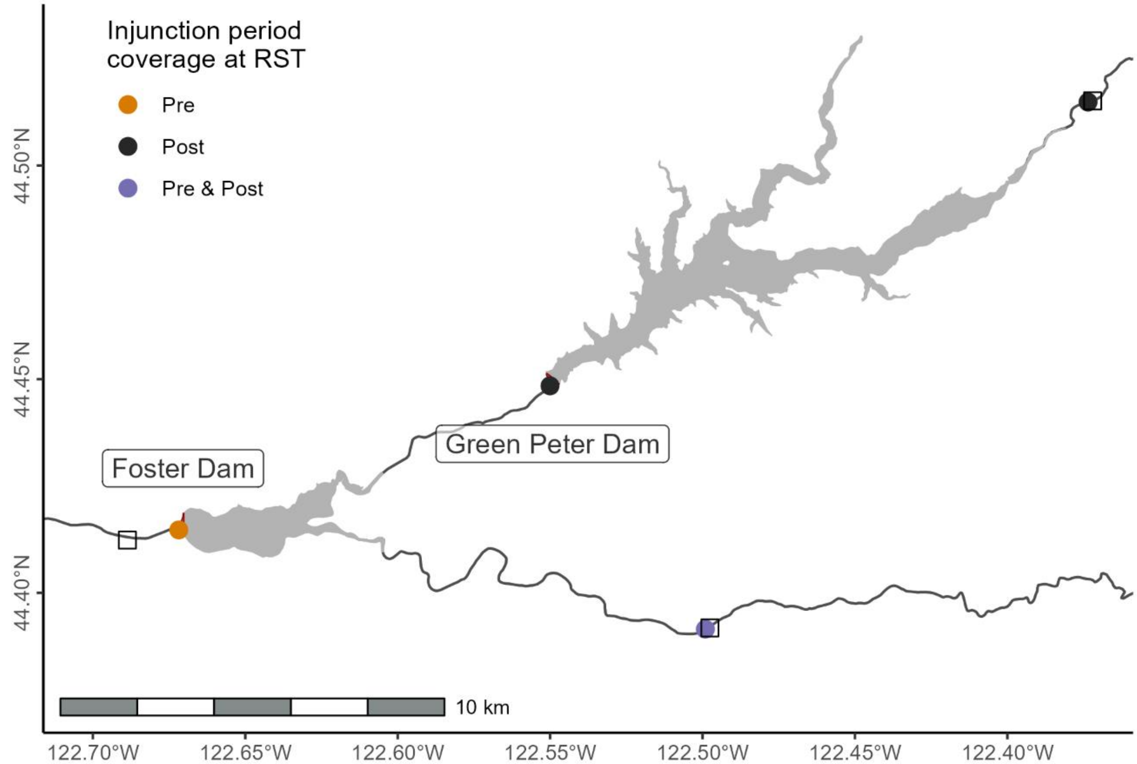

Figure 5. RST and USGS water gage station locations used in this report located within the South Santiam subbasin. RST locations are shown as colored points, where color represents data availability over time; squares show the location of USGS gages.

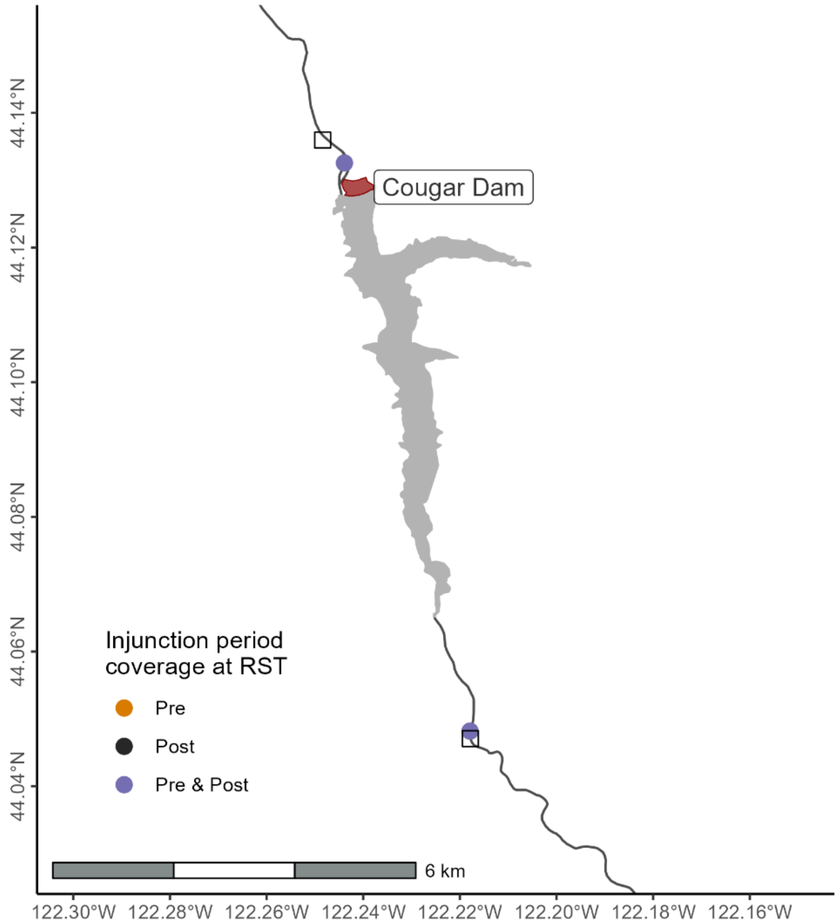

Figure 6. RST and USGS water gage station locations used in this report located within the South Fork McKenzie subbasin. RST locations are coloured points, with the color representing data availability over time; squares show the location of USGS gages.

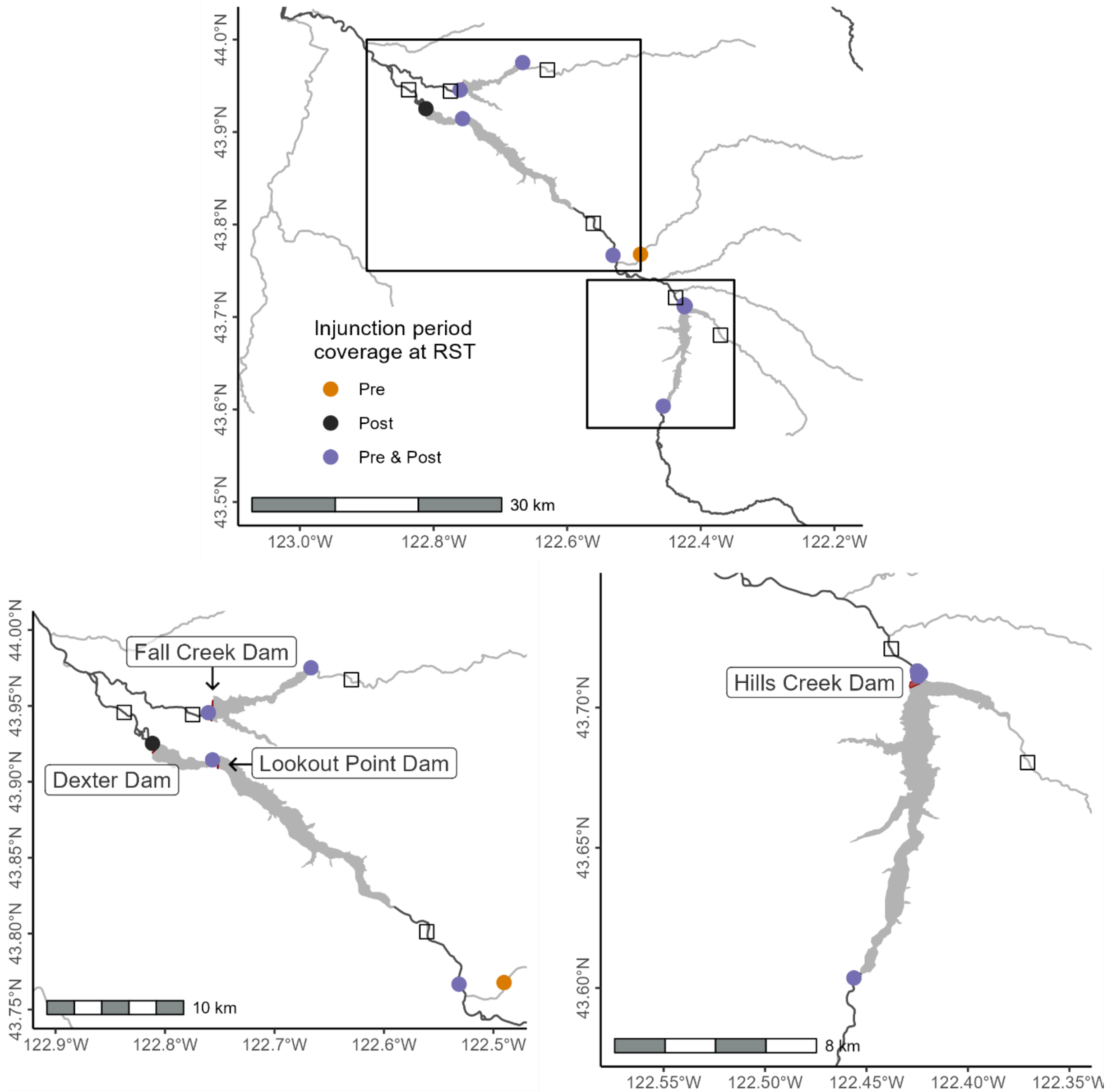

Figure 7. RST and USGS water gage station locations used in this report located within the Middle Fork Willamette subbasin. Inset maps zoom in to regions of interest; the overview map includes all projects in the subbasin. RST locations are coloured points, with the color representing data availability over time; squares show the location of USGS gages. At the tailrace of Hills Creek dam, there are three RST locations with positions that appear to overlap in the map overview.

RST data cleaning and preparation

The initial steps to conducting analyses of RST data were to compile and clean the data for Chinook salmon. This was challenging due to the varied operators and data recording quality during the two periods to be examined. During the pre-injunction period, Oregon Department of Fish and Wildlife (ODFW) operated RSTs between 2009 and 2016 above and below dams in the North Santiam, South Santiam and McKenzie, and above dams in the Middle Fork Willamette; while USACE operated RSTs between 2002 and 2019 above and below dams in the Middle Fork Willamette (Figure 1). During the post-injunction period, Cramer Fish Sciences (Cramer) operated RSTs during 2021 below Big Cliff, Cougar, Lookout Point dams and above Fall Creek reservoir, while USACE operated an RST below Fall Creek dam. In 2022, Environmental Assessment Services (EAS) took over operation of all these RSTs and operated additional RSTs to ensure there was trapping effort above and below dams in all subbasins, except for no operation of an RST below Foster or Detroit dams, or in Quartzville Creek above Green Peter dam.

Cramer and EAS each maintained a separate single database, while ODFW and USACE data files were typically stored on a site by year basis. These spreadsheet database files were sourced and compiled into a single spreadsheet database for each operator. While each operator recorded trap effort and individual fish data, the variables recorded and hence the data structures were different, and also evolved over time, e.g., ODFW and USACE data from later years were more detailed than in the earlier years. There appeared to be an element of learning which data to record during the pre-injunction period, which Cramer and EAS built upon in the post-injunction period. We took many steps to clean each database, these are summarized below for each operator. We also expanded the metadata provided by some operators to better explain the meaning of variables. The ultimate aim of this effort is to create a consolidated database for all traps and years; this step is still to be completed.

ODFW data

There were files for each RST and year containing two spreadsheets: 1) trapping effort data including trap check dates and times, trap operational status, trap revolutions per minute (RPM), river temperature, personnel, and general comments relating to each trap check event; and 2) individual fish data including trap check date, species, origin (hatchery or wild), fork length, whether it was live or dead, whether it was a recapture, whether it was marked or tagged, where it was released, and injury codes including whether copepods were present on gills and/or fins. In both sheets, trap names between years were consolidated so that there was only one name for each RST operated. The filter tool in Excel was used to search for multiple versions of the same name. For some traps, e.g., below Foster dam, the trap name (5ft or 8ft) was determined from entries in comments. In most years the traps were in the same location, where ODFW reports (Romer et al. 2012, 2013, 2014, 2015, 2016, 2017) indicated a trap was moved this was noted. The check dates and times were converted to a consistent YYYY-MM-DD HH:MM format.

The trapping effort sheet contained a summary of the numbers of fish of different species captured, their live/dead status, whether they were released downstream or upstream of the trap for trap efficiency (TE) trials, and whether they were a recapture of fish released for TE trials or were marked/tagged fish released further upstream, i.e., above a dam, for other experiments. There were typically large disparities in the total numbers of fish detailed in this sheet with the individual fish data sheet, with the greater numbers in the trapping effort sheet. It was assumed based upon comments in the trap effort sheet that the individual fish data represented only a sample of the total catch per check event, as these comments referred to fish not being measured for length. There were missing check time, temperature, and RPM data. Trap status (continued operation, interrupted operation, trap start, and trap stop events) was inferred for some events where it was missing where capture data indicated it was operational or had been started prior to an event.

In the individual fish sheet, data on length, mortality status, and recapture status were typically available for all sites and years, but data on fish origin and whether the fish was marked or had injuries were often missing, particularly in some earlier years where these variables were not recorded. In several instances tagging data were stored in mark columns, these were cleaned to allow PIT codes to be cross referenced with PTAGIS.

Comment cells were mined for data on all variables where data were missing, e.g., on recapture or mortality status, injury condition, and whether fish were marked with different fin clips. This led to recategorization of some dead fish to a 'Dead-Sampling' category where indication was that fish were killed during the handling process. Recapture data were considered carefully as the inclusion of fish released for TE could bias several of our analyses, e.g., run timing, as those fish would inflate numbers of migrating fish captured. TE recaptures were typically coded separately from other recapture types, but comment cells were used to confirm the recapture type of fish entered as recaptures. Where there was no data to the contrary, e.g., that fish were part of paired release experiments, reservoir snorkel seine studies, or active tag studies, fish recorded as recaptures were determined to be TE trial recaptures. To support this assumption, the TE recapture numbers were cross-referenced with the trapping effort summary tables where the total capture numbers by date were comparable. Fish were assumed to not be recaptures where data on recapture status was missing. This enabled us to remove recaptures related to TE trials from further analyses.

Injury condition codes were recorded as a text string in a single cell. To make these data more useable a column was created for each code and the text string used to determine presence or absence of a given condition. Data in these columns were augmented with information in comment cells where provided, this led to creation of a fish hooking injury column. If there were no injuries listed the fish was assumed to be in good condition.

USACE data

Most files were grouped across years by RST, with files containing a spreadsheet for each year. Each spreadsheet contained individual fish data that included repeated data on trapping effort variables by date within each row. The individual fish data recorded were similar to those recorded by ODFW. After combining all data into one spreadsheet, the next task was to create a separate trapping effort data sheet as recorded by ODFW, but the main problem was that in absence of information on trap start/stop dates and trap events with no captures, the trapping effort data available reflected only the dates on which fish captures were made. This problem was worse in years prior to 2015, after which recording of trap operational status, trap check times, and trap events where there were no captures was more consistent. The Middle Fork Willamette RST data prior to 2010 were used by Keefer et al. (2013), who included a figure showing the distribution of days that the RSTs were operated in each year. These trap start/stop dates were obtained (pers. comm., Matt Keefer) and incorporated into the trapping effort sheet under the assumption that all operational dates indicated continuous operation unless comments indicated operation was interrupted, e.g., by debris stopping the trap spinning. Additional trap start/stop dates were obtained for the Hills Creek RST (pers. comm., Todd Pierce) and similarly incorporated. However, we note that during these periods there likely remain unknown interruptions to trap operations that we cannot account for.

The individual fish sheets were quite sparse prior to 2015. Length data were frequently missing but where length was approximate, e.g., ~35mm, the length was assumed to be that value, and where length data were ranges, the length was assumed to be the centre of the range. Fish with missing mortality status were assumed to be live as many of these were referred to in injury codes or comments as being in good shape. In some years there were only one row of fish data per trap check date with a value in a 'count' column, commonly used for TE recaptures or for non-salmonid species. It was confirmed that these represented a sum of the number of fish by date with those capture data (pers. comm., Todd Pierce), so the data were expanded to provide one row per individual fish. Length data were always missing for these individuals. Injuries were referenced only in a comment cell and data recording was not consistent. Additionally, in some cases a code was used but in others a description was used. We made efforts to extract injury information into presence/absence of each injury type but note it is likely that injury data from these traps are underrepresented. Additional injury code classification and analysis was performed to assess injunction effects on reported injury rates; see section "Fish injury analysis: data used" for full details.

Cramer data

There was one data file containing spreadsheets for each of the RSTs which had been subject to a quality assurance and quality control (QAQC) check. Similar to the USACE data, each spreadsheet contained individual fish data that included repeated data on trapping effort variables by date within each row. Additional variables were recorded, including data on what type of visit to the trap site it was, i.e., installation or check, whether any fish were processed on a check date, debris loads in the trap, weather conditions, fish weight, and whether genetic samples were taken from fish. Instead of trap RPM, the number of seconds taken for three revolutions was recorded, as well as a count of the number of rotations since the last check from a rotation counter though these were frequently missing. The data also included dates of data entry and quality assurance (QA) checks and the Cramer personnel responsible. After combining all data into one spreadsheet, the next task was to create a separate trapping effort data sheet. As there were data for trap checks without any fish captures this was relatively simple, once the fish processed values entered as 1 were fixed to 0 when the fish count on a date was zero, i.e., no captures. Fish recorded as recaptures were the result of TE trials as the numbers matched data in the separate spreadsheet detailing TE recaptures. Overall, the QA process functioned to ensure that no further data cleaning steps were required.

EAS data

There was one annual data file containing spreadsheets for trapping effort and for individual fish data which had been subject to a quality assurance and quality control (QAQC) check. The data recorded were the same as for Cramer, with the addition of data on whether scales were removed for analysis. There were a few inconsistencies to remove for entered variables between years, e.g. Y was used to indicate presence in some years and TRUE for others. Several of the injury code columns contained only ' or . instead of Y/N or TRUE/FALSE, these were assumed to be data entry errors not caught during the QA process and were replaced with N/FALSE.

The recapture status of individual fish was often missing, and for some fish that were recorded as recaptures the type of recapture was ambiguous and could include those from TE trials at that trap, from TE trials at traps further upstream, or from bulk marking of fish released upstream. PIT tag codes and data from the mark type were used to determine what type of recapture each was, and also whether fish without recapture values were a type of recapture or not. For PIT tags, all individual fish PIT tag codes were queried in PTAGIS (http://www.ptagis.org/) to determine the PTAGIS mark data project and release site to screen for errors and determine the origin of any recaptures, e.g., whether they were related to bulk marking releases. Additional EAS files were made available to us that contained data on fish released for TE trials that enabled cross-referencing with recaptures to determine if they related to TE trials or not. Mark type data were then used to clarify any remaining recaptures, if fish were marked with Bismarck Brown dye they were assumed to be TE recaptures as this temporary mark was used for some trials, and clip locations of fish released in recent trials were also used to determine the type of recapture. Hatchery-origin Chinook salmon recaptures with only adipose fin clips were assumed to be TE recaptures at sites where no hatchery-produced fish could otherwise be caught. The comments were also searched for any information on the type of recapture. Wild Chinook salmon with missing recapture data were determined to not be recaptures if there were no marks recorded and if there were no run-of-river TE releases during the previous week. Hatchery-origin Chinook salmon with missing recapture data were determined not to be recaptures if the only mark present was an adipose fin clip.

Trap efficiency trial data

Trapping efficiency (TE), is defined as the proportion of fish of a given species passing by a RST that are captured in the trap. TE trials involved releases of marked fish of two types: 1) single releases of hatchery-origin fish above an RST, and 2) run-of-river (RoR) releases of mostly wild fish captured in the RST that are released back above the RST. We considered data for those experiments in which live fish were marked and released usually within 100-150m above each RST. Where RSTs were below the tailrace of a dam or in an outlet channel, fish were released below the dam but upstream of the RST. Marks are made using PIT tags, caudal or ventral fin clips, VIE marks, or Bismarck Brown dye. The number of recaptures of marked fish is recorded over the following week, though typically most recaptures are on the first day following release. The sum of recaptures divided by the number of releases is used as the proportional TE estimate for the trial. In the pre-injunction period, USACE conducted a relatively small number of single-release trials, while ODFW ran a larger number of RoR trials (Romer et al. 2012, 2013, 2014, 2015, 2016, 2017). In the post-injunction period, Cramer ran a number of single-release trials (Flaherty et al. 2023), while EAS ran and continue to run a larger number of single-release trials at all RST sites, as well as a smaller number of RoR trials where capture numbers allow (EAS 2024b). At 10 of the 20 RSTs with TE experiments, trials were performed both before and after implementation of injunction measures; one site only had pre-injunction trials, nine sites had only post-injunction trials (Table 3). Run-of-river TE trials were attempted at Breitenbush, Detroit HOR, Cougar HOR, Cougar PH, Cougar RO, Foster HOR, Fall Creek HOR, and Hills Creek PH using wild-caught juvenile Chinook salmon; all other TE trials were the results of single releases of hatchery-origin juvenile Chinook salmon. The number of experiments varied markedly by RST site, e.g., between 2 and 125 experimental trials for a single trap (Table 3).

In contrast to single-release TE estimates, RoR TE estimates result from release and recapture data pooled across a week. Given daily trap checks, this means the number of marked fish released on days 1-7 is compared to the number of recaptures on days 2-8. Following Romer et al. (2017), RoR trials were only used if ≥5 recaptures resulted from releases during a given week. We calculated TE estimates in this way for all sites where fish were released for RoR trials. For the ODFW data, we compared our TE estimates to those reported by Romer et al. (2012, 2013, 2014, 2015, 2016, 2017) and found that the TE ranges presented in those annual reports were within 1-2% of our calculated estimates. The differences could result from our additional data cleaning, but also Romer et al. produced some TE estimates by aggregating across larger time periods if captures at an RST site were too sparse during weeks within the main juvenile Chinook salmon migration period.

A total of 538 separate TE trials were available for analysis (Table 3). Of these trials, only 50 trials were from releases of dead fish, for which 36 (72%) trials resulted in no recaptures. Given the main interest was in the trap efficiency of migrating juvenile fish, and the poor success of dead fish TE trials, we therefore used only the TE estimates from the 488 releases of live fish in TE adjustment modelling. Trials resulted in TE estimates at these sites: Big Cliff (BCL), Breitenbush (BRE), Detroit HOR (DET HOR), Green Peter (GPR), Green Peter Head of Reservoir (GPR HOR), Foster HOR (FOS HOR), Cougar Powerhouse (CGR PH), Cougar Regulating Outlet (CGR RO), Dexter (DEX), Lookout Point Powerhouse 1 (LOP PH1), Lookout Point Powerhouse 2 (LOP PH2), Lookout Point Spill (LOP SP), Hills Creek Powerhouse (HCR PH), Hills Creek Regulating Outlet (HCR RO), Fall Creek (FCR), Lookout Point Head of Reservoir (LOP HOR), North Fork Middle Fork (NFMF), Hills Creek Head of Reservoir (HCR HOR), Fall Creek Head of Reservoir (FCR HOR). No TE estimates were available from RST located below Detroit Dam (DET) and Foster Dam (FOS). The TE estimates cover periods of several years at each site, highlighting that there have not been enough trials to apply individual TE estimates to each individual trap check event. Most TE estimates were <10% (Figure 8).

Because TE is expected to vary between RST sites and with changes in hydrological and other conditions at a given RST site, we conducted an analysis to determine how TE adjustments should be computed for each RST site. Raw RST records of, for example, catch rates of a given fish species of a given life history stage at a given site could then be standardized and made comparable within and between RSTs on a given body of water by dividing by the TE determined for a given trapping event for a given RST site. For TE adjustment modelling, mean discharge at each RST site during the week following a TE trial release was calculated for use as a covariate. The discharge data below dams were either the total outflow or the outflow specific to the route the trap was located in, e.g., Cougar RO used the spill outflow, Cougar PH used the generating outflow. Above dams, the data came from USGS gages located nearest to the RST. Discharge data were summarized hourly (see section, "Data sources: Hydrological variables and other covariates"). Data on mean trap revolutions per minute (RPM) during the week following release was also compiled. For Cramer and EAS trap effort data this required a conversion from the time taken for three revolutions, only RPM was available for ODFW and USACE operated traps. Not all TE estimates had corresponding covariate information on discharge and RPM. Particularly for USACE-operated traps in the Middle Fork, trap RPM data was not available for trials conducted in the pre-injunction period (as was the case for 12 of 20 RSTs with TE trials). In the post-injunction period, traps operated below Lookout Point and Fall Creek dams were often in low flow conditions and the traps were frequently not spinning, so trials conducted during these periods had few recaptures. Revolution counts can provide more information than RPM as they account for spin speed during the entire trapping event rather than just at the time of trap checking, e.g., could account for situations when flows are only going through an outlet at night. However, the counters have questionable reliability as the RST data indicated there were a lot of counter failures and hence missing data.

Table 3. Numbers of trap efficiency (TE) trials conducted at RST sites pre- and post-injunction. Trials are separated by mortality status of the released juvenile Chinook salmon. Mean TE estimates across the numbers of live release trials are shown for each period and pooled across both. 'nt' indicates sites where traps were not operated in a given period. Shaded cells indicate sites where there were no TE trials conducted despite traps operating.

RST site	N trials pre		N trials post		Live TE % Mean (±SE)		
	Live	Dead	Live	Dead	All	Pre	Post
North Santiam							
BCL	0	0	35	6	6.43 (±0.82)	-	6.43 (±0.82)
BRE	10	0	9	0	6.44 (±1.14)	6.03 (±1.12)	6.89 (±2.13)
DET	0	0	nt	nt	-	-	-
DET HOR	5	0	9	0	5.04 (±0.93)	3.12 (±0.72)	6.11 (±1.28)
South Santiam							
GPR	nt	nt	14	3	1.32 (±0.23)	-	1.32 (±0.23)
GPR HOR	nt	nt	6	2	0.04 (±0.03)	-	0.04 (±0.03)
FOS	0	0	nt	nt	-	-	-
FOS HOR	0	0	18	0	5.93 (±1.69)	-	5.93 (±1.69)
McKenzie							
CGR PH	22	1	15	1	11.59 (±1.29)	10.04 (±1.33)	13.87 (±2.47)
CGR RO	6	4	33	5	5.53 (±0.56)	6.74 (±2.06)	5.31 (±0.56)
CGR HOR	107	0	18	0	6.24 (±0.39)	6.47 (±0.44)	4.90 (±0.60)
Middle Fork							
DEX	nt	nt	30	0	0.66 (±0.25)	-	0.66 (±0.25)
LOP PH1	8	12	15	0	0.29 (±0.10)	0.75 (±0.22)	0.05 (±0.03)
LOP PH2	7	7	15	0	0.12 (±0.04)	0.24 (±0.07)	0.07 (±0.03)
LOP SP	0	0	14	0	0.16 (±0.13)	-	0.16 (±0.13)
HCR PH	1	0	13	0	5.15 (±0.97)	5.94	5.09 (±1.05)
HCR RO	0	0	22	0	0.71 (±0.19)	-	0.71 (±0.19)
FCR	17	8	8	0	2.99 (±0.73)	4.19 (±0.94)	0.44 (±0.30)
LOP HOR	0	0	19	0	1.61 (±0.67)	-	1.61 (±0.67)
NFMF	2	0	nt	nt	0.72 (±0.03)	0.72 (±0.03)	-
HCR HOR	5	0	1	1	7.69 (±2.33)	9.07 (±2.30)	0.79
FCR HOR	0	0	4	0	1.74 (±0.53)	-	1.74 (±0.54)

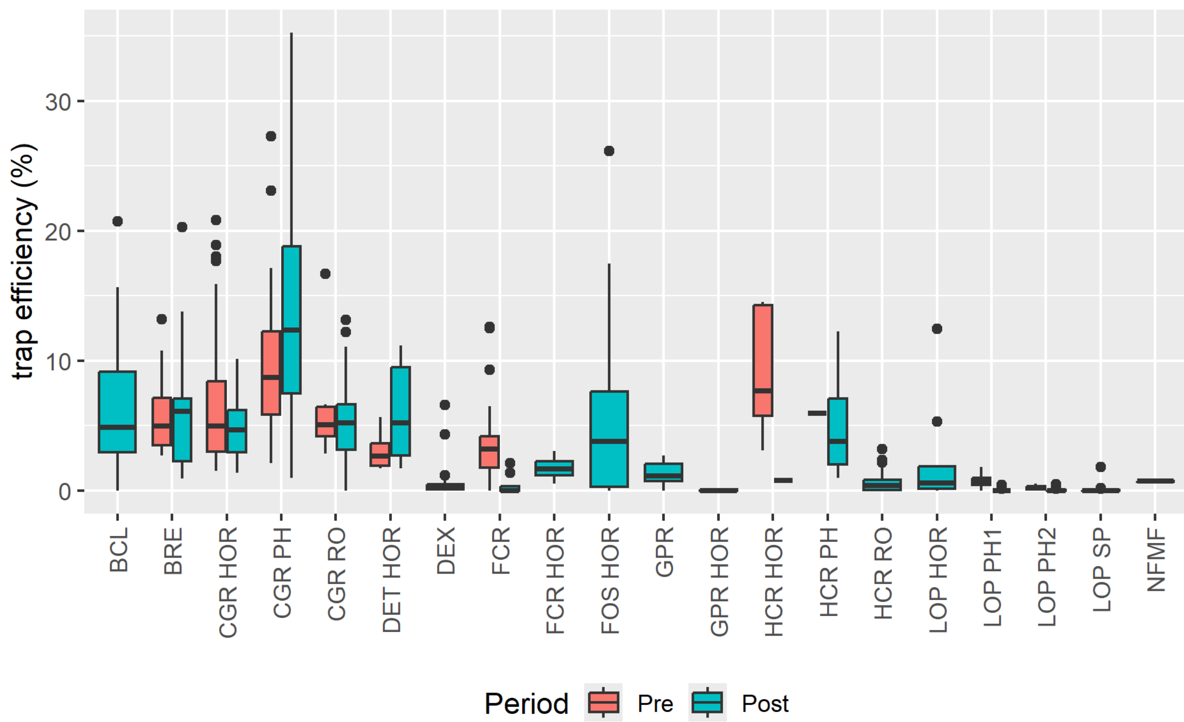

Figure 8. Boxplots of live fish trap efficiency estimates at all RST sites in the pre- and post-injunction periods. See Table 3 for estimates of the means and confidence intervals shown in the plot.

Trap efficiency: statistical approach

Water flow has been found to be a prevalent factor affecting TE in studies of juvenile salmonids (Dambacher 1991; Cheng and Gallinat 2004; Rayton and Wagner 2006; Volkhardt et al. 2007; Voss and Poytress 2020). EAS (2024b) recently explored the effects on TE of both flow and trap revolutions using TE trial data from 14 of their WVS RST operations from 2021-2024. Their findings favoured either use of mean TE data (6 sites) from a given RST site or models that predicted TE based on mean flow or mean trap revolutions per hour (MTR) (5 sites) or both mean flow and MTR (3 sites) from a given RST site. We have instead focussed our analysis of trap efficiency on TE trial data at 20 WVS project RST sites available from 2005-2024 from all five RST operators (i.e., Cramer, EAS, MHE, USACE and ODFW). Due to the far greater amount of TE trial data available with which to assess the potential relationship between TE and mean flow, we have focused this initial assessment of TE on assessing potential relationship between TE and mean flow during the week following release of fish in a TE trial, rather than TE and mean RPM during this week.

To develop understanding of the potential relationship between TE and mean flow, we first studied plots of estimated TE and the mean flow at the RST sites that had the most informative records, e.g., the Cougar Head of Reservoir and Big Cliff RST sites. The Cougar Head of Reservoir RST site, for example, had altogether 125 separate trials in which TE was assessed. For these RST sites, the range of mean flows in which trials took place was quite considerable. TE estimates were highest at lowest recorded mean flow, decayed swiftly and then appeared to remain on average constant over a large range of mean flows, e.g., for the Cougar Head of Reservoir RST site, from about 400 to 2000 cfs (Figure 9). But for the majority of RST sites which had records of mean flow, there appeared to be no consistent relationship between TE and mean flow and the range of mean flows under which TE was assessed was quite limited.

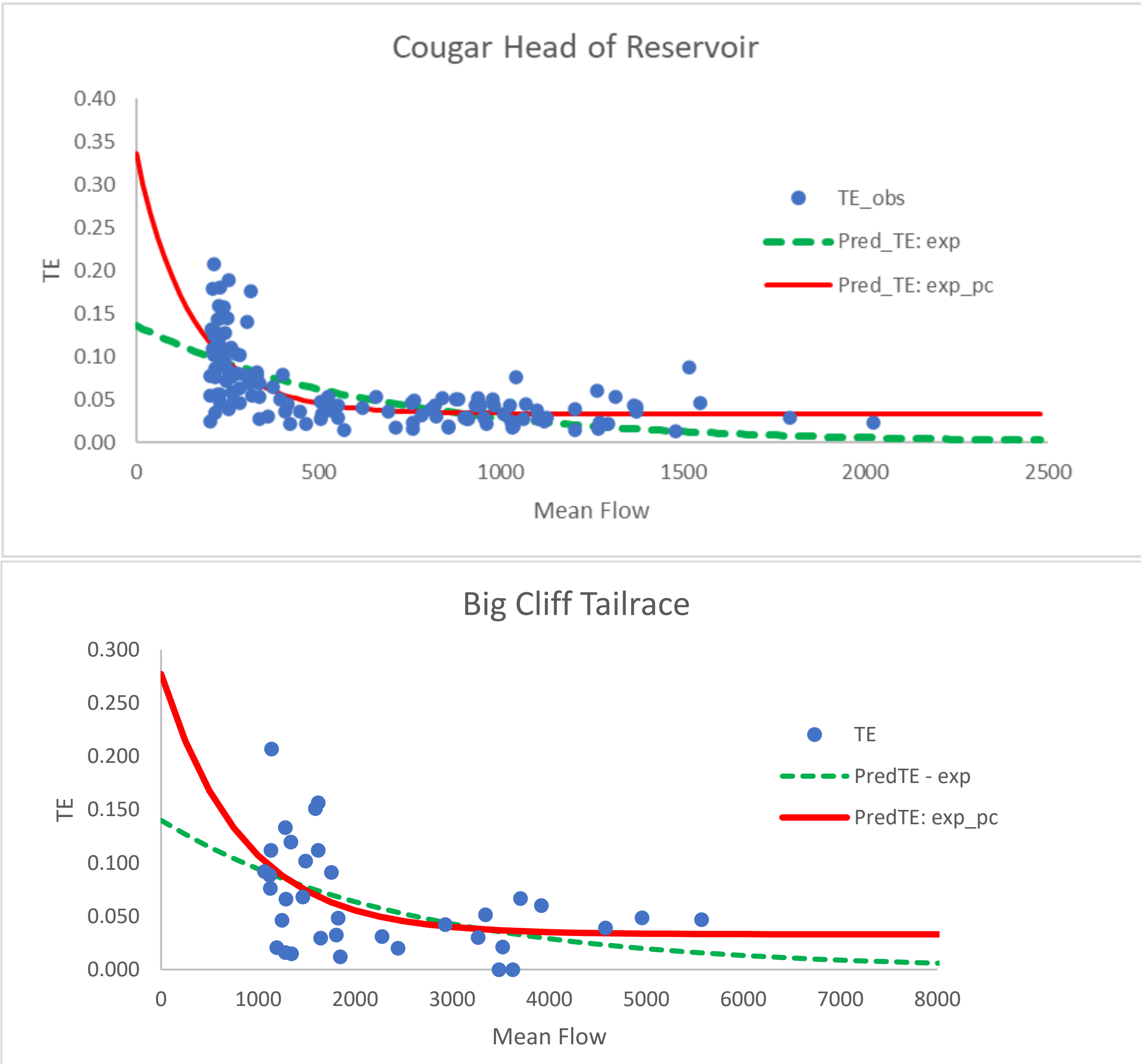

Figure 9. Plot of estimates of trapping efficiency (TE) versus mean flow over each trapping event for the Cougar Head of Reservoir RST site. Mean flow is in cubic feet per second (cfs). The fitted models shown are 1) exponential decay ("exp") and 2) exponential decay with an added constant ("exp_pc"). First Panel: Cougar Head of Reservoir. Second Panel: Big Cliff.

Two- and three-parameter exponential models that were fitted to these TE data included the following:

$$T_p = T_0 * \exp(Z * f/1000)$$

$$T_p = m + T_0 * \exp(Z * f/1000)$$

where T_p is the predicted trap efficiency, *m* is the TE floor, T_0 is an intercept term, and *Z* is the instantaneous rate of change in *TE* with mean flow, *f*. The parameters T_0 and *m* were constrained to be positive and both less than 1. The parameter *Z* was constrained to be not greater than zero. Parameter estimation for these models was conducted using maximum likelihood estimation (MLE)and assuming that deviations between observed and predicted TE were normally distributed:

$$T_o \sim Normal\left(T_p, \sigma^2\right)$$

We computed a coefficient of determination, i.e., an R-squared value, for each model fit using the following equation:

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}}$$

where

$$SS_{res} = \sum_i (y_i - f_i)^2 = \sum_i e_i^2$$

and

$$SS_{tot} = \sum_i (y_i - \bar{y})^2$$

$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i y_i$ is an individual estimate of TE from a TE experiment, n is the number of TE experiments for a given RST site, and f_i is the model-predicted value for the TE observation.

We also computed the Akaike information criterion (AIC) adjusted for potentially low sample size, AICc, for each model fit

$$AIC_c = AIC + \frac{2k^2 + 2k}{n - k - 1}$$

where

$$AIC = 2k - 2\ln(\hat{L})$$

k is the number of estimated parameters in the model and $\hat{L}$ is the maximum likelihood at the best fitting parameter values for the model (Akaike 1998).

Following the approach used by EAS (2024b), a two-parameter beta regression model was also fitted to the data for each RST using the betareg package (Cribari-Neto and Zeileis 2010) in R (R Core Team 2023). Similar to exponential models, the beta model also allows a curvilinear fit to the TE data. Unlike the exponential model, predicted values from a beta model adhere mathematically to the restricted range for TE (between 0 and 1). This beta model version however included no constraints on the value of the slope or intercept value fitted and thus allowed for predicted TE to increase monotonically with mean flow. Because constraints were placed on parameter values in the exponential (Exp) and exponential plus constant, (Exp_PC) models, calculated AICs for the beta model were in a few instances artificially lower than for the AICs for the Exp and Exp_PC models. Attempts to fit models to the TE data were made only when the number of TE trials exceeded 10. Models were thus not fitted to the data for RSTs located at Fall Creek, Green Peter HOR, Hills Creek HOR, and North Fork Middle Fork which had 4, 6, 6 and 2 TE experiments respectively.

Two alternative null models were also fitted to TE data for each of the 20 RSTs with TE experiments. These included a global mean model which estimated a single mean for of the TE estimates for a given RST site from all available TE records for the RST site (i.e., for all cases, whether TE trials were only available from before or after injunction measures implementation, or from both before and after injunction measures implementation). A second null model estimated a mean TE for pre-injunction years and a second mean TE for all years in which injunction measures had been implemented. 90% confidence intervals were computed for each of the sample means for TE. A more commonly used 95% confidence level was not considered because of the low number of experimental trials for many of the RST sites, the high variability in the data and the relatively low associated statistical power in testing whether the pre- and post injunction means differed. For RST sites where TE experiments were conducted both prior to and after implementation of injunction measures, the null hypothesis that the sample means were not different was tested based on whether there was overlap between the 90% confidence intervals for the sample means pre- and post-injunction. If there was no overlap, the null hypothesis was rejected and it was assumed that the sample means were different between pre- and post-injunction periods at the RST site; for all pre-injunction records for a given RST site, the pre-injunction sample mean was taken to be applied to all pre-injunction RST records and post-injunction sample mean taken for post-injunction records for the RST site. When the null hypothesis was not rejected at a given RST site, the mean taken from all available TE experiments pre-and post-injunction at that RST site (i.e., the global sample mean for that RST site) was taken to be applied to all fish capture records from that RST site. If AIC results did not favor one of the fitted models, then the sample mean from the available experiments for each RST site was taken to be applied to the RST records for these RST sites.

MLE estimates, sample means, confidence intervals and AIC values were all calculated using Excel 2019 software (Microsoft Corporation 2018).

Juvenile stage categorization

The juvenile stage of migrating Chinook salmon was determined based upon general size and timing rules (Table 4). We used a reservoir growth model that included each of the juvenile migrant types (Figure 3). The model used the mean observed length of fry and subyearlings captured in above reservoir RSTs to determine length at reservoir entry in each month of the year and, while accounting for lower growth rates during colder months, used estimated reservoir growth rates to predict the length at passage by month of each migrant type that would result in the observed distribution of lengths observed in below dam RSTs. The growth model remains under development but provided the below general rules for categorization of captured fish into fry, subyearling, yearling, and 2+ age Chinook salmon. Subbasin- and year-specific variation in these rules were not considered in Phase 1 analyses.

Table 4. Table of juvenile stage categorization based upon month and length of capture in an RST.

	Length (mm)				
Month	**<60**	**60-120**	**120-200**	**200-300**	**>300**
Jan	Fry	Yearling	Yearling	Yearling	2+
Feb	Fry	Yearling	Yearling	Yearling	2+
Mar	Fry	Yearling	Yearling	Yearling	2+
Apr	Fry	Yearling	Yearling	Yearling	2+
May	Fry	Subyearling	Yearling	Yearling	2+
Jun	Fry	Subyearling	Yearling	Yearling	2+
Jul	Subyearling	Subyearling	Subyearling	Yearling	2+
Aug	Subyearling	Subyearling	Subyearling	Yearling	2+
Sep	Subyearling	Subyearling	Subyearling	Yearling	2+
Oct	Subyearling	Subyearling	Subyearling	Yearling	2+
Nov	Fry	Subyearling	Subyearling	Yearling	2+
Dec	Fry	Subyearling	Subyearling	Yearling	2+

Recent work by EAS using scale analysis aimed to determine brood year of captured fish and indicated it may not be simple to categorize captures into different groups based only upon length, e.g., in the fall there may be migrants of similar size that can either be large subyearlings that most likely reared in the reservoir, or small yearlings that most likely reared in streams above the reservoirs and did not migrate in the spring (EAS 2024b). We examined the EAS scale data from 2022-2023 to determine how many captures we may have miscategorized.

EAS (2024b) stated they aimed for each sample to be read independently by two individuals, and for samples with conflicting age classifications based upon independent scale reads, a third read was performed by another reader. The scale age data made available to us indicate that out of 2,813 fish, 560 had an age determined by a single read, and where there were two reads, 250 of these had an age mismatch. Only a handful of third reads were recorded, but about 10% of the mismatches had a brood year assigned in a comment column. We filtered the scale data for those fish that had both a length and scale age based upon two or more reads. This resulted in a sample of 2,145 fish, of which the above rules assigned 1,813 as subyearlings and 332 as yearlings.

Out of those we categorized as subyearlings, 11.1% had mismatching scale readings, leaving 1,610 fish for comparison. 1,127 (70%) of these were subyearling-subyearling matches. Of the mismatches (Figure 10), 475 were scale aged as yearlings (29.5%) and eight were aged as 2+ (<1%). 96% of these mismatches were captured in below dam RSTs. The range in length of mismatches becomes greater in later months. However, 50% of mismatches in the fall were fish <150mm. Given nearly all these captures were in below dam RSTs, and because of higher reservoir growth rates compared to the streams above them, unless these fish were all stream-rearing subyearlings that moved to the reservoir late and passed immediately, it appears unlikely a Chinook captured in the fall is that small given it may have spent at least one summer in the reservoir. A further consideration that could lead to mismatches in November and December is that due to their aim of determining brood year, EAS assigned fish that are caught in November and December as yearlings, while our categorization would call them subyearlings. This could be further explored given data on emergence dates within each subbasin.

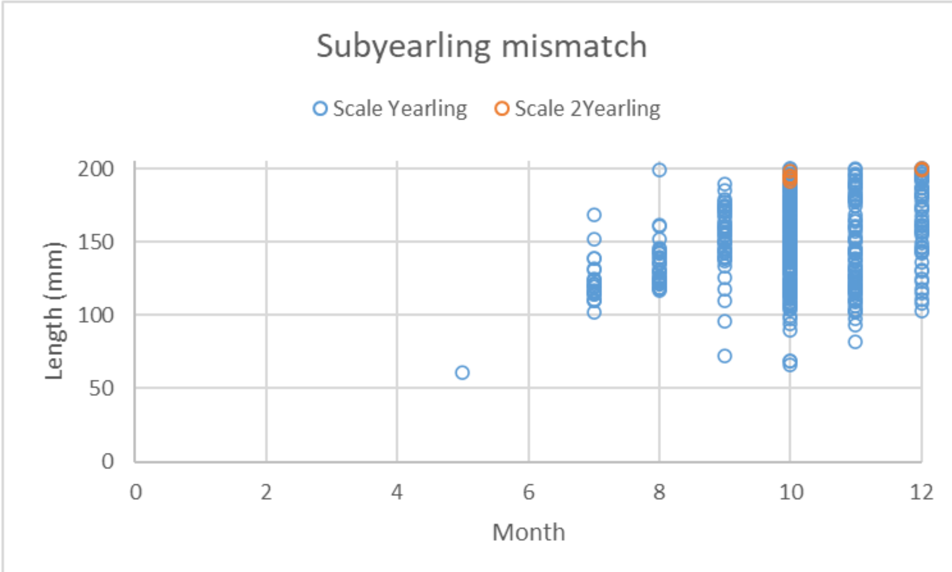

Figure 10. Length and month of capture of juvenile Chinook salmon categorized as subyearlings based upon size and timing but determined by scale age analysis to be yearlings or 2+ age fish.

Out of those we categorized as yearlings, 12.0% had mismatching scale readings, leaving 292 fish for comparison. 177 (61%) of these were yearling-yearling matches. Of the mismatches we categorized as yearlings (Figure 11), 114 were scale aged as subyearlings (39%) and one was aged as 2+ (<1%). 47% of these mismatches were captured in below dam RSTs. Given fry emerge around 30mm, it does not seem reasonable that there are subyearlings with lengths >100m before April. Even if the fry emerged in November and moved to the reservoir immediately, given lower temperatures over winter this amount of growth during this period is unlikely.

Overall, our size and timing categorization may be classifying some smaller yearlings as subyearlings in the fall, and some larger subyearlings as yearlings in the spring. However, it correctly assigns about two-thirds according to the scales. Given the mismatch rates and potential scale reading inaccuracy, combined with EAS potentially having different definitions of life stage in relation to brood year, it appears our general categorization is reasonable.

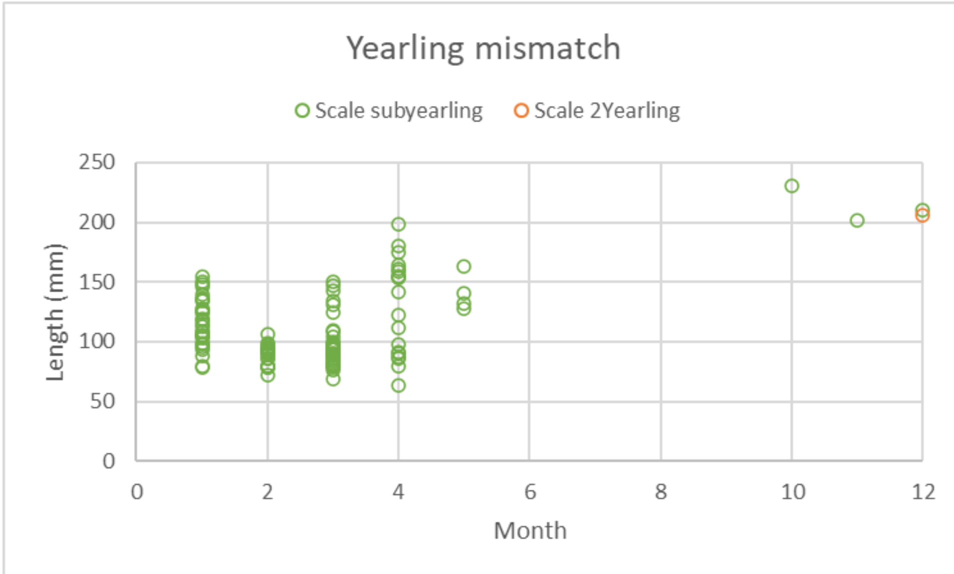

Figure 11. Length and month of capture of juvenile Chinook salmon categorized as yearlings based upon size and timing but determined by scale age analysis to be subyearlings or 2+ age fish.

RST data compilation: weekly records and zero-catch trap events

For analyses where it was necessary to identify zero-capture trapping events (including migration timing and PPE analysis), we combined trap log records (where available) with fish capture records to identify unique trapping events. The purpose of identifying trapping events was to both clean the data and to identify valid trap check events in which zero fish were recorded, as only trap checks with non-zero captures were included in fish logs.

First, we identified which trapping events were 1) not duplicated (indicated by matching combinations of unique site, trap, and date-time of the trap check) and 2) when the RST was operating in the period preceding the trap check (for example, if a given trap check event is a “trap start” event, there is no preceding time where there was active trapping and only subsequent trap checks are valid fish-check events). Any trap checks where the trap appeared operational but there was no record of a fish being captured in the fish capture logs was assumed to be a zero-catch trap event. Weeks where the trap was not operating were excluded from analysis. We assumed that any entries in the trap check log without an associated fish length entry had zero captures of target fish. We also included any dates where any fish from a non-target species was captured, processed, and entered in the fish log. On these dates, we also assumed that the capture of target species (e.g., spring Chinook) was zero. For each trap event, we also calculated the number of operational trapping hours since the last trap check.

We then aggregated RST records by trap event and by trapping week. First, we summed the number of juvenile Chinook of each migrant type captured in each RST in each trapping event by summing the number of corresponding entries in the fish log; the number of entries in the fish log associated with the date, RST trap, fish origin, and migrant type was summed to provide the catch per trap event. If there were no entries in the fish log, the catch per trap event was zero (as described above). On days with high number of captures, this approach may under-estimate the true number of fish that were captured if trap operators could not process all fish captured in the RST. For example, this issue was observed for some ODFW records where the trap log contained summarised total captures per event that did not match the total from the fish log; this may or may not reflect data entry errors. Apart from EAS, who did not sub-sample Chinook salmon, UBC has not received any specific information from operators regarding the number of fish captured but not processed during RST trapping. We then adjusted each trap event's number of captures by the appropriate trap efficiency calculation (including, where appropriate, flow, injunction period, etc.; see report section on "Trap efficiency" for full details). Finally, we aggregated the RST records into weekly timesteps.

Data sources: Hydrological variables and other covariates

To inform our statistical analysis of trap efficiency, PPE, and TDG, we compiled hydrological data covering the period during which the RSTs were operational. The covariates of interest included dam outflows (both in total and by dam outlet), biologically relevant water year types, and pool elevation.

Dam outflows were collected for each dam of interest for the entire period over which RSTs were active. Public-facing timeseries of hydrological data were downloaded from the DataQuery 2.0 website and database which includes data from the USACE Northwestern Division (https://www.nwd-wc.usace.army.mil/dd/common/dataquery/www/, last accessed September 11, 2024). For each dam of interest, we downloaded timeseries data describing 1) hourly flows used to generate power; 2) hourly spill records (which include all flow not going through the penstock; this can include flows through ROs and the spillway where applicable); 3) instantaneous total outflow; 4) instantaneous forebay elevation; 5) average hourly inflow into the reservoir; and 6) below-dam gas saturation (where available). Depending on the project, time series data were available on 15-minute or hourly intervals; in some cases, only hourly averages were available. We first combined the timeseries data into hourly records (i.e., averaging any records that occur on 15-minute intervals) to facilitate comparison of hydrological variables reported on hourly versus 15-minute timesteps.

We then noticed inconsistencies in the USACE data between total reported outflow and the sum of flows from individual dam outlets. There are cases where this is a result of outflow calculation method. For example, the outflow record from Foster Dam is calculated from the downstream USGS gage, South Santiam near Foster (after subtracting flows from Wiley Creek). Meanwhile, records of penstock and spill flows are calculated from ratings tables; errors in performing calculations with ratings tables, not accounting for flows that supply hatchery facilities, and local flows between the dam and USGS gage may introduce discrepancies and mismatches in outflow records (Joshua Roach, pers. comm).

In many instances, the difference between the sum of power generating and spillway flow was identified as several hundred cubic feet per second (cfs) different from the reported outflow record over short periods of time (rather than the relatively consistent disparity that would be expected if flows from, e.g., hatchery facilities, are not accounted for in every record). For every instance where the difference in total and calculated outflow was more than 250cfs, we manually assessed the raw hydrological data to identify potential errors. In some cases, we were able to identify and remedy mismatches caused by apparent data entry errors (for example, this included replacing blanks and zero-flow readings with reasonable values based on time-adjacent readings and the disparity between reported outflow, generating flow, and spill flow). In the few cases where it was not apparent why the reported outflows did not match, we removed those records from the hydrological timeseries by setting all flows to null.

We also compared outflow records to USGS gage data from which outflows are typically derived. We used the dataRetrieval R package (De Cicco et al. 2018) to access the National Water Information System database and download relevant daily and instantaneous records where available. We queried instantaneous discharge records from USGS gages 14181500 (below the Detroit/Big Cliff complex), 14187200 (below Foster Dam, in the South Santiam), 14159500 (below Cougar Dam), 14150000 (below the Dexter/Lookout Point complex), 14145500 (below Hills Creek), and 14151000 (below Fall Creek). USGS gage data were primarily used to compare against USACE-reported outflows. Using USGS gage records, we identified cases where the USACE-reported outflow was incorrect by more than several hundred cfs to see if we could identify and remedy the mismatch. For example, there were instances where USACE reported zero spill or generating flow in a given hour of records, but the USGS and USACE records agreed that outflow in that and adjacent hours was non-zero. In such cases, we assumed that the reported outflow was accurate and fixed the incorrect entry in the USACE data if the incorrect reading was apparent (e.g., if during spill-only operations, spill flow was recorded at 0cfs in a several-hour period where all other records were similar non-zero entries). If the mismatch could not be reconciled, we set all flows to null values. All data cleaning steps were recorded in a "cleaning notes" column retained in the hydrology datasheets for posterity.

We also used USGS data from above-dam gages to provide outflow rates for HOR RST locations. Some gage locations did not record discharge; at these locations gage height was used as alternative hydrological variable. USGS-reported data were not cleaned or processed as there were no indications of data entry errors.

As a final cleaning step, we also removed any inflows to the reservoir which were negative. USACE inflows are not directly measured but are calculated from USGS gage data and other variables, and there were several hours in the timeseries when calculated average inflows were negative.

Migration analyses

Cleaned and weekly aggregated data were used for analyses of injunction effects on migration (see section "RST data compilation: weekly records and zero-catch trap events"). Then the median fork length for the week was computed. This was done including both living and dead fish in the traps.

The weekly catch rates (adjusted by trap efficiency and the number of hours a trap was running in the week) was plotted for each of the unique sites, then a non-parametric test (Kolmogorov–Smirnov test) was applied to evaluate if the distribution of catch rates pre and post injunction was different. A similar approach was applied to the distribution of fork lengths.

Catch rates were defined as the following equation:

$$\mathrm{CR_w} = \mathrm{C_w}/(\mathrm{TE_w} * \mathrm{Hrs_w})$$

where the number of fish captured per week, $\mathrm{C_w}$, is divided by the trap efficiency adjustment for that trapping period, $\mathrm{TE_w}$, and the number of trapping hours in that week, $\mathrm{Hrs_w}$.

The distribution of raw counts (uncorrected by trap efficiency or hours of trap operation) was plotted by week and a mixture model was fitted to the observations to estimate the modal run timing from the count data.   The principal goal was to try to detect if run timing and fork length were meaningfully different pre and post injunction. Other analyses assessed run timing with project passage efficiency (see sections "Project passage efficiency: statistical model fitting" and "Appendix F, Statistical analysis").

Growth analysis: Data used to assess impacts of injunction measures on fish size and growth patterns

We estimated growth curves for each site where RST data were available on fish size. The purpose of this analysis was to assess whether there have been discernable changes to fish growth patterns—particularly the rate of growth and/or maximum size of growth, as estimated by growth curves. We hypothesized that injunction measures may, by reducing reservoir residence time of migrants, reduce the growth rate and truncate observed fish size at below-dam RST locations (c.f. Romer et al. 2016). Comparing above- and below-dam records within a single year demonstrates that any changes to growth across injunction periods may be a result of dam operations and not an effect of annual variation.

The RST records used to assess injunction effects on fish growth patterns used reporting from all operators: USACE, ODFW, Cramer, and EAS. For growth analysis, each dataset was combined into a master dataset for analysis. Filtering was performed to remove records that might not be within the expected growth ranges for their age and time of year. The following attributes of juvenile Chinook salmon were relevant for growth analysis:

- **Site**: The specific location where the fish were released and captured.
- **Day of Year (DOY)**: The day of the year when each individual fish was sampled, serving as a proxy for the age of the fish.
- **Fork Length (mm)**: The length of each fish, measured from the tip of the mouth to the fork of the tail, serving as a key indicator of growth.
- **Year**: The year in which the fish were released, allowing for the analysis of growth patterns over time.

Because of the multiple release/recapture locations, the data were categorized as either above- or below-dam sites. For example, sometimes there were multiple RST locations above a given dam (e.g., head-reservoir); these sites were combined into above-dam sites. The unique combinations of site-by-year were identified to facilitate the fitting of growth models across different combinations of these factors.

Growth analysis: Growth model specification

A logistic growth model (Richards 1959) was selected to describe the growth patterns of juvenile Chinook salmon. The logistic growth model is well-suited for biological growth processes where the growth rate decreases as the individual approaches a maximum size. The model was defined as follows:

$$L(t) = L_l + \frac{(L_u - L_l)}{(1 + qe^{-B*t})^{1/V}}$$

where L_l is the lower asymptote, representing the minimum length of the fish, L_u is the upper asymptote, representing the maximum potential length (e.g., above or below dams), B is the growth rate parameter, q is a scaling parameter controlling the symmetry of the curve, V is the shape parameter influencing the steepness of the growth curve (V>0), and t is the age of the fish, represented by DOY.

For each site-year combination, the logistic growth model was fitted to the data using non-linear optimization techniques. Specifically, the model parameters (L_l, L_u, B, V, q) were estimated using the optim function in R (R Core Team 2023), which minimizes the sum of squared residuals between observed and predicted fish lengths. The optimization was performed using the "L-BFGS-B" method, allowing for the imposition of constraints on the parameter values. Initial parameter guesses and appropriate lower and upper bounds were provided to ensure realistic and biologically meaningful estimates.

To assess the uncertainty associated with the parameter estimates, bootstrap resampling was employed. For each site-year combination, 10,000 bootstrap samples were generated by randomly sampling the data with replacement. The logistic growth model was then fitted to each bootstrap sample, yielding a distribution of parameter estimates. From these distributions, 95% confidence intervals for each parameter were computed using the 2.5th and 97.5th percentiles of the bootstrap estimates. This approach accounts for the variability in the data and provides a robust measure of the uncertainty of the parameter estimates. After fitting the growth models and estimating confidence intervals (CI), the logistic growth curves were plotted for each site-year combination, showing the relationship between DOY (age) and fork length. Combinations of site-year data were eliminated if the model did not converge.

Fish injury analysis: data used

RST records from all reporting agencies were used to assess if the prevalence of reported injuries was significantly different during the pre- and post-injunction phases. Both living and dead fish were included; we did not use living/dead status as an injury category for this analysis. Fish which were released and/or recaptured for TE trials were excluded from analysis (some trials released fish below the dam to estimate TE so fish associated with those trials would not have migrated through the dam and are not relevant for this analysis). We filtered RST records to include only Chinook salmon, considering both wild and hatchery-origin individuals. Inclusion of hatchery fish may over-represent some injury categories, as hatchery released fish may have injuries attributable to hatchery rearing instead of dam passage. For example, hatchery released fish may have higher rates of descaling as a result of being handled during release. Because there are some RST records where fish origin was not reported, we included fish of both natural and hatchery origin after removing TE-trial fish. A caveat of this approach is that some types of injuries/conditions experienced during hatchery rearing and release (e.g., descaling, parasitism) may be over-reported if the proportion of hatchery fish in downstream RSTs changed between pre- and post-injunction periods. This analysis will also include injuries incurred during RST trapping.

Injuries were reported by RST operators for each fish which was captured in an RST and subsequently processed. Injuries were typically recorded using injury codes, with consistent definitions, but not always. Many injury codes were operator-specific, and not every RST operator applied a consistent injury classification system. For example, especially when RSTs were operated by USACE, injury codes were not used consistently (and in some cases written comments were used instead of codes). While some fish comments included standardized injury codes, others used only written descriptions of injuries that are not standardized.

Using the written injury comments, we re-classified injuries into standardized injury codes. Wherever possible, we used injury codes that were already used by USACE operators or other RST operators. First, we used best judgement to interpret written fish condition fields and determine which injury code most appropriately described that type of injury or body condition. Where more than one injury was reported, we included multiple injury codes if appropriate. We also consolidated synonymous codes, as USACE operators in different years would sometimes use a different injury code to describe the same type of injury. Finally, where undefined codes were used (i.e., codes which are not included in published definition tables), we attempted to define these codes based on fish condition text.

We then consolidated injury codes used by the different RST operators into encompassing injury categories that were common to all. Following fish injury categories defined in previous research at USACE-operated dams (Normandeau Associates 2019), we defined the following eight injury categories (each of which encompasses at least one injury code, often several; see Table 5 for a dictionary of which codes used by the different RST operators fall under each larger category):

- **Body/fin injury:** External damage to the body, including bruises, scrapes, tears, and fin damage. Does not consider injury to the head or internal organs. Includes cases of minor descaling (<20% of the body).
- **Head injury:** External damage to the head, including bruises, scrapes, and tears. Does not include damaged or missing eyes, or damage to the gills, operculum, and isthmus (these injuries are captured in other injury categories).
- **Internal injury or trauma**: Non-external bodily injury, evidenced by bleeding from the vent or anus, bloating, and/or a distended body.
- **Body/head missing or nearly decapitated:** Includes fish captured with only a head, only a body, or cases where injury records report that head is nearly detached from the body.
- **Major descaling**: Descaling of more than 20% of the body.
- **Copepod infection**: Any presence of copepods on the external body; this metric does not account for the location of copepods or their number.
- **Eye damaged/missing**: Includes fish with ruptured, hemorrhaged, missing, or "popped" eyes.
- **Gill, operculum, and isthmus damage:** Includes external injury to the gills, including frayed gills but not including copepod infection, as well as damage to the operculum and/or isthmus.

Individual fish can have multiple injuries that fall under different categories. Several fish condition codes could not be assessed as they were used only by some RST operators; for example, when fish were observed as having loss of equilibrium was recorded at traps operated by USACE and the effect of injunction measures on observed disequilibrium could not be assessed. Several injury categories were used by multiple operators, but were not relevant when considering the impacts of dam operations on injuries sustained during downstream fish passage (e.g., indications of predation, fish hooks, and fungal infections). Given there were no specific experiments to understand whether injured fish were more or less likely to be trapped, we made the assumption that the proportion of Chinook salmon reported to have each type of injury code was the same in the captured and non-captured components of the total population of passing fish available for sampling during RST trapping events.

Table 5. Definitions of injuries, injury codes used by each RST operator, and injury categories for each injury type used in statistical analysis of injury reporting in the pre- and post-injunction periods. Blank cells indicate cases where a given injury code was not used by that RST operator. Table continues on the following page.

	Injury category used by operator				
Injury description	**USACE**	**ODFW**	**Cramer**	**EAS**	**Injury category for statistical analysis**
Bruising (not on the head)	BRU/BRS	BRU	BRU	BRU	Body injury
Descaling <20%	DS<20	DS<2	DS<20	DS<2	Body injury
Fin damage (including no tail)	FF	FID	FID	FID	Body injury
Fin blood vessels broken	FVB	FVB	FVB	FVB	Body injury
Hole behind pectoral fin	HRP/HLP/HBP	HBP	HBP	HBP	Body injury
Hole behind ventral fin	HRV/HLV/HSL	HBV			Body injury
Hole behind anal fin			HBA		Body injury
Body injury (tears, scrapes, mechanical damage)	TEA/VSR/VSL	TEA	TEA	TEA	Body injury
Bloody at fin base	BFB				Body injury
Body only	BO	BO	BO	BO	Body/head missing or nearly decapitated
Head barely on	HBO	HBO	HBO	HBO	Body/head missing or nearly decapitated
Head only	HO	HO	HO	HO	Body/head missing or nearly decapitated
Copepods	COP	COP	COP	COP	Copepods
Bloody/injured eye (including hemorrhage)	LEH/REH/EYI	EYB	EYB	EYB	Eye damaged or missing
Eye missing	EYM	EYM			Eye damaged or missing
Pop eye	POP	POP	POP	POP	Eye damaged or missing
Operculum damage	OPD	OPD	OPD	OPD	Gill/operculum/isthmus damage
Torn isthmus	TI				Gill/operculum/isthmus damage
Blood from gills/bad gills	GILL				Gill/operculum/isthmus damage
Bruising on the head	BRH				Head injury
Head injury	HIN/SA/SS	HIN	HIN	HIN	Head injury
Distended belly	BKD	BKD		BKD	Internal injury/trauma
Bloated	BL	BLO	BLO	BLO	Internal injury/trauma
Internal injuries	INT				Internal injury/trauma
Bleeding from vent/anus	BA	BVT	BVT	BVT	Internal injury/trauma

	Injury category used by operator				
Injury description	**USACE**	**ODFW**	**Cramer**	**EAS**	**Injury category for statistical analysis**
Descaling >20%	DS>20	DS>2	DS>20	DS>2	Major descaling
Fishing hook	FHK	FHK			*Not used in dam passage injury analysis*
Fungus	FUN	FUN	FUN	FUN	*Not used in dam passage injury analysis*
Moribund (almost dead)	MBD	MBD			*Not used in dam passage injury analysis*
Mortality without external injuries	MUNK	MUNK	MORT	MUNK	*Not used in dam passage injury analysis*
Predation marks	PRD	PRD	PRD	PRD	*Not used in dam passage injury analysis*
Mort upon handling	MUH		MORT		*Not used in dam passage injury analysis*
Mort upon release	MUR		MORT		*Not used in dam passage injury analysis*
Loss of equilibrium	H				*Not used in dam passage injury analysis*
Good shape	GS	GS	NXI	NXI	*Not used in dam passage injury analysis*
Gas bubble disease	GBD	GBD	GBD	GBD	*Not used in injury analysis; see TDG and GBD analysis*

Fish injury analysis: statistical analysis

After filtering to below-dam sites where RST data was available both pre- and post-injunction, we assessed the incidence of each category of injuries at nine RST locations located below Big Cliff (BCL), Cougar (CGR_PH, in the powerhouse channel, and CGR_RO, in the RO channel), Fall Creek (FCR), Hills Creek (HCR_PH in the powerhouse channel, HCR_RO in the RO channel, which was moved post-injunction downstream of the powerhouse-RO confluence and therefore captures fish from both outlets), and Lookout Point (LOP_PH1 and LOP_PH2 in the powerhouse channel, and LOP_SP in the spillway channel).

At each RST, we assessed if there was a statistically significant injunction effect on the proportion of processed fish with a given injury category by applying quasi-binomial regression. Observations of each injury category were fitted individually, with the proportion of fish reported to have a given injury type in a trapping event serving as the dependent variable with a single explanatory variable, injunction period. For each site, we assessed if there was a significant difference in reporting between injunction periods based on the statistical significance of the injunction effect coefficient. Because quasi-binomial regression allows for weighting each trap event by the total number of fish caught during that trap event, we included trap efficiency adjusted total catch rates in the weighting of observations. This approach assumes that injury status does not impact the likelihood that a fish is captured in an RST, because TE adjustments could not be used to adjust the observed proportion of fish with a given injury, just the weighting on those observations. Additionally, while trap efficiency estimates were generated using releases of live fish, this injury analysis includes records from all fish processed in an RST trapping event, living or dead.

At all RST locations, there was turnover in operators between the pre- and post-injunction periods such that any changes to reported injury rates post-injunction could reflect either injunction operations, change in RST operators, or both. Except at Fall Creek's tailrace RST, USACE and/or ODFW were responsible for trap operation pre-injunction, with operation changing to Cramer and/or EAS after the injunction (at Fall Creek's tailrace RST, USACE operated the RST before the injunction measures were put in place and for a portion of the time after the implementation of measures). Many sites were operated by multiple RST operators during the post-injunction period. To assess whether there was also a significant effect of operator on reported injury rates, we also applied a quasi-binomial regression model of injury rates as a function of trap operator. For all sites with multiple operators during the post-injunction period, we identified if there was a significant effect of operator based on the statistical significance of the operator term in fitted quasi-binomial regression results.

Using injury records from Fall Creek's tailrace RST, we also assessed the influence of operator and injunction period using model fitting and selection. Fall Creek's tailrace RST was operated by USACE both before and after the injunction was implemented, but with EAS taking over RST operation after the first year post-injunction. To assess the relative impacts of operator and injunction period on recorded injury rates, we applied binomial regression to fit four candidate models to explain observed injury rates: 1) a constant-only model; 2) a model including only injunction period as an explanatory variable; 3) a model including only operator as an explanatory variable; and 4) a model including both operator and injunction period. Using the glm R package (R Core Team 2023) to fit the binomial regressions, the four fitted candidate models were then ranked using Akaike information criterion (AIC; Burnham and Anderson 2010). Because the binomial regression weighted each trap event's observed proportion by the number of fish captured at that trap event, we weighted observations by trap-efficiency adjusted estimates of the total number of fish passing a given RST location in a given period.

TDG effects on barotrauma and mortality analysis: background

Total dissolved gas (TDG) is the total amount of dissolved air in a water body. Supersaturation occurs when water contains more dissolved gas than it can normally hold in solution at a given temperature and atmospheric pressure, i.e., the water becomes greater than 100% saturated. This is a natural process and water can contain more gas under high pressure, i.e., at depth, or at low temperatures. Dam spill operations introduce air bubbles into water that is plunged deep into stilling basins and tailrace waters, these entrained bubbles are dissolved into solution in the deeper water. When this water returns to the surface downstream, where hydrostatic pressure is lower, it is supersaturated with TDG. The excess TDG dissipates at the surface downstream due to the concentration difference between water and atmosphere but dependent on several factors, including river flow and bathymetry, can remain many kilometers downstream of the source and persist for a few hours once the source is removed. Oregon water quality standards state that TDG supersaturation of water may not exceed 110% except under exceptional flood discharge events (Oregon Department of Water Quality n.d.).

Gas bubble disease or trauma (GBD) may be experienced by fish in water supersaturated with TDG (Weitkamp and Katz 1980; Pleizier et al. 2020a). This occurs when fish equilibrate with supersaturated TDG and gases form bubbles at nucleation sites in small blood vessels within their tissues; the bubbles accumulate most visibly in the fins, gills, and eyes. GBD causes sub-lethal effects that can lead to mortality, including tissue necrosis, impaired development, increased vulnerability to disease and risk of predation (Pleizier et al. 2020b). TDG also causes positive buoyancy due to swim bladder over-inflation. Possibly due to this, there is evidence for depth compensation behaviour by fish in TDG supersaturated water, which may alleviate GBD. As depth increases, greater hydrostatic pressure causes bubbles to shrink until they collapse. In natural waters, fish exposed to high TDG will seek greater depth where gas saturation is lower, not because they can detect TDG directly, but because they can detect positive buoyancy (Pleizier et al. 2020b). Fish generally do not experience GBD at TDG less than 110% (Maule et al. 1997; Mesa et al. 2000), but the threshold does vary by species. As well as gas bubble disease, TDG may result in other barotrauma-related injuries, including bloating, broken blood vessels, eye haemorrhage, and pop-eye. However, these can also be related to other factors, including disease, so the link between these injuries and TDG may be less clear than with gas bubble disease.

The Corps has implemented operational measures at several dams to reduce the impact of TDG on Chinook salmon and steelhead (Table 1). This includes a reduction in flow passing via the spillway and use of multiple gates to spread the total flow across the spillway during spill operations. Further abatement measures are planned, including installation of boulders in the tailrace to increase TDG dissipation rates.

Although the effect of TDG on GBD incidence is well studied in lab environments, there is only limited understanding from field studies. This is in part because obtaining data on GBD incidence requires some form of fish trapping effort under different TDG levels, which is generally expensive, and it is very difficult to separate TDG effects in the field from other effects of dams when fish are passing downstream through dams. Extreme high or low flows can also make it difficult to sample fish. There appear to be site-specific differences in the level of TDG that causes GBD, and little is known about the effect of TDG abatement measures on GBD incidence. We aimed to understand the effects of TDG on

GBD and other barotrauma-related injuries, as well as on mortality, in the UWR basin, using RST data available on Chinook salmon caught below dams.

TDG effects on barotrauma and mortality analysis: data used

We used data available on juvenile Chinook salmon caught in RSTs located in dam tailraces. We had data from two periods, pre- and post-implementation of TDG abatement measures following the 2021 injunction. Trapping took place in the tailraces below most dams in the WVS, but the availability of data on potential hydrological variables, including TDG, was very limited, particularly in the pre-injunction period. Traps below Big Cliff dam (BCL) and in the regulating outlet channel below Cougar dam (CGR-RO) were operated in both periods and data were available on all hydrological variables to be included in the analysis.

RSTs were typically checked every 1-2 days during operational periods. We used data on trapping effort to summarise the number of Chinook salmon captured within discrete trap events and the proportions of these with the following conditions: 1) GBD, 2) any barotrauma-related injury, or 3) mortality. Barotrauma-related injuries include gas bubble disease but also eye haemorrhage and pop eye, broken fin blood vessels, bleeding from vent, and bloating. The observed number of captures were adjusted for trap efficiency (TE). For numbers captured below Big Cliff dam, total outflow was used as a predictor of TE using the exponential plus constant model (see Results section on “Trap efficiency”). For numbers captured below Cougar RO, the mean TE estimated across TE trials was applied as there was no relationship with outflow (see Results section on “Trap efficiency”). Given there were no specific experiments to understand whether injured fish were more or less likely to be trapped, and very few TE trials involving dead fish releases at these sites ($n \le 5$), we made the assumption that the proportion of Chinook salmon with each of the conditions were the same in the captured and non-captured components of the total population available for capture during the RST trapping events.

TDG effects on barotrauma and mortality analysis: statistical modelling

We considered continuous and factor explanatory variables for each of the fish conditions: TDG (%), spill discharge (cfs), reservoir forebay elevation (ft), mean length of each fish sample captured per trap event (mm), the duration of each trap event (hours), river temperature (°C), season (spring/ summer/ fall/ winter), site (BCL/ CGR-RO), and injunction period (pre or post). Trap check times, temperature and fish lengths were measured by the crews operating each RST (ODFW pre-injunction, Cramer Fish Services and EAS post-injunction). TDG, spill and elevation data were summarized for the period prior to each trap check time, i.e., when the fish could have been passing the dam and entering the trap. TDG, spill discharge and reservoir forebay elevation data were obtained for each dam from the Corps Dataquery 2.0 database (see “Data sources: Hydrological variables and other covariates”). The hydrological data were typically available on an hourly timestep, so we matched the start and end times of each trap event to calculate the mean and maximum values for TDG, discharge, spill, and elevation during each event.

TDG was measured at USGS gages downstream of the dams. The gage below Cougar (USGS 14159500) was <500m downstream of the RST, while the gage below Big Cliff at Niagara (USGS 14181500) was >1km downstream. Over this distance, some dissipation of TDG was possible so an attempt was made to correct for this to more appropriately model fish condition as a function of TDG at the RST. Since 2023, USACE has operated a TDG gage directly at the RST site below Big Cliff. We obtained data from the RST gage for the 7 February 2023 to 11 February 2024 period (pers. comm., Norm Buccola, USACE) and related these TDG readings (n=7,540) to the USGS gage readings for the same period using a linear regression model (Figure A 7). The model had an R^2 of 0.885 and resulted in an equation to correct Niagara values for all dates pre- and post-injunction:

$$TDG_{BCL} = 1.9875 + 0.9915 \times TDG_{Niagara}$$

Forebay elevation varied at each site. For Big Cliff, as it is a re-regulating dam the elevation does not vary (range pre-injunction 1186-1203 ft, post-injunction 1188-1203 ft) as much as at Detroit (range pre-injunction 1426-1564 ft, post-injunction 1445-1560 ft). To account for injuries detected below Big Cliff that could result from passage at Detroit, we used the combined elevation across both dams during each trap event. The range of elevation was greater at Cougar (pre-injunction 1472-1691 ft, post-injunction 1500-1647 ft). Given the difference in elevation values at each site (Figure A 8), we normalized them by subtracting the mean values and dividing by the standard deviations at each site. Similar to elevation, we combined the spill discharge data from Big Cliff and Detroit to account for injuries detected below Big Cliff that could result from passage at Detroit. This approach was confirmed by improved relationships of TDG with spill compared to a lack of relationship between TDG and spill at Big Cliff only (Figure A 9).

To model the observed proportions with different conditions in each trap event *i*, we used Binomial Generalized Linear Models (GLM). Response variable Y_i is number dead, injured or parasitized out of n_i Chinook salmon captured during trap event *i*. Each trap event was weighted by the TE-adjusted n_i values. The models were fit using the 'glm' function in R (R Core Team 2023) and took the form:

$$Y_i \sim B(n_i, \pi_i)$$

$$E(Y_i) = \pi_i \times n_i \text{ and } \mathrm{var}(Y_i) = n_i \times \pi_i \times (1 - \pi_i)$$

$$\mathrm{logit}(\pi_i) = \alpha + \beta_1 \times variable_i + \cdots$$

Biologically reasoned interactions between explanatory variables were examined, including between TDG and trap hours, TDG and temperature, temperature and trap hours, trap site and temperature, spill and length, elevation and length, trap site and injunction period. Data on both mean and maximum TDG and mean the maximum spill were available. These were highly collinear so one TDG and one spill variable were initially removed based upon which variable had the highest variance inflation factors in a full model containing both, and by examining the single variable relationships with each condition and whether each was significant at each site and in each period.

Binomial model fits showed that the count data were over-dispersed so we assessed the fit of a quasi-binomial model. In all cases the quasi-binomial model was chosen as the residual deviances were much larger than the degrees of freedom. This meant that model variable selection by AIC was not suitable; instead the optimal model was selected by dropping one explanatory variable in turn and applying an analysis of deviance test using the 'drop1' function in R (R Core Team 2023). Models were validated by examination of residual plots (Zuur et al. 2009).

Project passage efficiency: data filtering

We tested for an effect of injunction measures on observed catch rates using RST data that had been cleaned and compiled to a weekly timestep (see section “RST data compilation: weekly records and zero-catch trap events”). Reliable statistical estimation of PPE in each of the injunction time periods (i.e., the periods before and after injunction measures were implemented) requires multiple overlapping years of data from both head-of-reservoir and tailrace traps. This limited the number of sites where we could estimate PPE. We identified appropriate sites for testing an injunction effect on PPE by filtering RST records that met the following criteria:

- A site must have RST capture records from a head-of-reservoir (HOR) trap and at least one below-tailrace trap (where data allow, combine below-dam traps if their years of sampling overlap). Applying this criterion excludes, for example, records from RSTs associated with Green Peter (where RST records are only available from the post-injunction period) and Foster Dam (where there are no data available from RSTs below the dam during the post-injunction period).
- Below-dam RSTs are only comparable across injunction periods if they are in the same outlet channel (small movements within the channel are acceptable). For example, records from a below-dam RST placed in an RO channel are not compared to records from an RST placed in a powerhouse channel.
- Above- and below-dam RST records are available from within the same Julian year(s), such that the fish captured in the traps are from the same cohort.
- A minimum of two years of overlapping HOR and tailrace RST trapping records during each of the pre- and post-injunction periods (this eliminated, for example, Hills Creek where the only year of post-injunction data available are from 2023 and the Detroit-Big Cliff complex). This requirement reflects both biological and statistical requirements; multiple years of data from the post-injunction period are required for statistical estimation, and a cohort of fish requires two years to pass fully below dams.

After filtering by these criteria, three sites remained with which to assess injunction effects on PPE from RST records: Cougar Dam and reservoir, Fall Creek Dam and reservoir, and Lookout Point Dam and reservoir. A summary of RST traps, years of operation, trap operators, and other information for this analysis is given in Table 6. See “Appendix F: Project passage efficiency” for location-specific details of how RST records from these sites were compiled (e.g., multiple below-dam traps were combined to assess PPE at Cougar).

RST records for each project were filtered to include only living wild spring Chinook salmon. PPE implicitly includes reservoir and dam passage mortality, and therefore dead fish do not contribute to PPE. We also filtered the RST datasets to include only wild fish (except for years where origin was not recorded; over several years in the pre-injunction phase, USACE operators did not indicate the origin of captured fish in the majority of fish capture records, especially at Fall Creek’s HOR trap).

Table 6. Summary of locations and times where RST records were used to statistically fit and estimate an injunction effect on project passage efficiency (PPE). RST site codes reflect the location of the RST trap(s) used in estimation. Projects include Detroit Dam (DET) and downstream reregulating dam Big Cliff (BCL); Cougar Dam (CGR); Lookout Point (LOP); Fall Creek Dam (FCR); and Hills Creek Dam (HCR). To estimate PPE at each dam, above- and below-dam RST records are combined by years; years of overlap are shown in the "Year(s)" columns. HOR: head of reservoir; PH: powerhouse; RO: regulating outlet; ODFW: Oregon Department of Fish and Wildlife; USACE: US Army Corps of Engineers; CA: Cramer & Associates; EAS: Environmental Assessment Services LLC.

	Pre-injunction		***Post-injunction***		
RST site code	**Year(s) overlap**	**Operator(s)**	**Year(s) overlap**	**Operator(s)**	**Trap selection notes**
CGR HOR (above)	2012-16	ODFW	2022-23	EAS	Overlapping data from 2010-11, but during this time there were 2x5ft traps in the RO channel
CGR PH (below)	2012-16	ODFW	2022-23	EAS	
CGR RO (below)	2012-16	ODFW	2022-23	EAS	
LOP HOR (above)	2010-14	ODFW	2022-23	EAS	5ft trap
LOP PH1 (below)	2010-14	USACE	2022-23	EAS	Before 2017: all LOP trap(s) were in the PH channel. No HOR records are available from the pre-injunction period when spillway RST in operation
FCR HOR (above)	2006-08	USACE	2021-23	USACE; CA; EAS	8ft trap
FCR (below)	2006-08	USACE	2021-23	USACE; CA; EAS	8ft trap

Project passage efficiency: catch rates as a proxy for fish abundance

We then used RST records to inform statistical models of "project passage efficiency", the proportion of migrants of a given type that successfully pass the reservoir and dam.

Conceptually, PPE is related to the relative abundance of fish above and below dams. The abundance of fish of a given migrant type in a tailrace RST can be predicted from 1) the abundance of migrants entering the reservoir earlier in the year, and 2) reservoir and dam operation conditions that influence migration patterns, survival, and dam passage. For example, the tailrace abundance of fry may be predicted from the abundance at the head of reservoir as follows:

$$N_{f,T,y} = N_{f,H,y} * S_{f,R,y} * P_{f,R,y} * \ P_{f,D,y} * S_{f,D,y}$$

where $N_{f,T,y}$ is the abundance of fry at the tailrace in trapping event T of year y, $N_{f,H,y}$ is the abundance of fry at the head of reservoir in year y, $S_{f,R,y}$ is the reservoir survival of fry in year y, $P_{f,R,y}$ is the proportion of fry in year y that pass the reservoir as fry instead of rearing to subyearling stage, $P_{f,D,y}$ is the proportion of fry that successfully pass the dam as fry (i.e., dam passage efficiency), and $S_{f,D,y}$ is dam passage survival for fry. The product of these final four terms is what we term project passage efficiency, $\mathrm{PPE}_{f,y}$:

$$N_{f,T,y} = N_{f,H,y} * \mathrm{PPE}_{f,y}$$

which may be expressed as the ratio of abundance at the tailrace over that at the head of reservoir:

$$\mathrm{PPE}_{f,y} = \frac{N_{f,T,y}}{N_{f,H,y}}$$

Because we do not have direct estimates of fish abundance, for statistical estimation of PPE we used TE-adjusted catch rates as an index of abundance. After compiling RST records into weekly captures by site, we calculated the catch rate ratio of each migrant type (see “Juvenile stage categorization”).

For example, the catch rate ratio for the fry migrant type, CRR_f, is calculated as:

$$CRR_f = \frac{\widehat{CR_{f,T,y,\iota}}}{\widehat{CR_{f,H,y}}}$$

where the denominator of the ratio, $\widehat{CR_{f,H,y}}$, is the mean fry catch rate at the HOR RST over the calendar year (e.g., after calculating weekly catches-per-hour, average across weeks) and the numerator, $\widehat{CR_{fry,TR,\iota}}$, is the mean fry catch rate per hour in each trapping week, *i*.

To calculate the catch rate ratio for subyearling migrants, CRR_s, we included both fry and subyearling migrants entering the HOR in our estimation of PPE (see section “Juvenile stage categorization” for details on how we distinguished migrant types and how the abundance of fry entering a reservoir contribute to the abundance of subyearlings observed passing the tailrace):

$$CRR_s = \frac{\widehat{CR_{s,T,y,\iota}}}{\widehat{CR_{f+s,H,y}}}$$

Where $\widehat{CR_{f+s,H,y}}$ is the average annual catch rate of fry and subyearlings at the HOR RST, and $\widehat{CR_{s,T,y,\iota}}$ is the weekly subyearling catch rate in trapping week *i*.

Project passage efficiency: statistical model fitting

Using catch rate ratios as a proxy for abundance, we then performed statistical analysis to assess whether there was a detectable effect of injunction period on PPE. We attempted to account for other variables known to impact observed catch rates by week (particularly run timing by week; see “Appendix F: Project passage efficiency” and Figure A 25 for descriptions of how weekly run timing was mathematically defined in statistical models). To facilitate efficiency in statistical analysis, we linearized the model by log-transforming catch rates (see “Appendix F: Project passage efficiency” for details on the transformation) and added a small positive constant to all tailrace RST catch rate records (equal to the lowest observed trap-efficiency adjusted catch rate at that tailrace RST across the time series multiplied by 0.01). In some years where there were zero catches at the HOR RST, to facilitate analysis we added a constant equal to the catch rate that would result from one fish being caught over the year (adjusting for trap efficiency and number of operational trapping hours over the week).

At each of the three sites which met our criteria for PPE analysis, we fitted multiple competing models to observed catch rate ratios of fry and subyearlings (we did not have sufficient time to assess yearling PPE in Phase 1). Each model included at least a global intercept, and potentially also at least one of 1) an injunction factor, to assess if there is a detectable change in catch rate ratios in the post-injunction period, and 2) weekly run timing. We attempted to fit models that also included hydrological variables of interest, including depth to outlet, river temperature, and outflow through the outlet(s) where RSTs were located. However, we were unable to fit any models containing both a week effect and any hydrological variable and models including weekly run timing and any one of these covariates failed to converge in all cases. Examination of model fit summaries suggested that the failure of these models to converge may be attributable to high correlation between these variables and week of the year. Because we expected the weekly run timing effect to be more important to describing PPE than hydrological variables, we prioritized the estimation of weekly run timing effects over estimating the effects of hydrological variables. At Fall Creek, due to limited data, we also ran a model with only an injunction factor and no weekly run timing.

Models were fitted to observed catch rate ratios of fry and subyearlings using non-linear estimation techniques. Model parameters were estimated with the optim function in R (R Core Team 2023) using the “BFGS” method to minimize the negative log-likelihood function of the parameters. For each model, we provided multiple sets of initial parameter estimates. In some cases, limited information in the observed data led to poor model fit and lack of convergence. Lack of convergence can indicate, among other issues, that there is not enough information in the data to support the complexity of the model, which can result in unreliable parameter estimates. Results of models which did not successfully converge are not reported here.

For models which successfully converged, we report the mean and standard error of those parameter estimates by calculating the square roots of the diagonal elements of the inverse of the Hessian matrix at the maximum likelihood estimate. We then calculated confidence intervals around parameter estimates by multiplying standard errors by t-values, calculated based on a significance level of p=0.05 and degrees of freedom are equal to the number of weeks with observations minus the number of parameters estimated by the model.

Results

Trap efficiency

The TE estimates by RST site varied markedly between experiments with TE estimates typically ranging more than an order of magnitude between minimum and maximum values for non-zero estimates (see figures in "Appendix B: Trap efficiency"). The mean TE estimates also varied markedly between RST locations with some RSTs having mean TEs as low as 0.0004 (Green Peter HOR) and as high as 0.116 (Cougar PH). Although trap efficiency is site specific, where TE trials had been carried out within subbasins both at head of reservoir and below the dam, the mean TEs tended to more similar, for example, with mean TEs tending to be relatively high for RSTs associated with the Cougar Dam and reservoir (i.e., 0.0490-0.1159), and being very low for the Lookout Point project (i.e., 0.0005-0.0161) and Fall Creek HOR and Fall Creek tailrace (i.e., 0.0044-0.0299; Table 7). However, mean TEs for some RST sites changed markedly between pre-and post-Injunction periods, e.g., dropping markedly after injunction measures implementation for RSTs located at the Hills Creek HOR, Fall Creek, and Lookout Point PH (Table 7).

For four of the 10 RST sites in which TE records were available before and after Injunction measures implementation, the mean TE following injunction measures implementation was significantly different from the mean of the TE prior to injunction, i.e., the 90% confidence intervals for the mean TE before and after Injunction measures implementation did not overlap (Table 7). This was found for the Fall Creek, Hills Creek HOR and Lookout Point PH1 and Lookout Point PH2 RST sites. For each of these instances, the ratio of mean TE post to pre-implementation ranged between 0.06 for Lookout Point PH1 and 0.27 for Lookout Point PH2. For all four of these RST sites, the ratio of mean flows at the site was close to 1, i.e., ranging between 0.77 for Lookout Point PH1 and 0.96 for Hills Creek Head of Reservoir sites and not significantly different (Table 8). For those six RST sites where no significant difference was found in mean TE before and after implementation, the ratio of TE means post to pre-implementation ranged between 0.76 and 1.14. The ratios of mean flow post to pre-implementation varied slightly more, ranging between 0.47 for the Breitenbush to 0.85 for the Cougar Head of Reservoir site.

Success in fitting the beta model was achieved for fewer of the RSTs than for the Exp and Exp_PC models. The beta model was successfully fitted for RST sites at Big Cliff, Breitenbush, Cougar HOR, Cougar PH, Cougar RO, Detroit HOR, Dexter, Fall Creek, Foster HOR, Green Peter, Hills Creek PH, Hills Creek RO, Lookout Point HOR, Lookout Point PH1, and Lookout Point PH2 RST sites. In contrast, the Exp and Exp_PC models could be fitted to all 16 RST sites where there were at least 10 TE estimates. For four of the 16 RST sites where TE models could be fitted, fitted models were selected over models based only on the mean TE. The Exp_PC model was selected for the Big Cliff and Cougar HOR RST sites (Table 9). The AICc values were lowest for this model for both RST sites. For both RST sites, observed TEs were on average highest at the lowest mean flows (Figure 9). The average TE decayed rapidly with increasing mean flow and flattened out at intermediate mean flows and stayed relatively low up to the maximum recorded mean flows. For the Big Cliff RST site, the Exp_PC model could explain 23% of the variability in TE while the Exp and beta regression models could explain only 20% and 19%, respectively, of the variability in the data (Table 9). For the Cougar HOR RST site, the Exp_PC model could explain approximately 49% of the variance in observed TE. In contrast the Exp and beta regression models could only explain 40% and 37%, respectively, of the variance in observed TE (Table 9). Maximum likelihood parameter estimates (MLE) for the models selected for TE adjustments for the 20 RST sites for which there are TE studies are shown in Table 10.

Table 7. Results on the sample means for live fish trapping efficiency (TE) and 90% confidence intervals for the global, pre-injunction and post-injunction means. The ratio of pre-injunction to post-injunction TEs is shown under Pre/Post. An alpha level of 0.1 was applied to evaluate whether there was a difference in the mean TE pre- and post-injunction. In cases where results were statistically significant, the 90% intervals for TE did not overlap and the ratio of post injunction to pre-injunction sample means was less than 0.3. LB: lower bound; UB: upper bound.

RST Location	Global Mean	LB	UB	Pre-Injunction mean	LB	UB	Post-Injunction mean	LB	UB	Post/Pre	Sig. dif?
BCL	0.0643	0.0514	0.0792	NA	NA	NA	0.0643	0.0514	0.0792	NA	NA
BRE	0.0644	0.0468	0.0859	0.0603	0.0423	0.0831	0.0689	0.0376	0.1154	1.1	No
CGR_HOR	0.0624	0.0562	0.0690	0.0647	0.0577	0.0722	0.0490	0.0394	0.0690	0.8	No
CGR_PH	0.1159	0.0955	0.1389	0.1004	0.0793	0.1248	0.1387	0.1001	0.1863	1.4	No
CGR_RO	0.0553	0.0464	0.0653	0.0674	0.0353	0.1177	0.0531	0.0442	0.0631	0.8	No
DET_HOR	0.0504	0.0359	0.0685	0.0312	0.0187	0.0493	0.0611	0.0408	0.0879	2.0	No
DEX	0.0066	0.0034	0.0115	NA	NA	NA	0.0066	0.0034	0.0115	NA	NA
FCR_HOR	0.0174	0.0351	0.0929	NA	NA	NA	0.0174	0.0351	0.0929	NA	NA
FCR	0.0299	0.0192	0.0438	0.0419	0.0278	0.0601	0.0044	0.0011	0.0116	0.10	Yes
FOS_HOR	0.0593	0.0082	0.0337	NA	NA	NA	0.0593	0.0082	0.0337	NA	NA
GPR_HOR	0.0004	0.0001	0.0012	NA	NA	NA	0.0004	0.0001	0.0012	NA	NA
GPR	0.0132	0.0096	0.0176	NA	NA	NA	0.0132	0.0096	0.0176	NA	NA
HCR_HOR	0.0769	0.0405	0.1338	0.0907	0.0517	0.1498	0.0079	0.0016	0.0370	0.09	Yes
HCR_PH	0.0515	0.0364	0.0705	0.0594	0.0161	0.2103	0.0509	0.0347	0.0716	0.86	No
HCR_RO	0.0071	0.0044	0.0109	NA	NA	NA	0.0071	0.0044	0.0109	NA	NA
LOP_HOR	0.0161	0.0074	0.0297	NA	NA	NA	0.0161	0.0074	0.0297	NA	NA
LOP_PH1	0.0029	0.0015	0.0050	0.0075	0.0042	0.0123	0.0005	0.0002	0.0011	0.06	Yes
LOP_PH2	0.0012	0.0007	0.0019	0.0024	0.0014	0.0040	0.0007	0.0002	0.0014	0.27	Yes
LOP_SP	0.0016	0.0003	0.0044	NA	NA	NA	0.0016	0.0003	0.0044	NA	NA
NFMF	0.0072	0.0058	0.0091	0.0072	0.0058	0.0091	NA	NA	NA	NA	NA

Table 8. Results on the sample means for mean flow and 90% confidence intervals for the global, pre-injunction and post-injunction means. Mean flow is reported in cfs. The ratio of pre-injunction to post-injunction flows is shown under Pre/Post. An alpha level of 0.1 was applied to evaluate whether there was a difference in the mean flow between pre- and post-injunction TE experiments. In cases where results were statistically significant, the 90% intervals for mean flow did not overlap and the ratio of post injunction to pre-injunction sample means was less than about 0.5. For all other RSTs where no difference was found in mean flow between pre-injunction and post-injunction TE experiments the ratio of mean flows ranged from 0.77-0.96. LB: lower bound; UB: upper bound.

RST Location	Global Mean	LB	UB	Pre-Injunction mean	LB	UB	Post-Injunction mean	LB	UB	Ratio post/pre	Sig Dif?
BCL	2252	1914	2626	NA	NA	NA	2252	1914	2626	NA	NA
BRE	353	274	446	471	353	614	223	162	299	0.47	Yes
CGR_HOR	632	572	697	646	582	714	551	378	697	0.85	No
CGR_PH	597	513	690	746	646	855	379	284	493	0.51	Yes
CGR_RO	867	765	978	1158	828	1578	815	711	927	0.70	No
DET_HOR	719	562	903	1061	732	1497	529	453	613	0.50	Yes
DEX	2754	2328	3229	NA	NA	NA	2754	2328	3229	NA	NA
FCR_HOR	3.5	3.2	3.8	NA	NA	NA	3.5	3.2	3.8	NA	NA
FCR	591	409	818	623	429	869	522	180	1184	0.84	No
FOS_HOR	414	260	619	NA	NA	NA	414	261	618	NA	NA
GPR_HOR	1.7	1.1	2.5	NA	NA	NA	1.7	1.1	2.5	NA	NA
GPR	1519	1132	1988	NA	NA	NA	1519	1132	1988	NA	NA
HCR_HOR	10.2	9.8	10.6	10.3	9.8	10.7	9.8	8.6	11.2	0.96	No
HCR_PH	590	488	706	698	340	1417	582	473	708	0.83	No
HCR_RO	846	667	1053	NA	NA	NA	846	667	1053	NA	NA
LOP_HOR	2143	1669	2700	NA	NA	NA	2143	1669	2700	NA	NA
LOP_PH1	3300	2694	3989	3882	2531	5687	2990	2387	3688	0.77	No
LOP_PH2	3224	2604	3934	3725	2214	5883	2990	2387	3688	0.80	No
LOP_SP	2785	2241	3414	NA	NA	NA	2785	2241	3414	NA	NA
NFMF	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 9. Akaike information criterion (AICc) results for each alternative model for predicting trapping efficiency at each of the 20 RST sites where TE experiments were conducted. AICc results were one of considerations in selecting between the mean (i.e., null), exponential (Exp), exponential plus constant (Exp_PC), and Beta regression models. R-squared values, and plots of model fits and residual patterns from model fits were also considered. A statistical test at the alpha = 0.1 level, considering whether the 90% confidence intervals overlapped or not for the pre-injunction and post-injunction means for TE, was applied to test whether the pre-injunction mean for TE was different from post-injunction mean for TE. If the 90% confidence intervals for the means did not overlap, the model in which the pre-injunction mean was considered to be different from the post-injunction (PP_mean) mean was adopted. Otherwise, a model based on the sample mean from the combined pre-injunction and post-injunction trials was used (i.e., global mean or G_mean). Due to the high between trial variability in TE estimates at a given site and relatively low number of TE trials at most sites, statistical power and R-squared values are expected to be relatively low even when some non-null model could actually be present. See Table 7 for results on the sample means for TE and confidence intervals for the pre-injunction and post-injunction means. Table continues on following pages.

RST	Model	R^2	AICc	Delta AICc	Selected Model
BCL	G_mean	NA	-111.0	6.5	
	PP_mean	NA	-111.0	6.5	
	Beta_R	0.19	-116.3	1.2	
	Exp	0.20	-116.6	0.9	
	Exp_PC	0.23	-117.5	0.0	Exp_PC
BRE	G_mean	NA	-59.0	0.4	G_mean
	PP_mean	NA	-59.4	0.0	
	Beta_R	0.00	-56.5	2.9	
	Exp	0.00	-56.5	2.9	
	Exp_PC	0.00	-55.7	3.7	
CGR_HOR	G_mean	NA	-429	81.5	
	PP_mean	NA	-438	73.2	
	Beta_R	0.37	-484	26.8	
	Exp	0.40	-492	18.9	
	Exp_PC	0.49	-511	0.0	Exp_PC
CGR_PH	G_mean	NA	-82	3.0	
	PP_mean	NA	-85	0.0	
	Beta_R	0.12	-85	0.5	
	Exp	0.12	-85	0.5	Exp
	Exp_PC	0.12	-84	1	
CGR_RO	G_mean	NA	-149.6	0.0	G_mean
	PP_mean	NA	-148.5	1.0	
	Beta_R	0.00	-147.1	2.5	
	Exp	0.00	-147.3	2.2	
	Exp_PC	0.00	-147.0	2.6	
DET_HOR	G_mean	NA	-53.1	3.3	
	PP_mean	NA	-56.4	0.0	
	Beta_R	0.073	-51.4	5.0	

RST	Model	R^2	AICc	Delta AICc	Selected Model
	Exp	0.073	-51.4	5.0	Exp
	Exp_PC	0.072	-50.1	6.3	
DEX	G_mean	NA	-171.4	0.0	G_mean
	PP_mean	NA	-171.4	0.0	
	Beta_R	0.000	-169.0	2.4	
	Exp	0.00	-169.1	2.3	
	Exp_PC	0.00	-168.6	2.8	
FCR_HOR	G_mean	NA	-24.0	0.0	G_mean
	PP_mean	NA	-22.0	2.0	
	Beta_R	NA	NA	NA	
	Exp	0.00	-22.0	2.0	
	Exp_PC	NA	NA	NA	
FCR	G_mean	NA	-93.4	19.9	
	PP_mean	NA	-113.3	0.0	PP_mean
	Beta_R	0.00	-87.5	25.8	
	Exp	0.00	-91.0	22.3	
	Exp_PC	0.00	-90.4	22.9	
FOS_HOR	G_mean	NA	-39.10	0.00	G_mean
	PP_mean	NA	-39.10	0.00	
	Beta_R	0.13	-38.77	0.33	
	Exp	0.00	-36.47	2.63	
	Exp_PC	0.00	-35.64	3.46	
GPR_HOR	G_mean	NA	-68.34	0.00	G_mean
	PP_mean	NA	-68.34	0.00	
	Beta_R	NA	NA	NA	
	Exp	NA	NA	NA	
	Exp_PC	NA	NA	NA	
GPR	G_mean	NA	-92.4	0.0	G_mean
	PP_mean	NA	-92.4	0.0	
	Beta_R	0.00	-85.9	6.5	
	Exp	0.00	-89.6	2.8	
	Exp_PC	0.00	-88.3	4.1	
HCR_HOR	G_mean	NA	-15.3	0.0	
	PP_mean	NA	-15.2	0.1	PP_mean
	Beta_R	NA	NA	NA	
	Exp	NA	NA	NA	
	Exp_PC	NA	NA	NA	
HCR_PH	G_mean	NA	-52.1	0.0	G_mean
	PP_mean	NA	-49.7	2.4	
	Beta_R	0.00	-48.7	3.4	
	Exp	0.00	-49.0	3.1	
	Exp_PC	0.00	-47.7	4.4	

RST	Model	R^2	AICc	Delta AICc	Selected Model
HCR_RO	G_mean	NA	-143.6	0.0	G_mean
	PP_mean	NA	-143.6	0.0	
	Beta_R	0.00	-139.6	4.0	
	Exp	0.00	-140.3	3.4	
	Exp_PC	0.00	-140.5	3.1	
LOP_HOR	G_mean	NA	-79.1	0.0	G_mean
	PP_mean	NA	-79.1	0.0	
	Beta_R	0.04	-77.3	1.8	
	Exp	0.00	-76.6	2.5	
	Exp_PC	0.00	-75.7	3.4	
LOP_PH1	G_mean	NA	-177.7	39.1	
	PP_mean	NA	-216.8	0.0	PP_mean
	Beta_R	0.08	-177.3	39.6	
	Exp	0.00	-175.3	41.5	
	Exp_PC	0.00	-174.6	42.2	
LOP_PH2	G_mean	NA	-217.3	4.4	
	PP_mean	NA	-221.8	0.0	PP_mean
	Beta_R	0.08	-218.6	3.2	
	Exp	0.00	-214.9	6.9	
	Exp_PC	0.00	-214.2	7.6	
LOP_SP	G_mean	NA	-108.11	0.00	G_mean
	PP_mean	NA	-108.11	0.00	
	Beta_R	NA	NA	NA	
	Exp	0.00	-105.35	2.76	
	Exp_PC	0.00	-104.05	4.07	
NFMF	G_mean	NA	-20.93	0.00	G_mean
	PP_mean	NA	-20.93	0.00	
	Beta_R	NA	NA	NA	
	Exp	NA	NA	NA	
	Exp_PC	NA	NA	NA	

Table 10. Details on models and parameter values to apply for TE adjustments to RST catch records that are to be used in further analysis of potential effects of injunction measures on fish passage metrics of interest. Standard errors in parameter estimates are shown in parentheses. Standard errors for Exponential (Exp) and Exponential plus constant (Exp_PC) parameter estimates were obtained by fitting these models in a Bayesian statistical framework using WinBUGS software (Lunn et al. 2000) and with the use of uniform priors for the estimated parameters.

RST Location	Model selected	Mean pre-injunction	Mean post-injunction	Global mean	Nz	Z	mn
BCL	Exp_PC				0.24 (0.28)	-1.19 (2.21)	0.033 (0.010)
BRE	G_mean			0.064 (0.011)			
CGR_HOR	Exp_PC				0.303 (0.195)	-6.44 (1.60)	0.0338 (0.0020)
CGR_PH	Exp				0.173 (0.043)	-0.706 (0.369)	
CGR_RO	G_mean			0.055 (0.006)			
DET_HOR	Exp				0.0722 (0.052)	-0.52 (0.53)	
DEX	G_mean			0.0066 (0.0025)			
FCR_HOR	G_mean			0.01737 (0.0053)			
FCR	PP_mean	0.0419 (0.0094)	0.0044 (0.0030)				
FOS_HOR	G_mean			0.059 (0.017)			
GPR_HOR	G_mean			0.0004 (0.0003)			
GPR	G_mean			0.0132 (0.0023)			
HCR_HOR	PP_mean	0.0907 (0.023)	0.0079 (0.0377)				
HCR_PH	G_mean			0.0515 (0.0097)			
HCR_RO	G_mean			0.0071 (0.0019)			
LOP_HOR	G_mean			0.0161 (0.0067)			
LOP_PH1	PP_mean	0.0075 (0.0022)	0.00048 (0.00029)				
LOP_PH2	PP_mean	0.00245 (0.0069)	0.00065 (0.00034)				
LOP_SP	G_mean			0.00158 (0.0013)			
NFMF	G_mean			0.00724 (0.0003)			

A histogram of residuals from the fit of the Exp_PC model for the Cougar Head of Reservoir RST shows that the frequency distribution of residuals does not appear to deviate from a bell-shaped normal type distribution (Figure 12). However, a plot of residuals versus predicted TE shows that the spread of residuals may increase with predicted TE values, suggesting that some other likelihood function than the normal distribution could be considered to account for potential heteroskedasticity in residuals (Figure 12). Both the fitted Exponential and Beta regression models underpredicted TEs under the lowest and higher mean flows (Figure 9) and had higher AICc values.

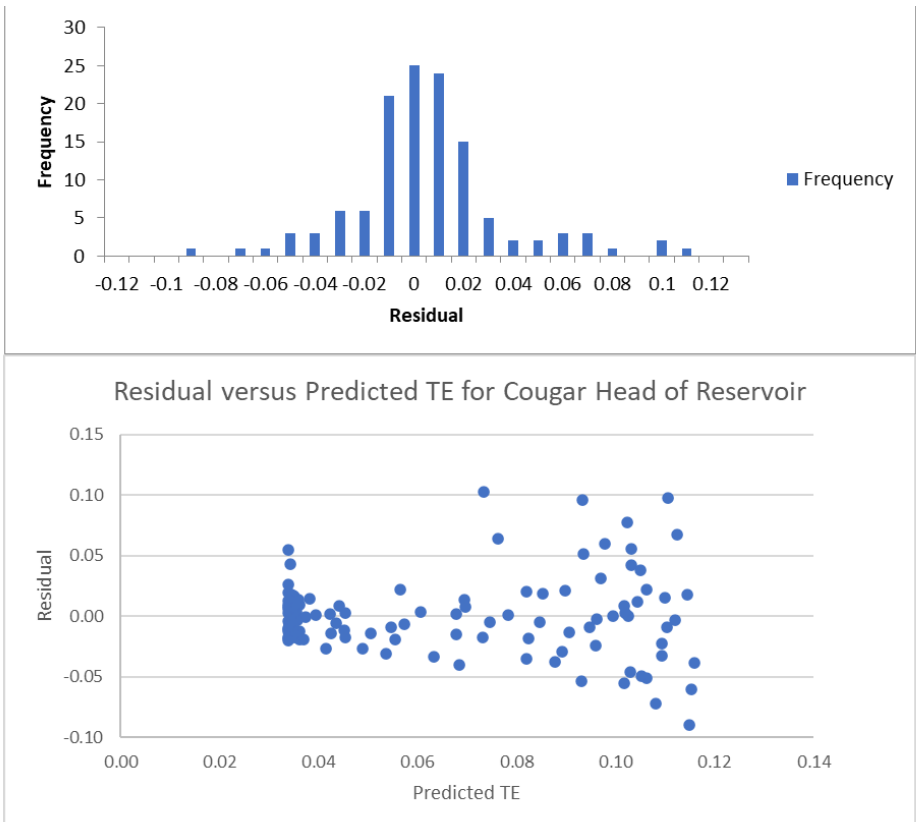

Figure 12. Model fit diagnostics for the fit of the exponential plus constant model to TE data for the Cougar HOR RST. Top panel: histogram of residuals from the fit of the Exp_PC model for the Cougar HOR RST. Bottom panel: plot of residuals versus predicted TE from the Exp_PC model fit.

The Exp model was selected for the Cougar PH and Detroit HOR RSTs. When the Exp_PC model was fitted the maximum likelihood estimate for the base mean parameter was zero for both of these RST sites, but the fitted model still showed a pronounced decay in predicted TE with increase in mean flow (Figure A 2 and Figure A 3). For the Detroit Head of Reservoir RST, the AICc was lowest for the mean models. However, the Exp model fit was within 1.7 AICc units of the global mean model and, if the exponential model were correct, the mean models would lead to under-prediction of TE at low mean flow and over-prediction at higher mean flows (Figure A 3).

For the other RSTs for which there was sufficient data to fit models, the fitted models were rejected in favour of either the global mean model (for 12 RSTs) and pre- and post-implementation mean TE model (for four RSTs; Table 9, Table 10, Figure A 3).

Growth analysis

Characterizing growth for specific site-year combinations proved challenging due to limited length ranges across a wide range of days of year (DOY). A diverse length range at DOY is essential for obtaining reliable growth estimates with low uncertainty. The absence of larger individuals limits the model's ability to characterize maximum potential length and growth rate, while a lack of smaller individuals presents similar issues. Interpretations must consider these limitations. Estimated growth rate and asymptotic length for above and below-dam RSTs (including confidence intervals on estimates), are presented in a series of tables in "Appendix C: Estimated growth parameters from above- and below-dam RSTs".

In a few instances, the data effectively characterized growth and maximum potential length (e.g., Figure 13; see Detroit, "DET-Above" and Foster, "FOS-Above"). For above-dam data, the mean growth rate (B) at DET was 0.02 mm/day with an upper asymptote (L_u) of 131 mm in the pre-injunction period, while for FOS, the B estimate was 0.025 mm/day with estimated L_u = 120 mm. The combined B and L_u across years and sites were 0.019 and 140 mm, respectively (Figure 13, Figure 14). There was insufficient data post-injunction to compare with pre-injunction growth.

For below-dam data, FOS exhibited a growth rate of 0.027 mm/day and L_u of 151 mm during the pre-injunction period. CGR had a lower growth rate of 0.013 mm but a higher L_u of 160 mm. Notably, NS showed higher L_u values (L_u = 189 mm, B = 0.016). The combined B and L_u across years and sites below the dam were 0.018 and 174 mm, respectively (Figure 15, Figure 16). Again, there were not enough data post-injunction for a reliable comparison with pre-injunction years.

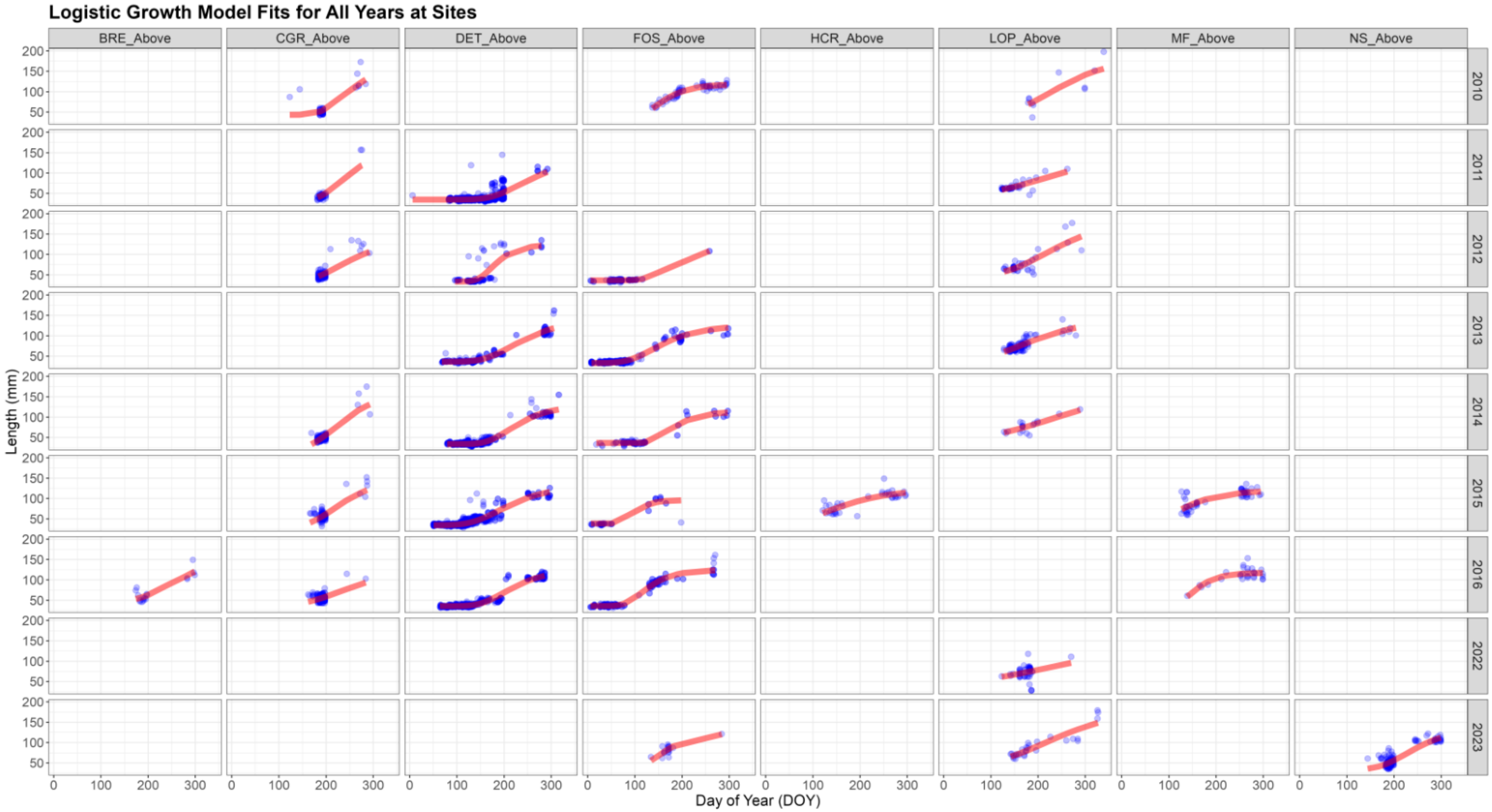

Figure 13. Fitted logistic growth models for juvenile Chinook salmon, plotted against Day of Year (DOY) and Length (mm). The scatter points represent the observed data, while the red lines indicate the fitted logistic growth curves for each site and year. Each panel corresponds to a specific combination of year and RST site for records collected from above-dam RSTs.

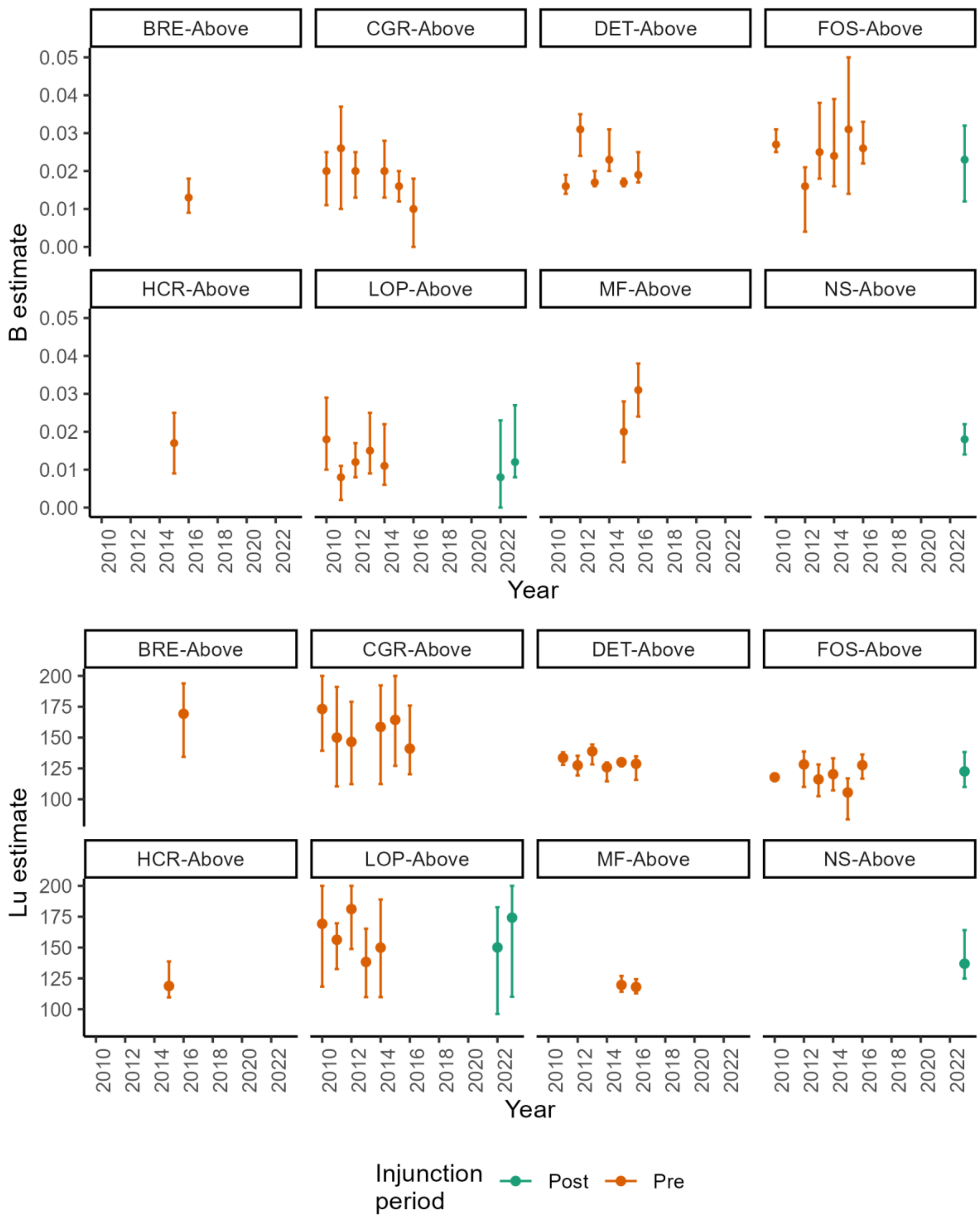

Figure 14. Growth rate parameter (B, upper plot) and asymptotic length (Lu) estimates for juvenile Chinook salmon across different sites and years for RSTs above dams. Each point represents the estimated growth rate for a specific year, with the corresponding vertical error bars indicating the 95% confidence intervals derived from bootstrap resampling.

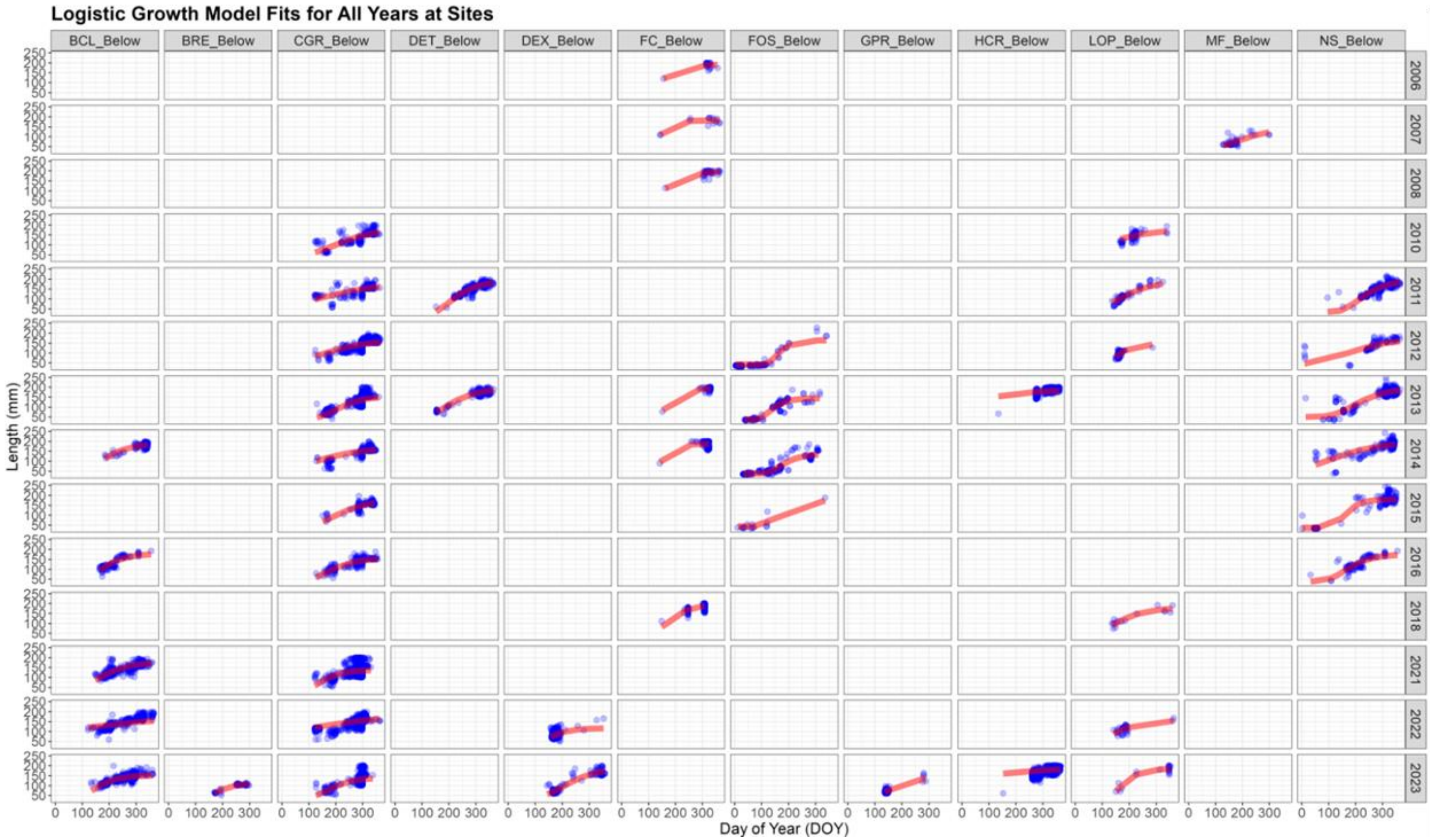

Figure 15. Plot of the fitted logistic growth models for juvenile Chinook salmon, plotted against Day of Year (DOY) and Length (mm). The scatter points represent the observed data, while the red lines indicate the fitted logistic growth curves for each site and year. Each panel corresponds to a specific combination of Year and Site, for data below dams.

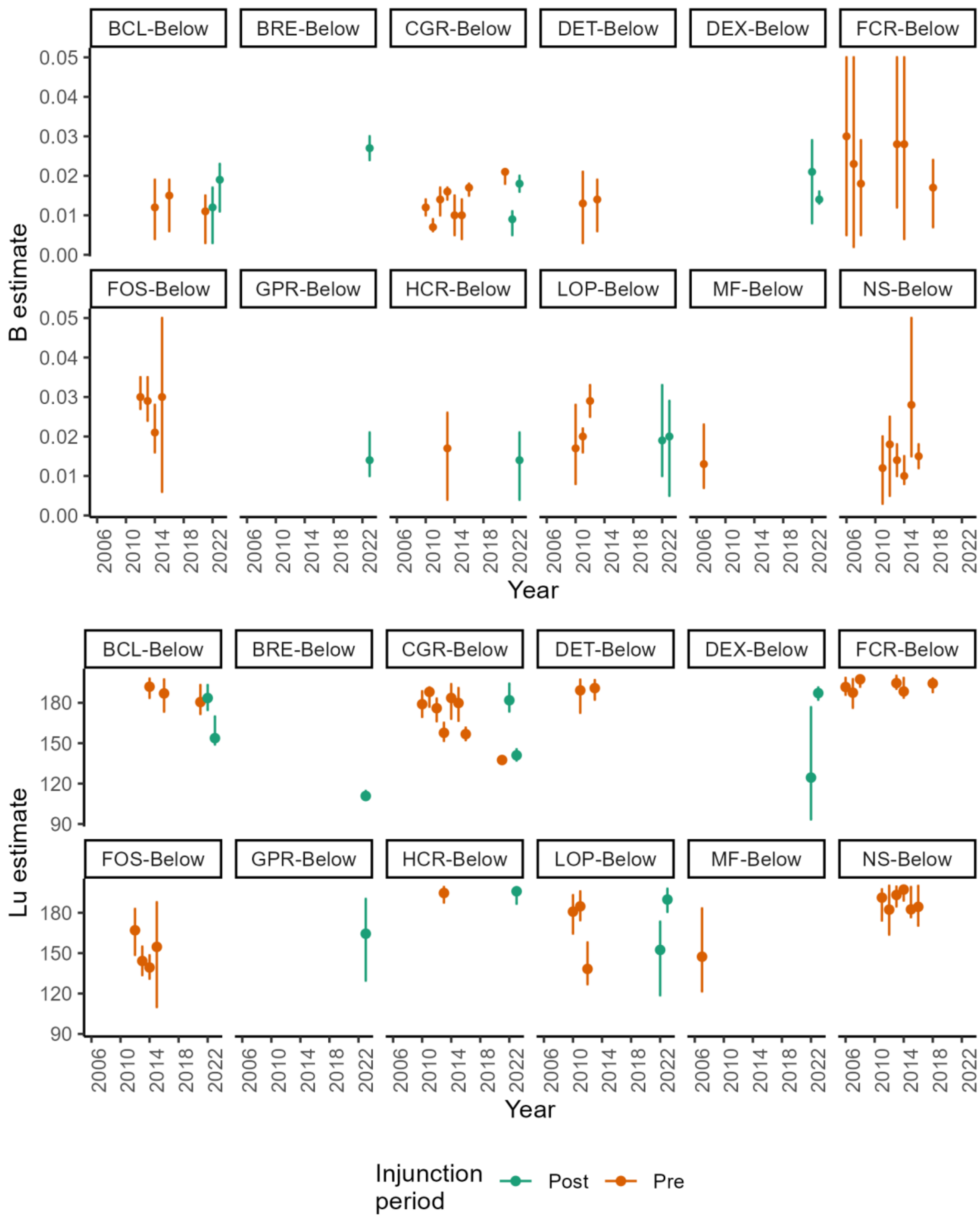

Figure 16. Plot of the growth rate (B) and asymptote length (Lu) estimates for juvenile Chinook salmon across different sites and years for data below dams. Each point represents the asymptote length for a specific year, with the corresponding vertical error bars indicating the 95% confidence intervals derived from bootstrap resampling.

Run timing and fork length analyses

In many cases it appears that there might be different run timings before and after the injunction was implemented. This is suggested from both looking at the catch rates and the direct observation in the RST data. However, since there have not been many years post injunction, some care may need to be taken in the interpretation of these results. It may be a judgement call about how big of difference is meaningful and changes in passage survival and health of fish may be more important to meeting the goals of injunction measures than changes in run timing.

For each of the Chinook juvenile migration types, we produced figures showing the distribution of catch rates by week (Figures 17-20), the distribution of median fork lengths by week, (Figures 21-24) and the distribution of raw counts (i.e., unadjusted by trap efficiency) by week (Figures 25-28). In cases where a statistical test was performed there had to be at least 10 samples pre and post injunction only figures with a p-value met that criterion. These results show in which weeks there are data at each site and aim to highlight differences between pre and post injunction time periods.

Catch Rate Analyses

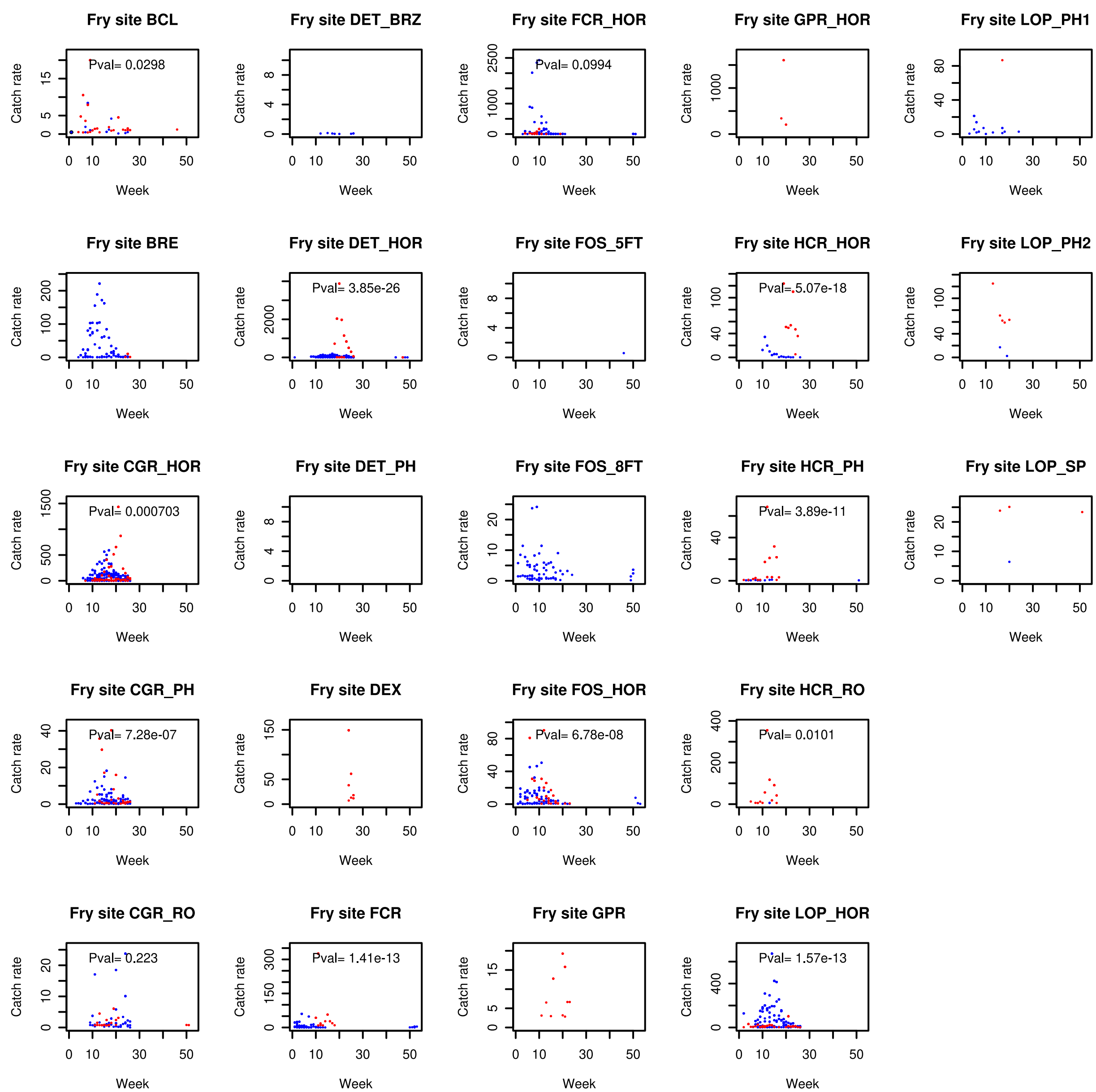

Figure 17. Fry catch rates by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

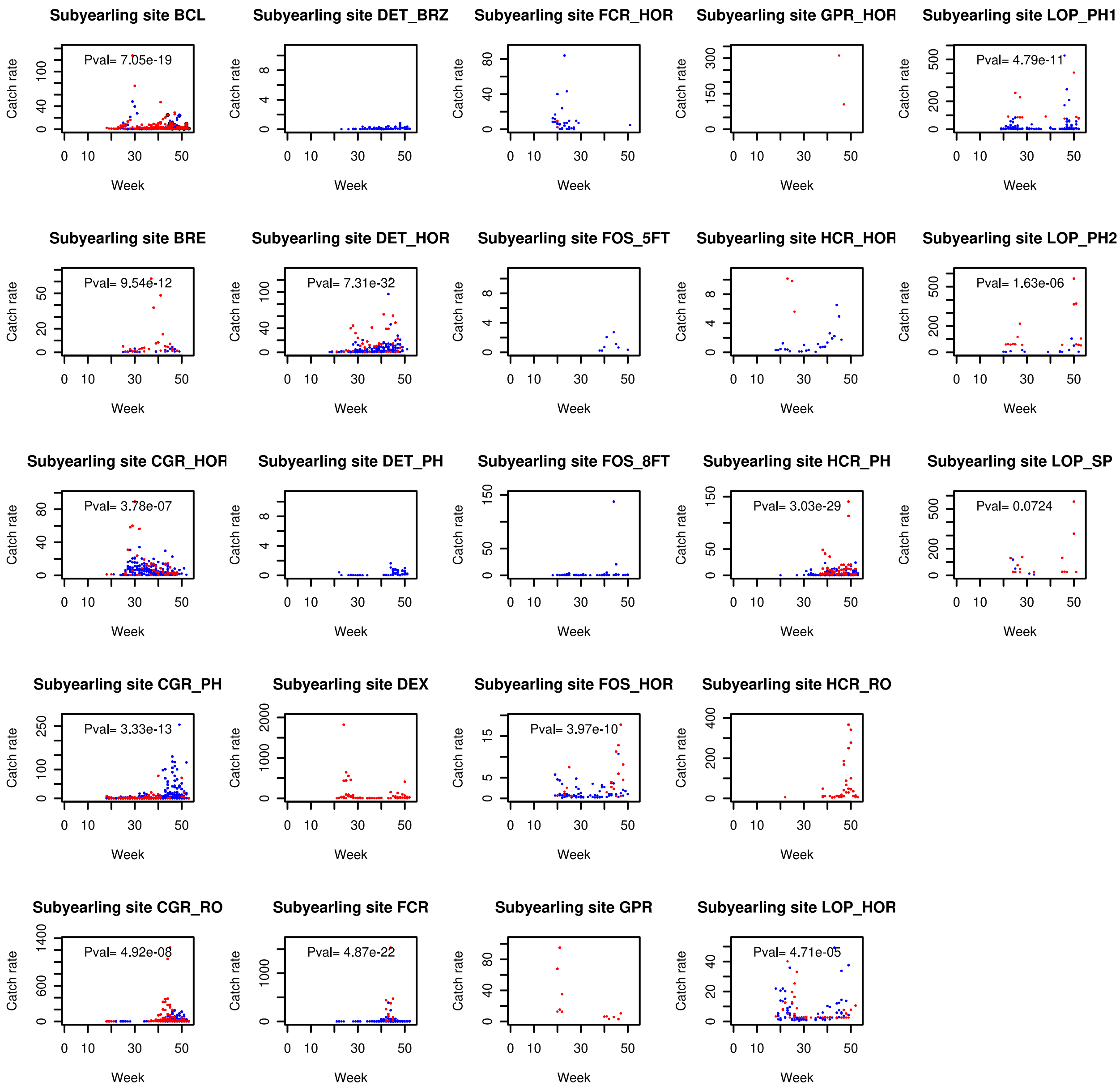

Figure 18. Subyearling catch rates by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

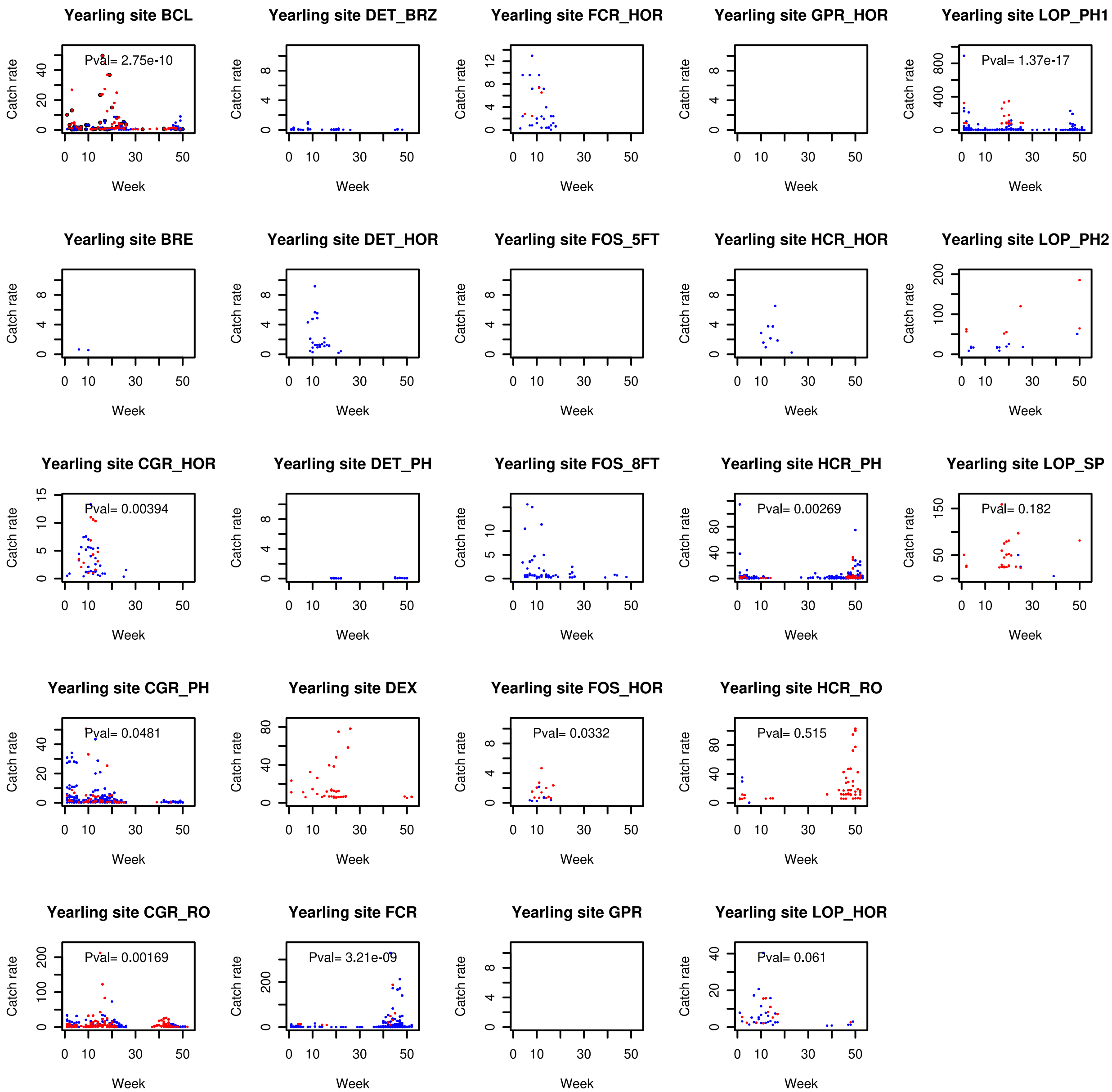

Figure 19. Yearling catch rates by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

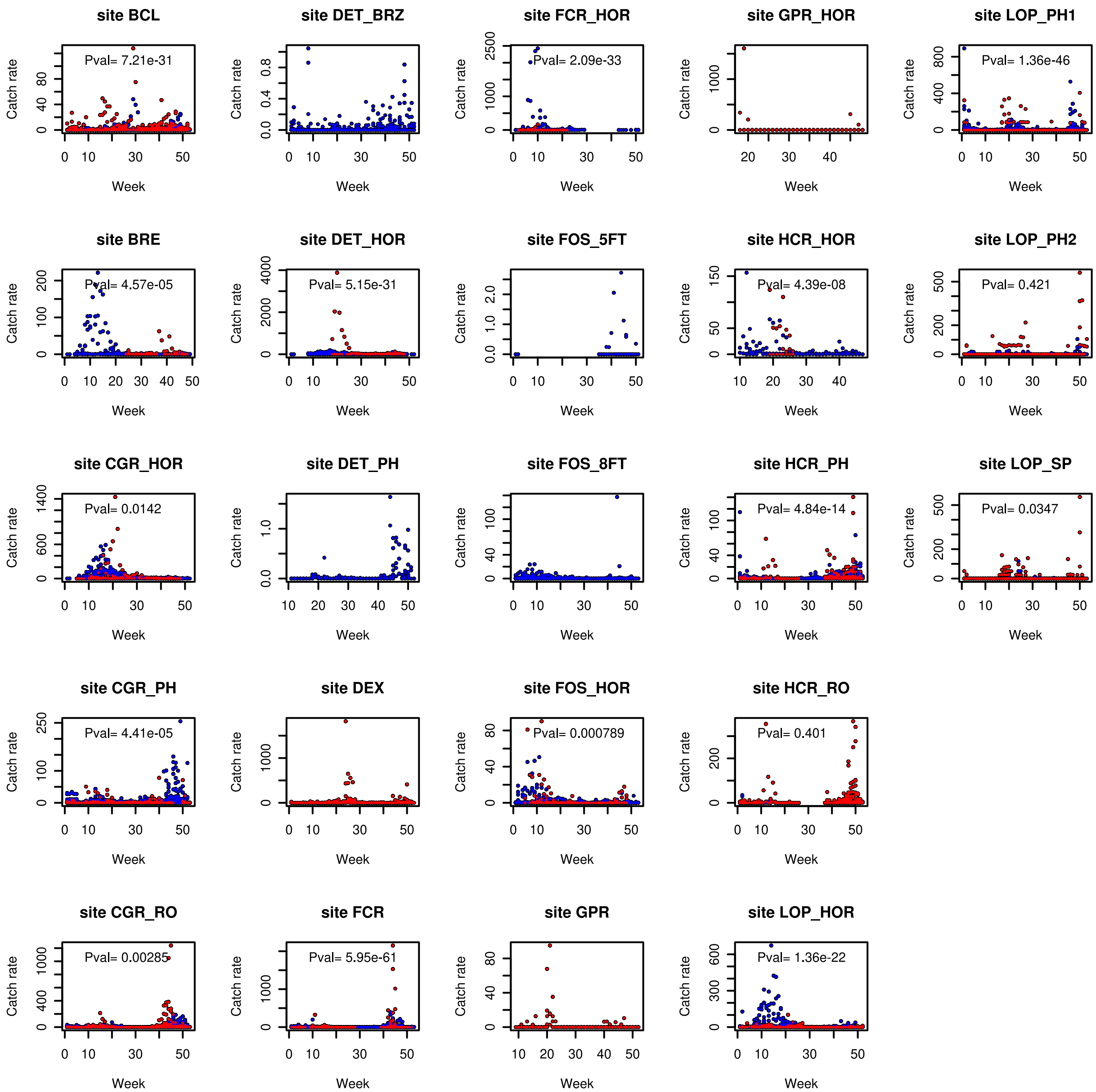

Figure 20. All migrant types catch rates by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

Fork Length Analyses

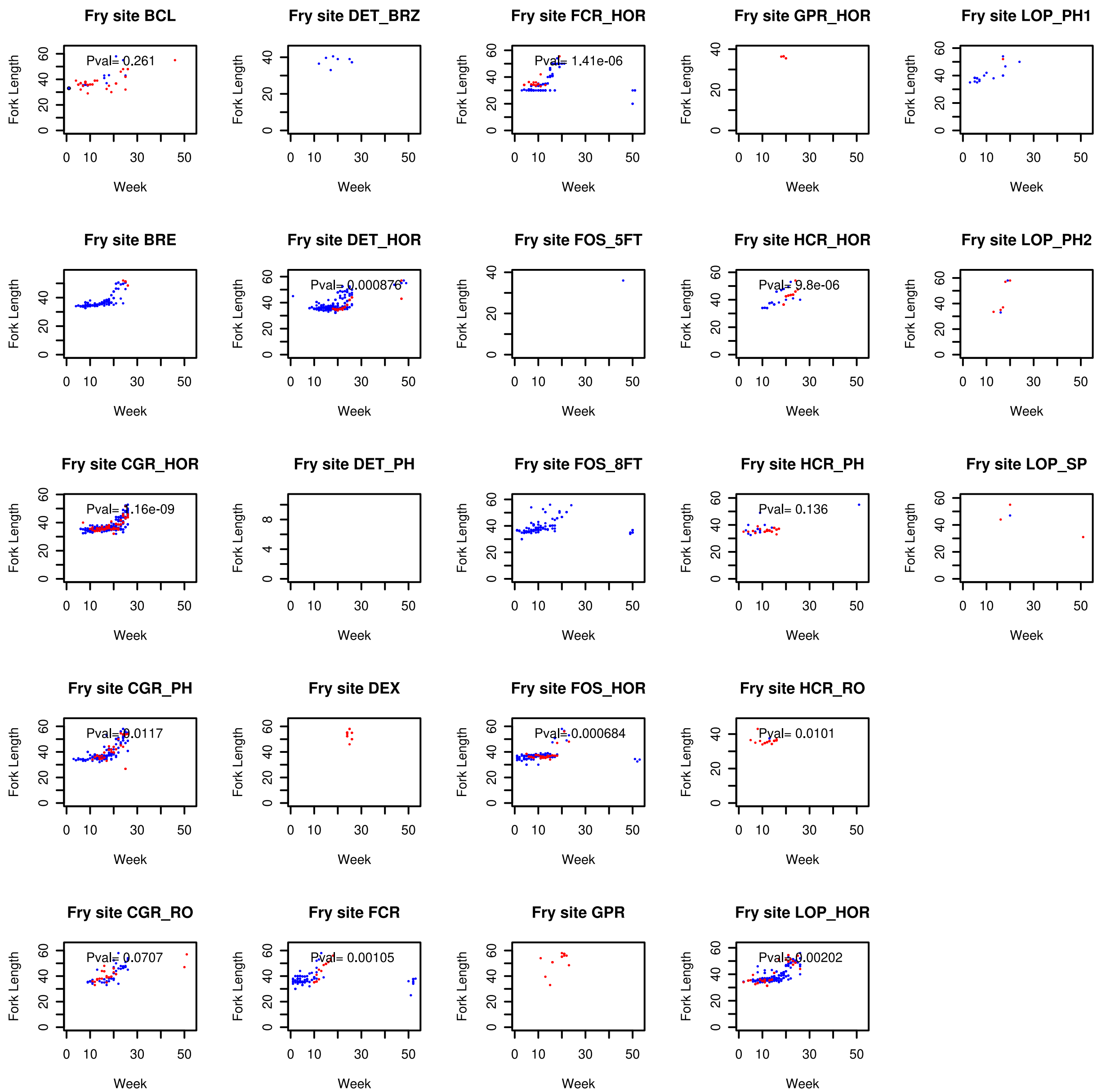

Figure 21. Fry fork lengths by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

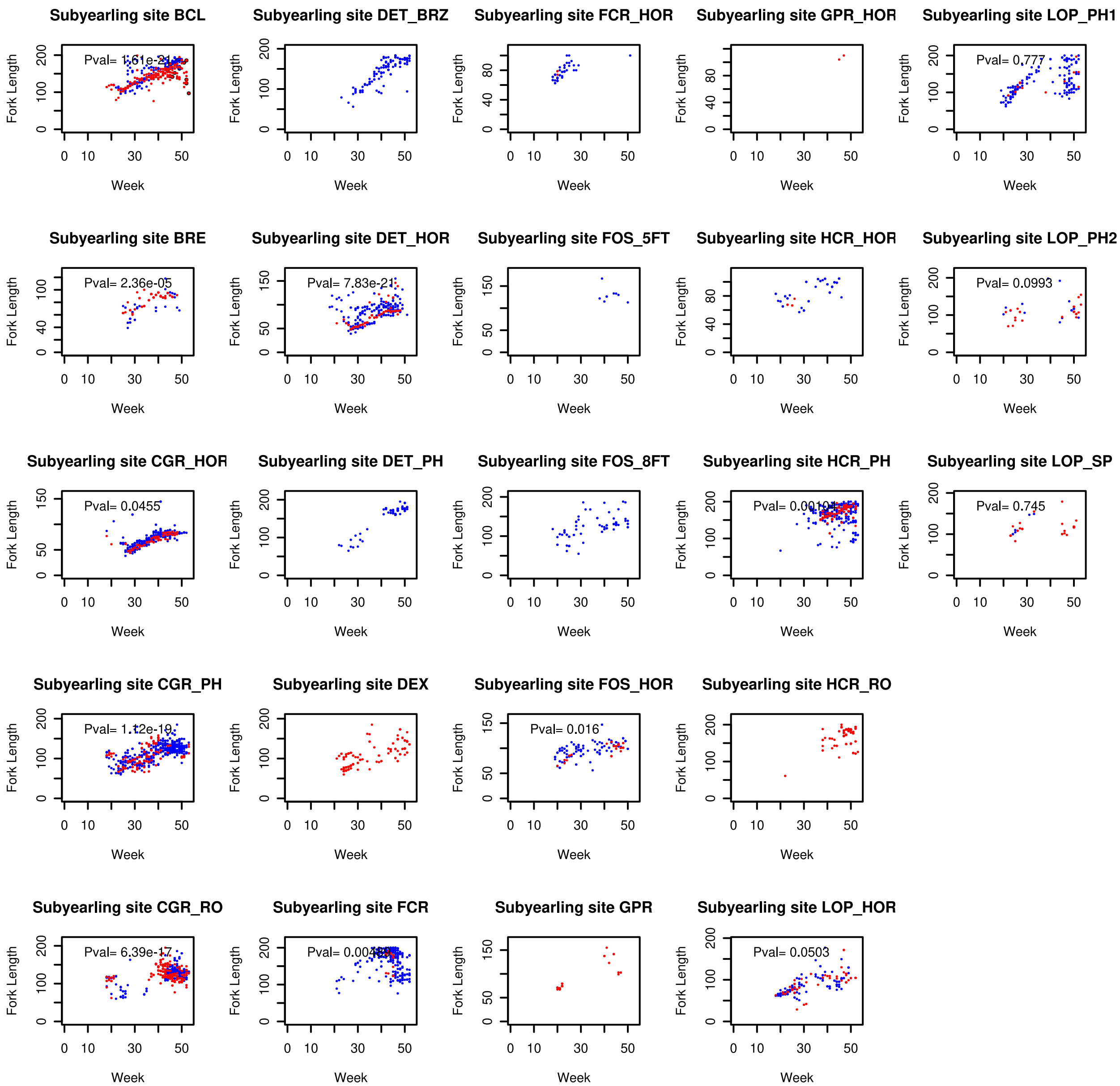

Figure 22. Subyearling fork lengths by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

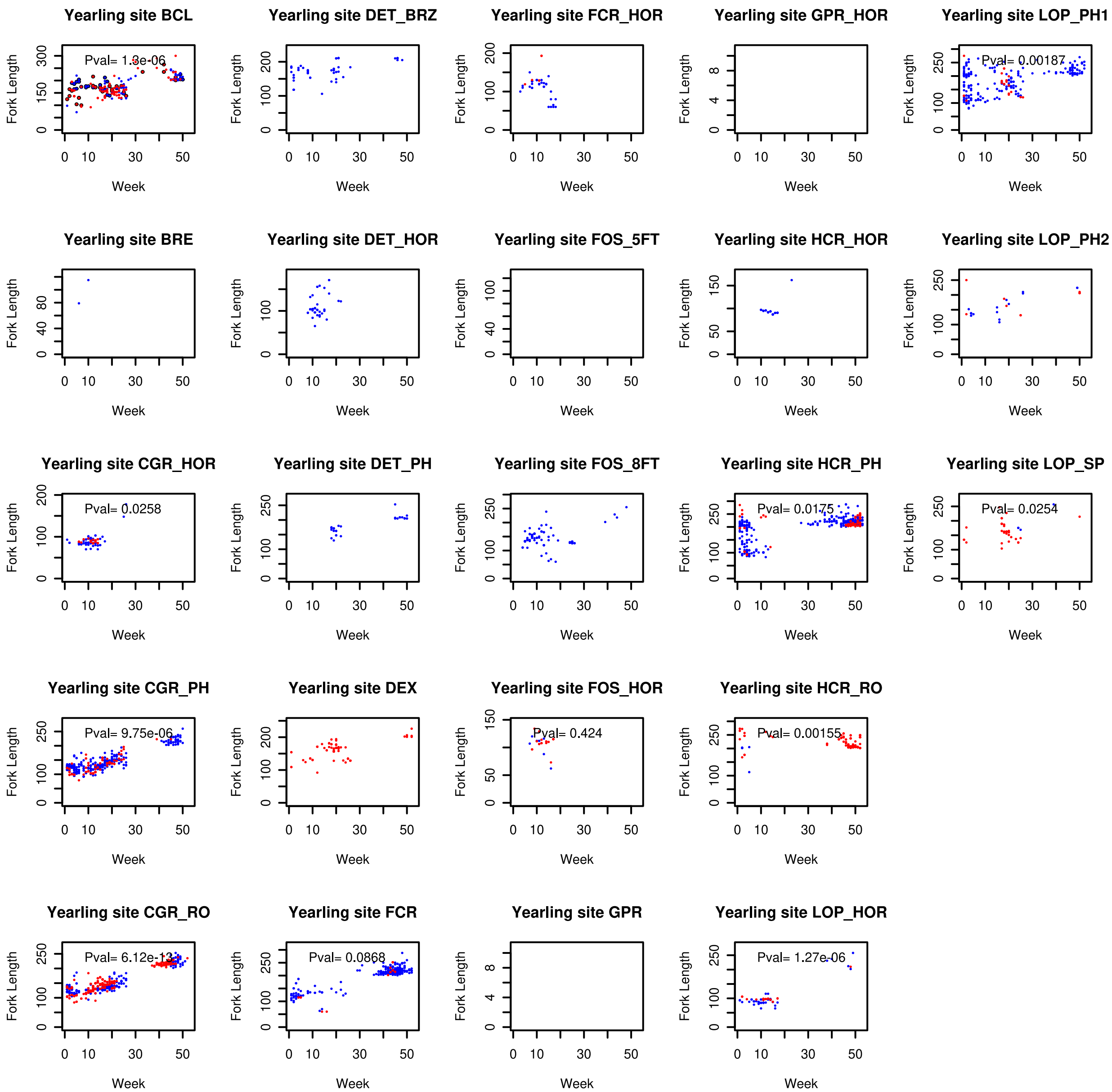

Figure 23. Yearling fork lengths by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

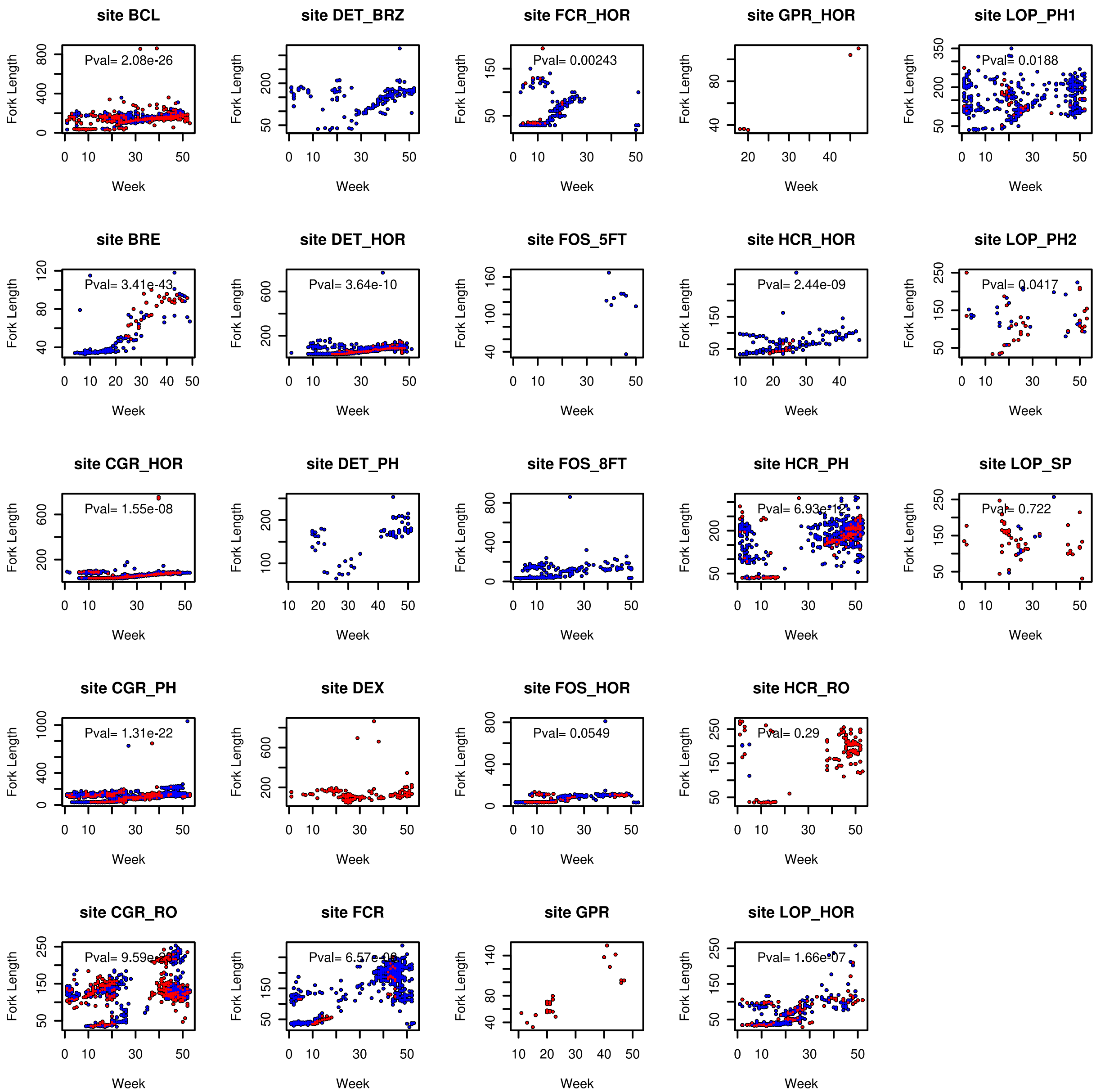

Figure 24. Aggregated fork lengths by week and RST site. Blue dots are pre injunction, red dots are post injunction. The P-value is the result of a Kolmogorov-Smirnov test.

Sampling distribution by week not adjusted by TE

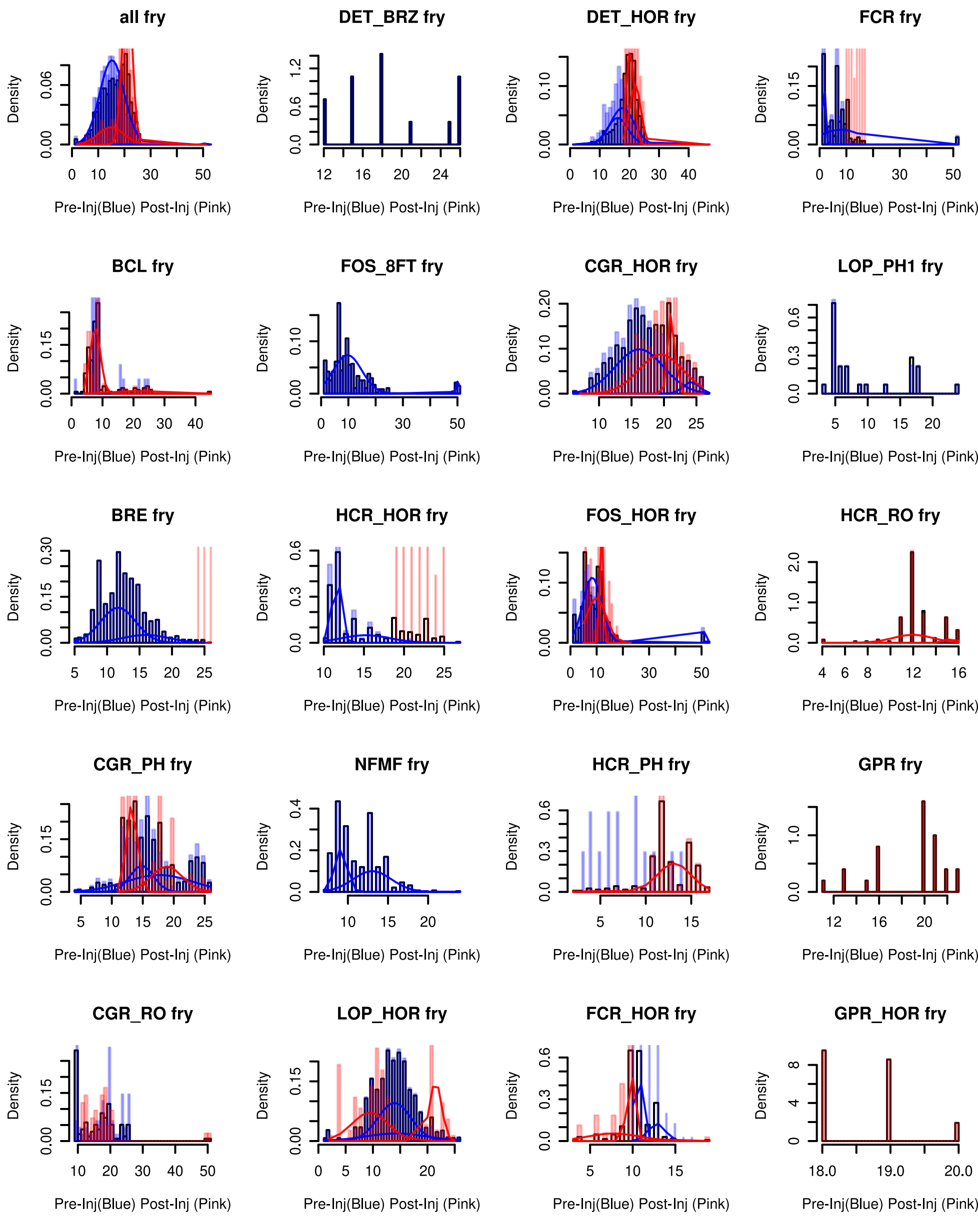

Figure 25. Distribution of raw counts of fry by week and RST site. The curves are mixture models to help identify periods of high counts.

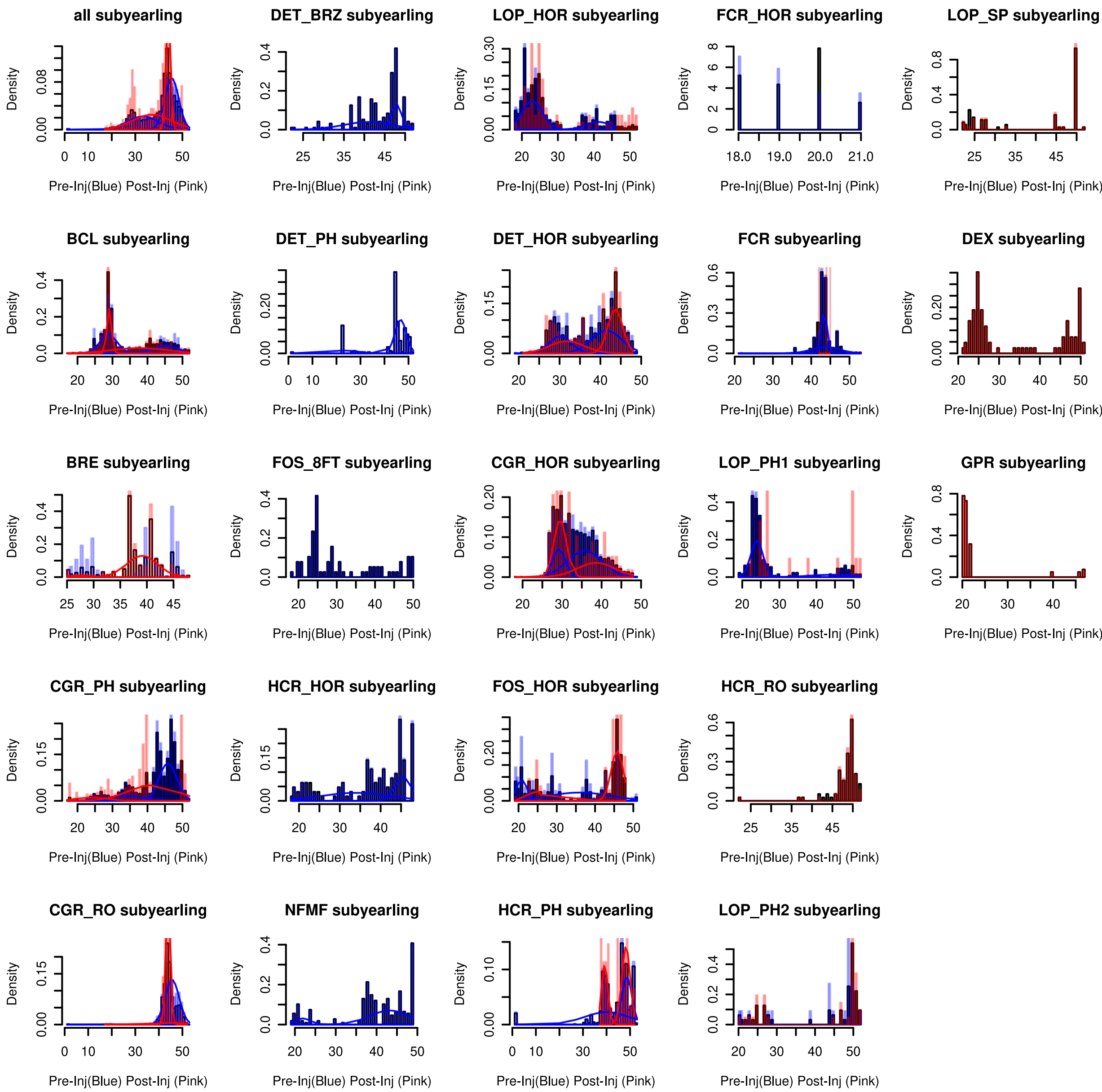

Figure 26. Distribution of raw counts of subyearlings by week and RST site. The curves are mixture models to help identify periods of high counts.

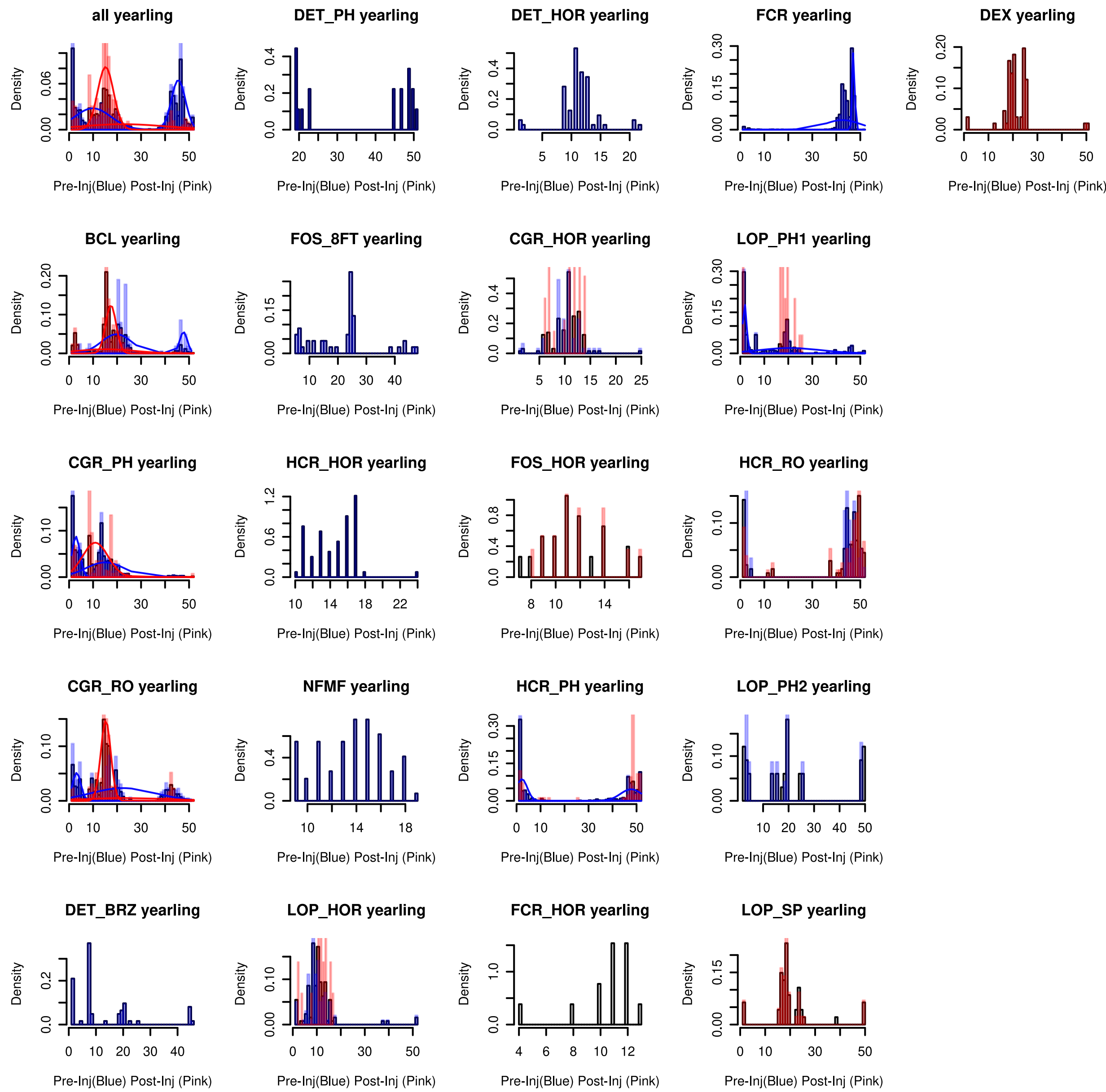

Figure 27. Distribution of raw counts of yearlings by week and RST site. The curves are mixture models to help identify periods of high counts.

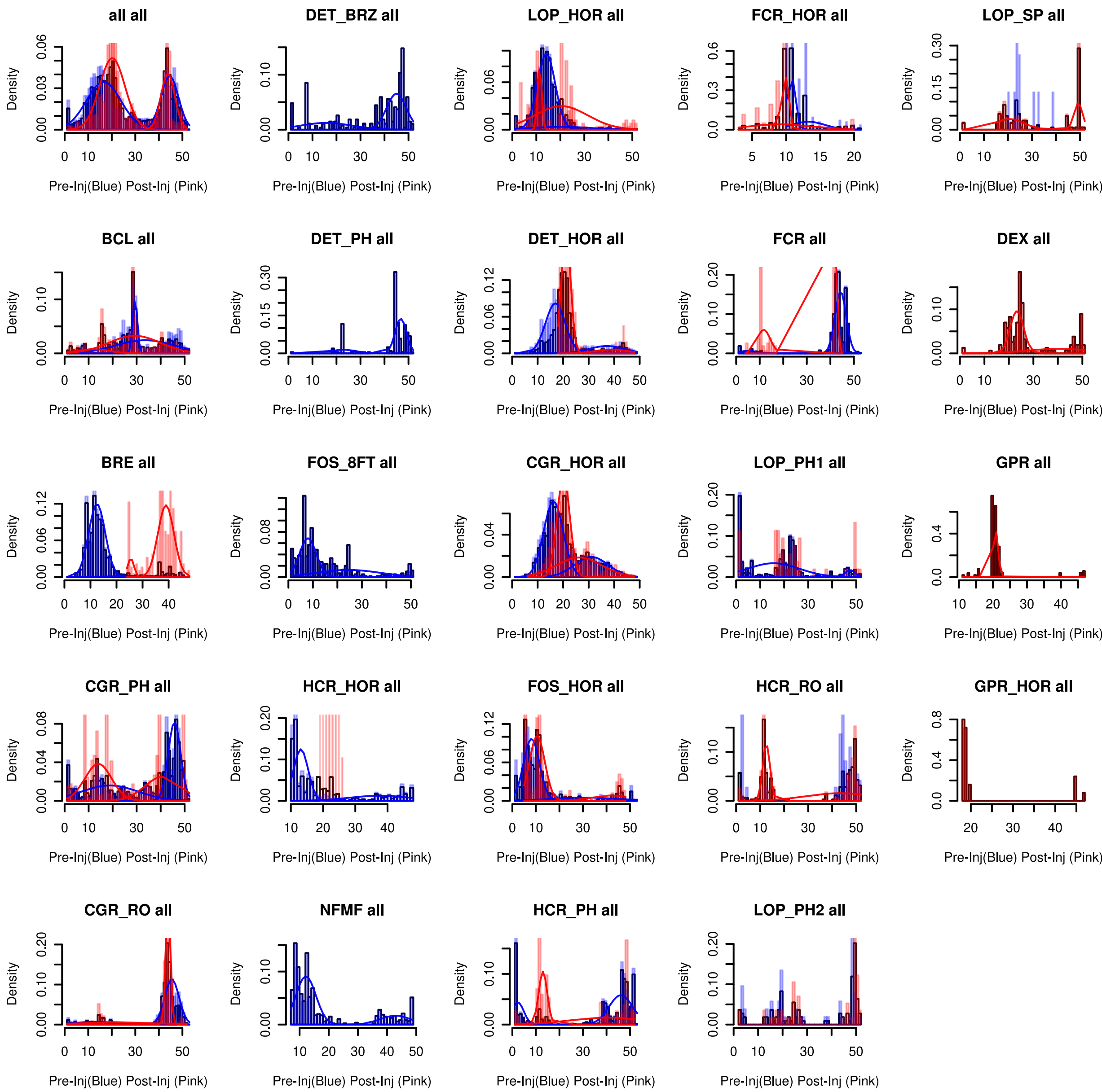

Figure 28. Distribution of raw counts of all migrant types by week and RST site. The curves are mixture models to help identify periods of high counts.

Fish injury analysis: Testing for injunction effect on injury rates

Almost all injury types were recorded below-dams by all operators; the only injury codes related to injuries likely to be sustained during downstream dam passage that were removed from this analysis included loss of equilibrium, as this injury type was only reported when USACE operated the RSTs. A summary of all reported injury categories at below-dam RST locations is shown in Table 11., which also includes injury reporting for sites with only pre- or post-injunction RST records (e.g., Green Peter, GPR, traps below Foster dam, FOS…, and Dexter, DEX).

Quasi-binomial regressions of injury rate in each trap event at each RST site revealed varying patterns depending on injury type and location. Generally speaking, at sites with a significant injunction effect, post-injunction injury reporting was higher than what was reported pre-injunction.

Considering the most prevalent injury type, body injury, all sites except for the RO channel RST at Hills Creek had higher reporting of body injury post-injunction (see Figure 29; the proportion of fish reported to have body injuries at the Hills Creek RO RST was not significantly different between injunction periods). At these sites, post-injunction body injury reporting was significantly higher when EAS operated the RSTs except for those in the Lookout Point powerhouse channel. Similar patterns were seen for head injuries; post-injunction head injury reporting was significantly higher (where significance is indicated by a p-value < 0.05) at four of the nine below-dam RST locations in this analysis (all other sites had non-significant injunction effects; Figure 30). At sites with significant injunction period effects on head injury reporting except for Lookout Point’s PH1 trap (i.e., BCL, CGR RO, and HCR PH), there was also a significant effect of RST operator.

Table 11. Site by injunction period reporting of downstream dam passage related injuries at USACE-operated projects. RST records are either from the pre-injunction period or post-injunction period. The table summarizes both proportion and number of fish (in parentheses and italics) with a given injury type as well as the total number of fish processed and included in injury analysis (total n). Because an individual fish may have injuries falling into multiple categories, the sum of fish with body injuries may not equal the total fish count. Counts represent the raw counts of the number of fish captured in the RST during the pre- or post-injunction period and are not adjusted for trap efficiency.

RST	**Period**	**Total n.**	**Body/fin injury**	**Head injury**	**Internal**	**Body/head missing**	**Major descaling**	**Copepods**	**Eye damage/ missing**	**Gill/isthmus/ operculum injury**
BCL	Pre	*740*	0.1939 (*143*)	0.0014 (*1*)	0.1989 (*147*)	0.011 (*8*)	0.2127 (*157*)	0.7295 (*540*)	0.0431 (*32*)	0.0028 (*2*)
BCL	Post	*2599*	0.695 (*1806*)	0.0451 (*117*)	0.0303 (*79*)	0.0139 (*36*)	0.1927 (*501*)	0.759 (*1972*)	0.0643 (*167*)	0.1079 (*281*)
CGR PH	Pre	*12083*	0.201 (*2436*)	0.008 (*97*)	0.0115 (*140*)	0.0126 (*153*)	0.0219 (*264*)	0.349 (*4219*)	0.0132 (*160*)	0.0072 (*88*)
CGR PH	Post	*1986*	0.531 (*1055*)	0.0176 (*35*)	0.0316 (*63*)	0.006 (*12*)	0.0868 (*172*)	0.497 (*987*)	0.0289 (*57*)	0.0373 (*74*)
CGR RO	Pre	*7341*	0.519 (*3811*)	0.0213 (*156*)	0.0433 (*318*)	0.0044 (*32*)	0.174 (*1274*)	0.658 (*4833*)	0.0708 (*520*)	0.0579 (*425*)
CGR RO	Post	*10182*	0.841 (*8567*)	0.0324 (*330*)	0.0271 (*276*)	6e-04 (*6*)	0.208 (*2117*)	0.871 (*8867*)	0.097 (*988*)	0.141 (*1434*)
DET PH	Pre	*402*	0.0697 (*28*)	0.0025 (*1*)	0.0672 (*27*)	0.0075 (*3*)	0.102 (*41*)	0.8209 (*330*)	0.0348 (*14*)	0.005 (*2*)
DEX	Post	*1141*	0.8598 (*981*)	0.021 (*24*)	0.0079 (*9*)	9e-04 (*1*)	0.1227 (*140*)	0.0438 (*50*)	0.0219 (*25*)	0.0561 (*64*)
FCR	Pre	*6718*	0.0481 (*323*)	0.0077 (*52*)	0.0048 (*32*)	0.0077 (*52*)	0	0.0019 (*13*)	0.0156 (*105*)	0.0112 (*75*)
FCR	Post	*812*	0.2106 (*171*)	0.0123 (*10*)	0.0209 (*17*)	0.016 (*13*)	0.0628 (*51*)	0.2365 (*192*)	0.0283 (*23*)	0.1182 (*96*)
FOS 5FT	Pre	*17*	0.1765 (*3*)	0	0.0588 (*1*)	0	0	0	0.0588 (*1*)	0
FOS 8FT	Pre	*1039*	0.0202 (*21*)	0.001 (*1*)	0.0077 (*8*)	0.001 (*1*)	0.0106 (*11*)	0.0192 (*20*)	0.001 (*1*)	0.0029 (*3*)
GPR	Post	*112*	0.8571 (*96*)	0.1339 (*15*)	0.0893 (*10*)	0	0.2589 (*29*)	0.0625 (*7*)	0.1518 (*17*)	0.125 (*14*)
HCR PH	Pre	*3302*	0.1487 (*491*)	0.0236 (*78*)	0.0251 (*83*)	0.0491 (*162*)	0	0.0012 (*4*)	0.0485 (*160*)	0.0439 (*145*)
HCR PH	Post	*1400*	0.832 (*1165*)	0.1107 (*155*)	0.1757 (*246*)	0.0357 (*50*)	0.48 (*672*)	0.775 (*1085*)	0.1414 (*198*)	0.1979 (*277*)
HCR RO	Pre	*17*	0.2353 (*4*)	0	0	0.1176 (*2*)	0	0	0.3529 (*6*)	0.1176 (*2*)
HCR RO	Post	*785*	0.8191 (*643*)	0.172 (*135*)	0.172 (*135*)	0.0344 (*27*)	0.4854 (*381*)	0.7745 (*608*)	0.1643 (*129*)	0.251 (*197*)
LOP PH1	Pre	*2992*	0.0314 (*94*)	0.0047 (*14*)	0.007 (*21*)	0.0033 (*10*)	0	0	0.0194 (*58*)	0.0067 (*20*)
LOP PH1	Post	*63*	0.8095 (*51*)	0.0952 (*6*)	0.0952 (*6*)	0.0317 (*2*)	0.3968 (*25*)	0.3492 (*22*)	0.1429 (*9*)	0.1905 (*12*)
LOP PH2	Pre	*49*	0.0408 (*2*)	0	0.0204 (*1*)	0.0204 (*1*)	0	0	0	0
LOP PH2	Post	*64*	0.8906 (*57*)	0.125 (*8*)	0.0781 (*5*)	0	0.3125 (*20*)	0.1562 (*10*)	0.125 (*8*)	0.1562 (*10*)
LOP SP	Pre	*6*	0.3333 (*2*)	0.1667 (*1*)	0	0	0	0	0.1667 (*1*)	0
LOP SP	Post	*128*	0.8047 (*103*)	0.1016 (*13*)	0.0234 (*3*)	0.0156 (*2*)	0.375 (*48*)	0.2734 (*35*)	0.1016 (*13*)	0.125 (*16*)

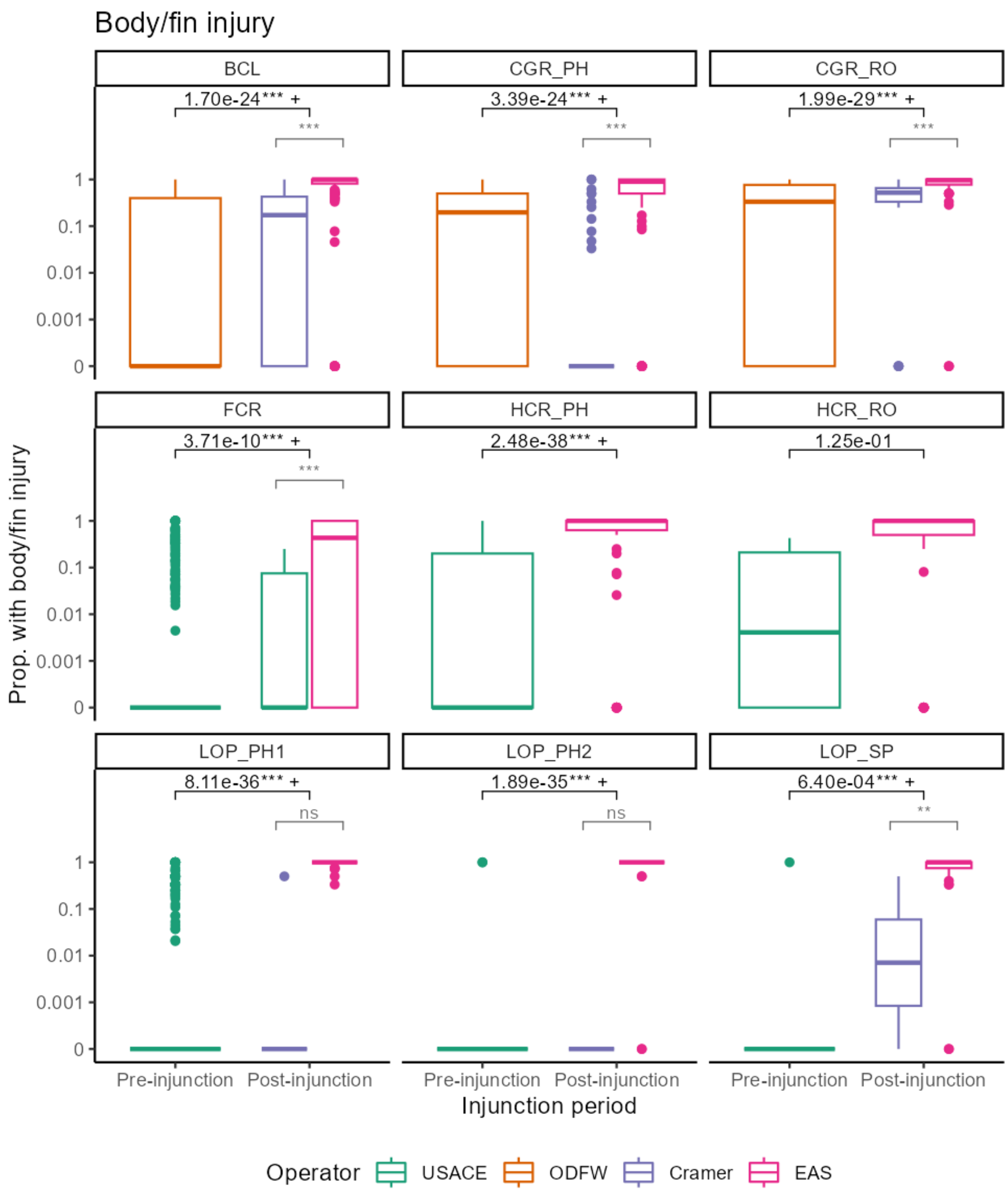

*Figure 29. Boxplots of the proportion of fish reported to have body and/or fin injuries at RSTs below USACE-operated WVS dams. Boxplots show medians, 1.5*inter-quartile ranges, and outliers. Labelled brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-") . Where multiple operators were active in the post-injunction period, grey brackets indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. Note the non-linear y-axis.*

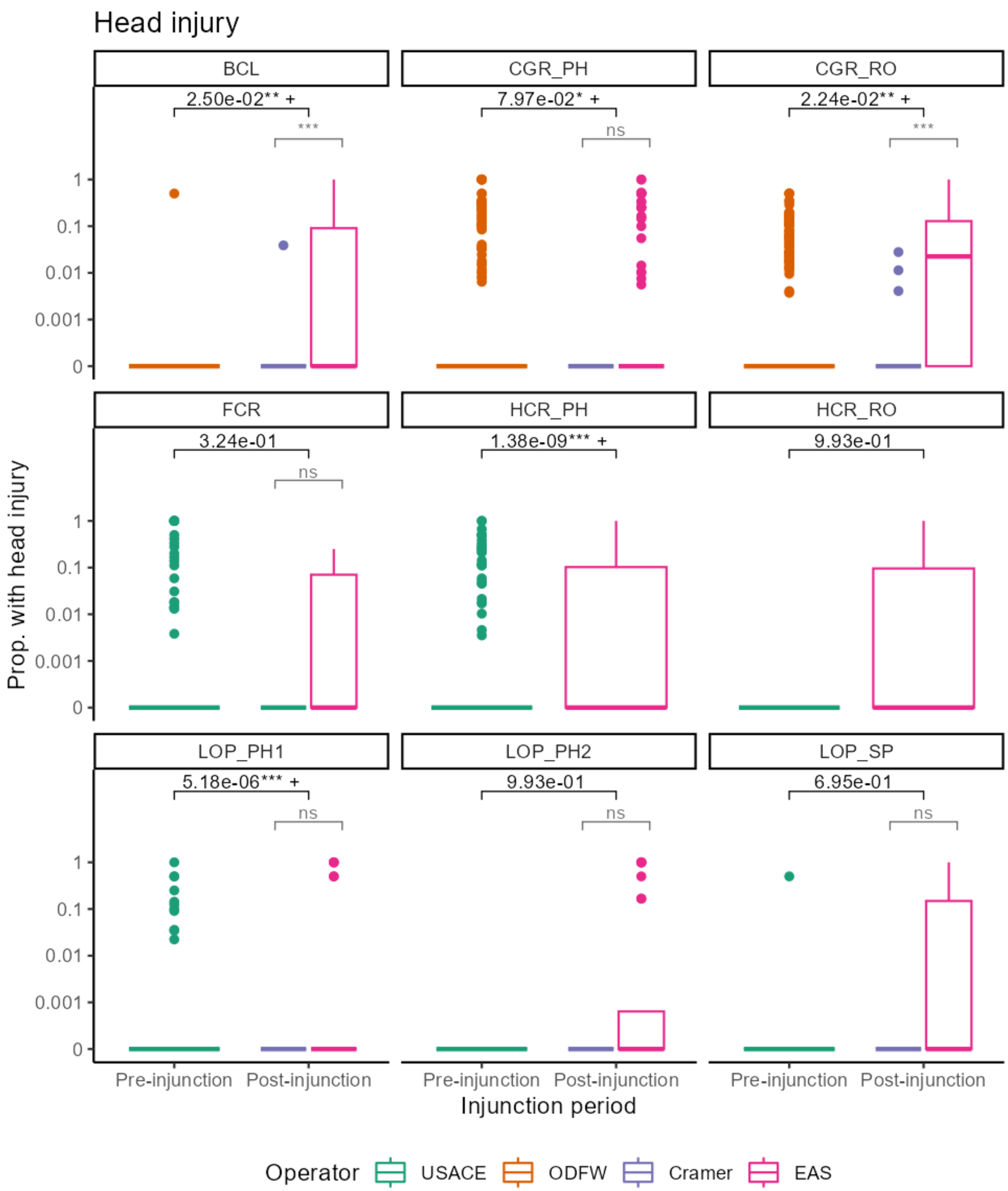

*Figure 30. Boxplots of the proportion of fish reported to have head injuries at RSTs below USACE-operated WVS dams. Boxplots show medians, 1.5*inter-quartile ranges, and outliers. Labelled brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-") . Where multiple operators were active in the post-injunction period, grey brackets indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. Note the non-linear y-axis.*

The proportion of fish captured in an RST with only a head, only a body, or nearly decapitated was not consistently higher or lower in the post-injunction period (Figure 31). The results of quasi-binomial regression showed a significantly lower proportion of fish with such injuries post-injunction in the Cougar RO RST, but a significantly higher proportion at the Lookout Point PH1 trap. At no site was there a significant operator effect on the proportion of reported fish with head injuries.

Considering fish with major descaling, only at Cougar's PH RST was there a significant effect of the injunction effect on reported injury rates (which was significantly higher post-injunction; Figure 32). Here, there was a weak operator effect (which was not significant according to the $p < 0.05$ definition). Otherwise, quasi-binomial regression did not estimate a significant injunction effect at any sites. At Big Cliff, despite no significant difference in injury reporting between the pre- and post-injunction periods, post-injunction reporting of major descaling was significantly higher under EAS as opposed to Cramer.

The proportion of fish reported to have eye damage was significantly higher in the post-injunction period at five of nine sites (Cougar's PH and RO RSTs, below Fall Creek, Hills Creek's RO RST, and Lookout Point's PH1 trap); at no site was eye injury reporting significantly lower during the post-injunction period (Figure 33). At these five sites with a significant injunction period effect, only one site included a significant operator effect: Cougar's RO RST. As with other injury types, reporting of eye injuries was significant higher when EAS operated the trap compared to Cramer.

Similar results were seen for fish reported to have gill, operculum, and/or isthmus damage (Figure 34). Post-injunction injury reports for this category were significantly higher during the post-injunction period at six of the nine sites (all expect Lookout Point's PH2 and spillway traps, and Hills Creek's RO channel RST). Of these sites, only at Big Cliff was there also a statistically significant operator effect in the post-injunction period (higher under EAS compared to Cramer; while there was an operator effect observed at Cougar's RO RST, it was not significant according to $p < 0.05$).

Compared to other injury types, copepod infection rates were relatively high and commonly reported. The reported proportion of fish having a copepod infection was higher post-injunction, with a statistically significant effect of the injunction found at four of the nine RST sites according to quasi-binomial regression results (Figure 35). No site reported a significant reduction in reported copepod infection post-injunction. At all sites with a significant injunction effect except one (i.e., Cougar's PH RST) there was also a significant effect of operator during the post-injunction period.

Considering the final injury category, internal injuries, both positive and negative injunction effects were predicted by quasi-binomial regression results (Figure 36). At two sites, Cougar's RO channel and Big Cliff, there was a significant reduction in internal injury reporting post-injunction. In contrast, at Cougar's PH RST, Fall Creek's tailrace RST, Hills Creek's PH RST, and both Lookout Point PH RSTs, a statistically significant positive injunction effect was estimated by regression models. Only at two sites, Cougar's RO RST and Fall Creek's tailrace RST was there a significant operator effect on reporting rates; here, EAS reported statistically significantly higher internal injury rates than Cramer (at Cougar's RO) or USACE (at Fall Creek).

See "Appendix D: Injury analysis" more complete descriptions of the quasi-binomial regression model results.

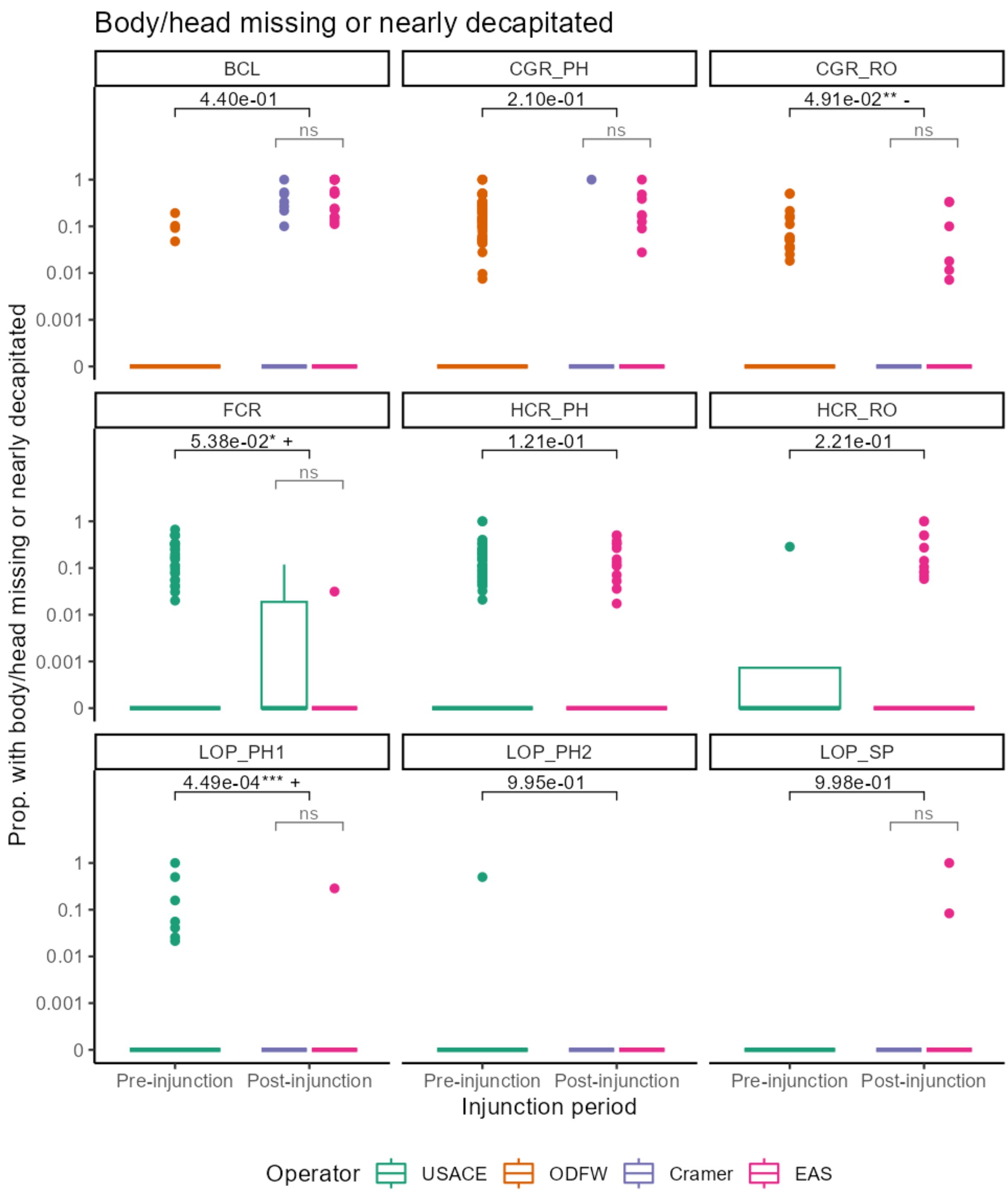

*Figure 31. Boxplots of the proportion of fish reported to be decapitated at RSTs below USACE-operated WVS dams. Boxplots show medians, 1.5*inter-quartile ranges, and outliers. Labelled brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-") . Where multiple operators were active in the post-injunction period, grey brackets indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. Note the non-linear y-axis.*

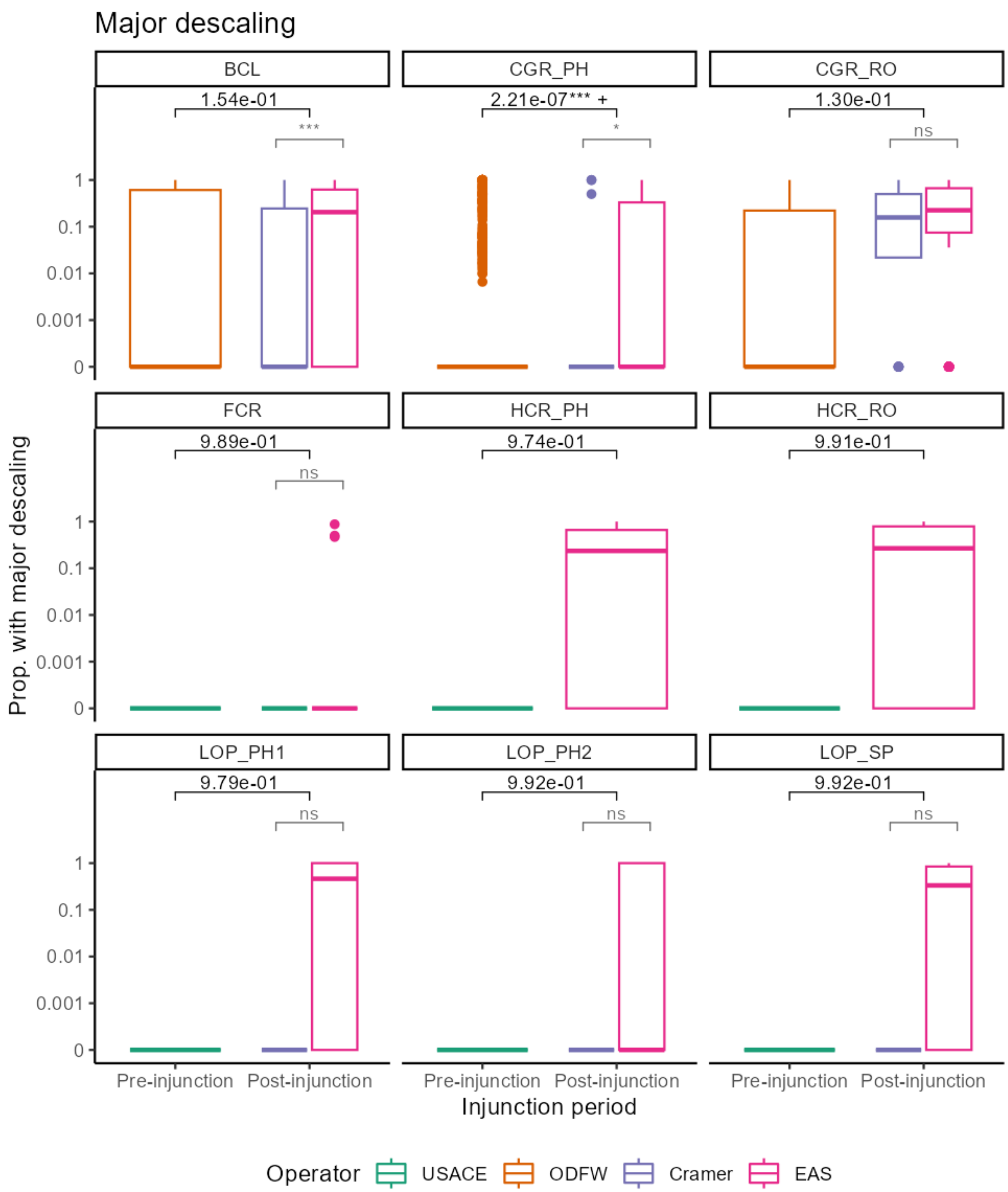

*Figure 32. Boxplots of the proportion of fish reported to have major descaling at RSTs below USACE-operated WVS dams. Boxplots show medians, 1.5*inter-quartile ranges, and outliers. Labelled brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-") . Where multiple operators were active in the post-injunction period, grey brackets indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. Note the non-linear y-axis.*

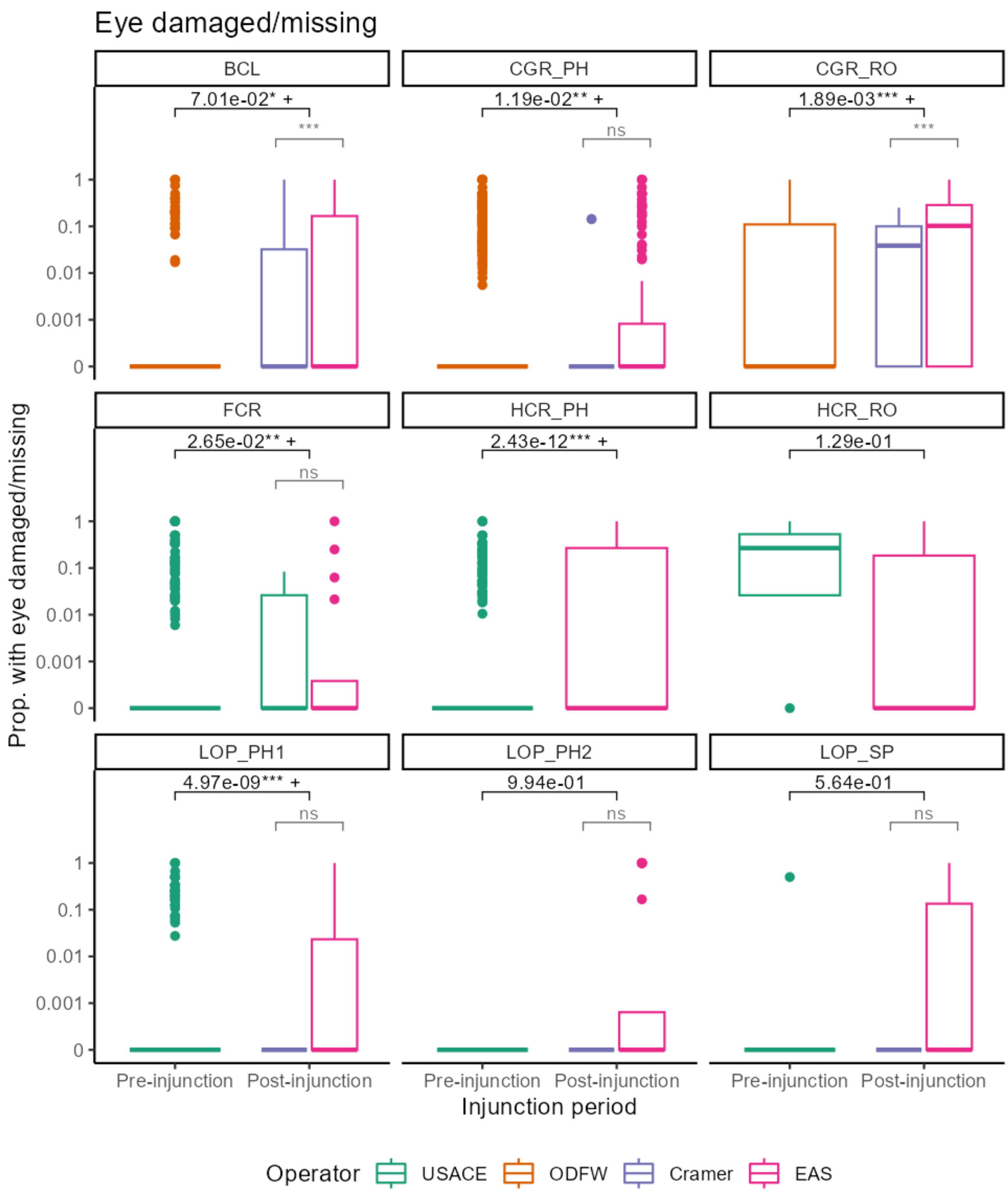

*Figure 33. Boxplots of the proportion of fish reported to have eye injuries at RSTs below USACE-operated WVS dams. Boxplots show medians, 1.5*inter-quartile ranges, and outliers. Labelled brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-") . Where multiple operators were active in the post-injunction period, grey brackets indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. Note the non-linear y-axis.*

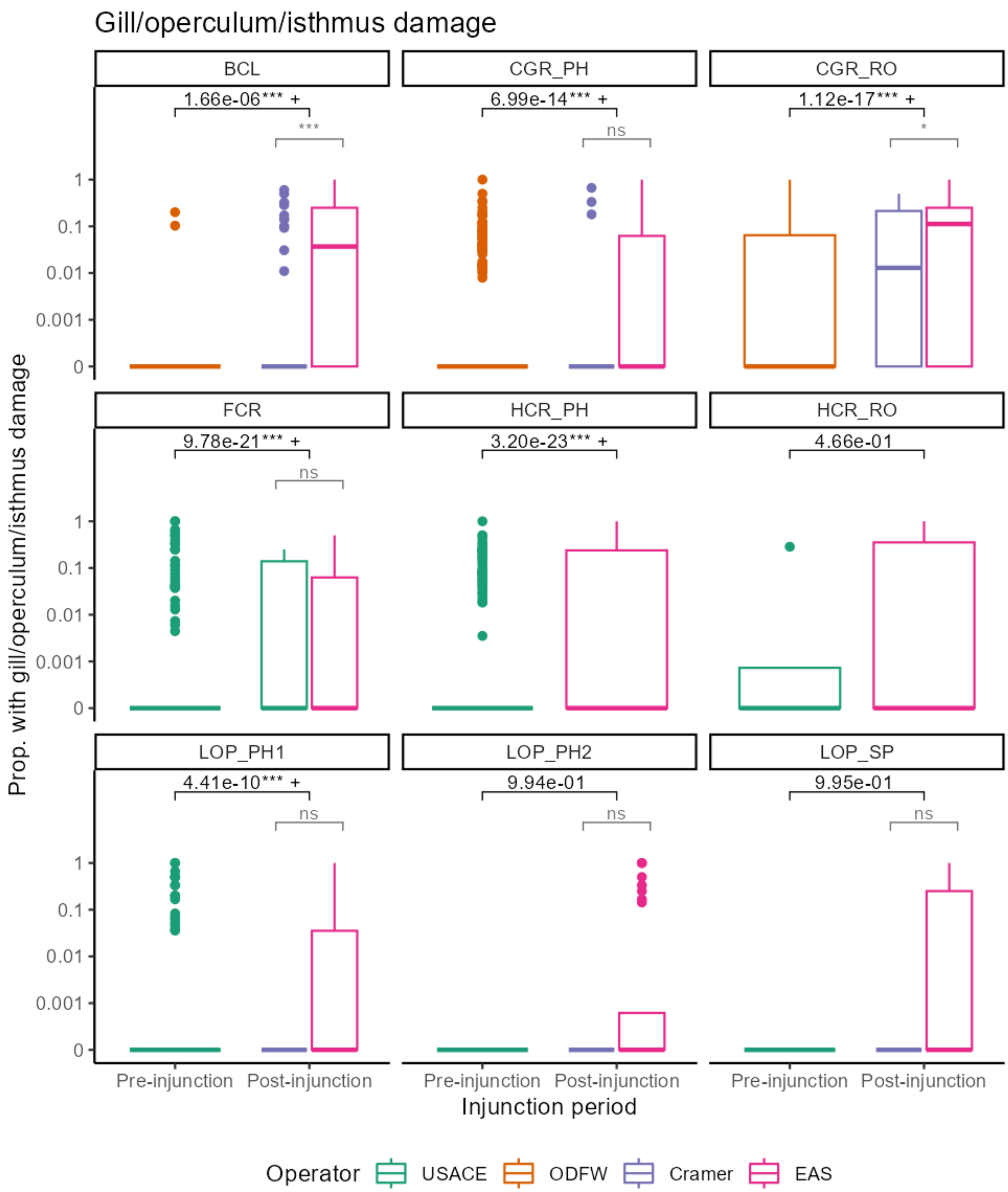

*Figure 34. Boxplots of the proportion of fish reported to have gill/operculum injury at RSTs below USACE-operated WVS dams. Boxplots show medians, 1.5*inter-quartile ranges, and outliers. Labelled brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-") . Where multiple operators were active in the post-injunction period, grey brackets indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. Note the non-linear y-axis.*

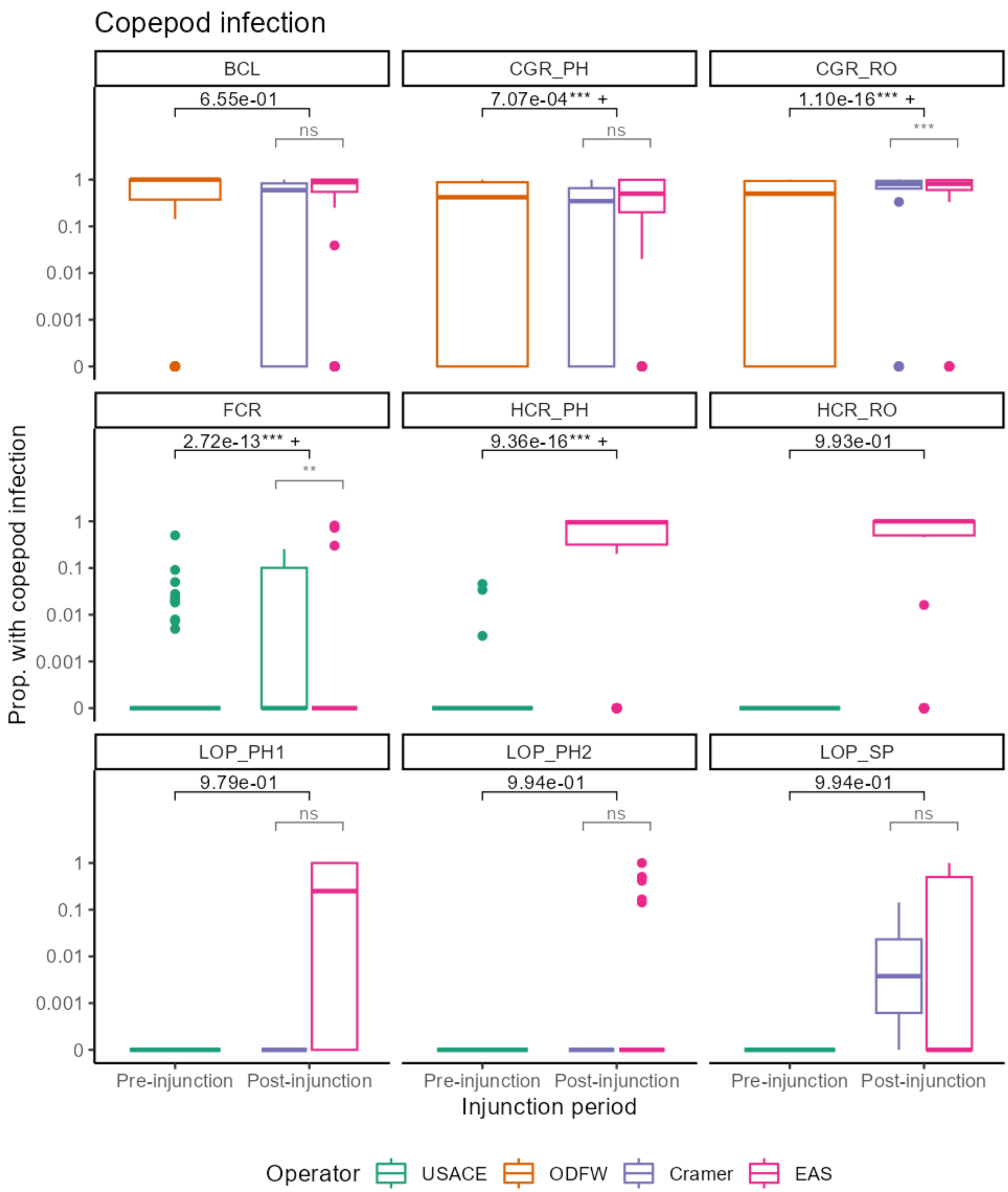

*Figure 35. Boxplots of the proportion of fish reported to have copepod infection at RSTs below USACE-operated WVS dams. Boxplots show medians, 1.5*inter-quartile ranges, and outliers. Labelled brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-") . Where multiple operators were active in the post-injunction period, grey brackets indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. Note the non-linear y-axis.*

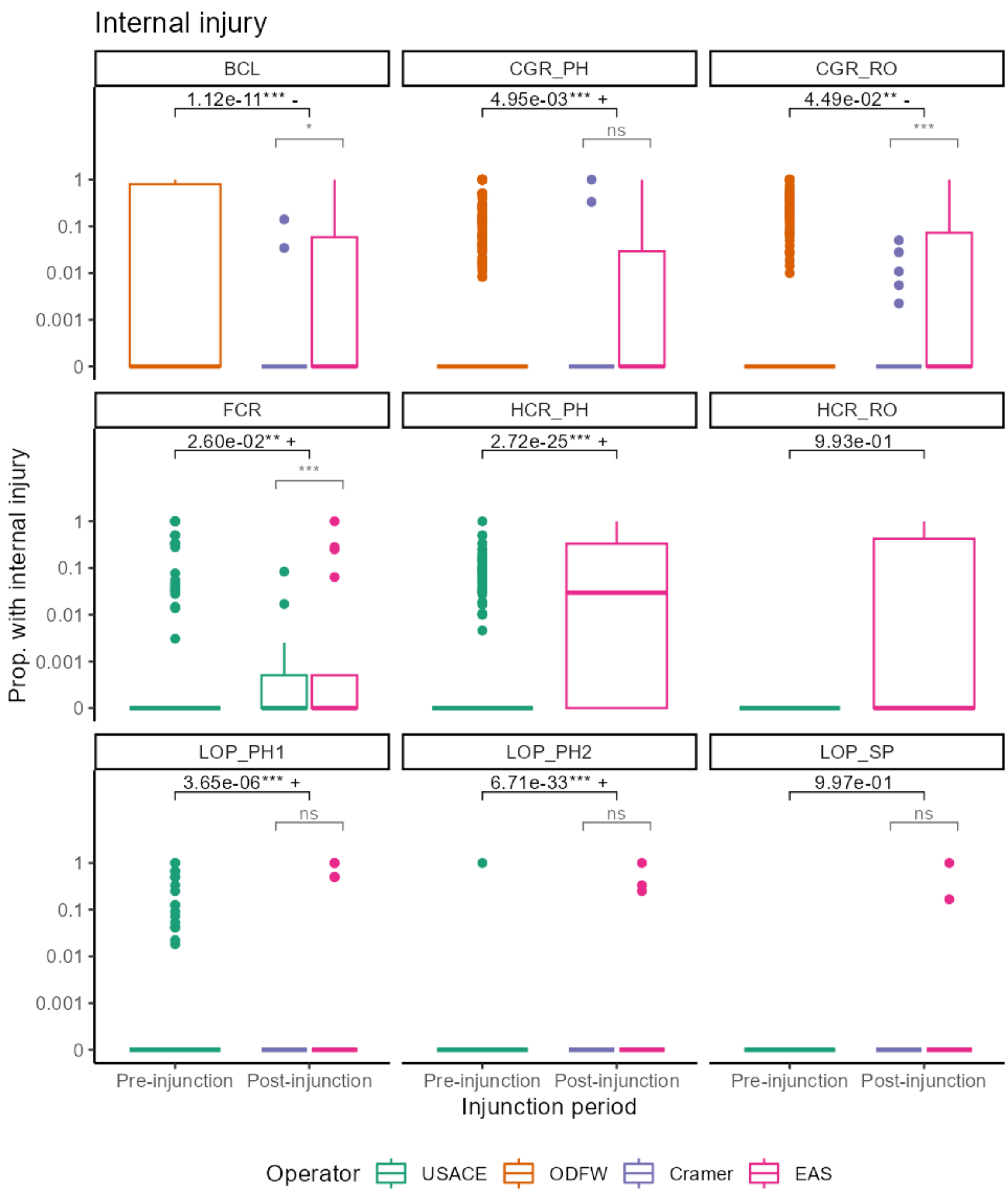

*Figure 36. Proportion of fish reported to have signs of internal injury at nine RSTs below USACE-operated dams. Labelled black brackets above each pre- and post-injunction pair of boxplots summarizes the results of quasi-binomial regression at each site. Values report the p-value, statistical significance of the injunction effect on injury rate, and direction of the effect if significant (i.e., "+" or "-"). At sites where multiple operators were active in the post-injunction period, there are also labelled grey brackets which indicate the statistical significance of the operator effect in quasi-binomial regressions of post-injunction injury reporting versus operator. *** = p < 0.01, ** = p <0.05, * = p < 0.1, ns = not significant. The y-axis has been transformed to better show low-estimated injuries.*

Fish injury analysis: Comparison of operator and injunction effects

Fall Creek offered the opportunity to compare injunction and operator effects on observed injury rates via model comparison using AIC. Because quasi-binomial regression cannot produce AIC values with which to compare across models, we applied binomial regression for this analysis. A summary of reported injury prevalence at Fall Creek is shown in Table 12.

Table 12. Summary of injury rates at Fall Creek's tailrace RST from 2006-2023, divided by injunction period and by RST operator. For each injury category column, the mean and standard deviation (in parentheses) of the proportion of captured fish with that injury type are reported. The Fall Creek tailrace trap was operated by USACE during the pre-injunction phase and for several months post-injunction (2006-2022), while EAS operated the trap during most but not all of the post-injunction period (late 2022 to the present). USACE did not report any injuries that we categorized as "major descaling" during trapping so this injury category is not included in this table. Grey boxes indicate that a statistically significant difference (p < 0.05) was identified for the effect of injunction period and/or operator on a given injury category.

		Injury category						
Explanatory variable		*Body/fin injury*	*Head injury*	*Eye damaged/ missing*	*Gill, isthmus, operculum damage*	*Copepod infection*	*Body/head missing*	*Internal injury*
Injunction period	*Pre-*	0.071 (0.203)	0.026 (0.143)	0.045 (0.165)	0.022 (0.109)	0.002 (0.029)	0.019 (0.080)	0.022 (0.126)
	Post-	0.325 (0.432)	0.028 (0.070)	0.056 (0.195)	0.072 (0.122)	0.095 (0.211)	0.011 (0.029)	0.063 (0.201)
Operator	*USACE*	0.070 (0.200)	0.025 (0.141)	0.044 (0.163)	0.023 (0.109)	0.005 (0.034)	0.019 (0.079)	0.022 (0.124)
	EAS	0.512 (0.476)	0.048 (0.087)	0.083 (0.252)	0.076 (0.144)	0.115 (0.266)	0.002 (0.008)	0.100 (0.256)

USACE and EAS RST operators recorded injuries that fall under seven of the eight injury categories analyzed in the previous section of this report (we could not definitively classify any USACE fish condition comments as falling under "major descaling", >20% of the body, so this injury classification is not included here). Of the injury categories used by both operators, AIC-based model selection identified a single top model for all categories expect internal injury: one that includes both operator and injunction period as explanatory variables. In models where internal injury reporting rate was used as the dependent variable, two models were top ranked (as they fell within two AIC units of one another): the model including only operator, and the model including both operator and injunction period. See Table 13 for regression results and associated likelihood and AIC values for binomial regressions fitted to observations of each injury category.

For the majority of injury categories, reporting of that injury increased post-injunction and when EAS operated the Fall Creek tailrace RST. Regression results suggested that body injury reporting was significantly higher in the post-injunction period (0.885, SE = 0.014) and significantly higher when operated by EAS compared to USACE (2.74, SE = 0.014). Similar results were seen when eye injuries were treated as the dependent variable in model fitting (reporting rate was 0.583 times higher post-injunction (SE = 0.026) and 0.172 times higher when EAS reported compared to USACE (SE = 0.034)). Copepod infection reporting was also significantly higher post-injunction (4.848, SE = 0.057) and while EAS operated the RST (1.041, SE = 0.013). The top-ranked model of head injury reporting rate included both injunction period and operator, but neither explanatory variable was significant (only the constant was significant in this case) with high standard errors on the estimated effects of the explanatory variables.

There was no single top model describing internal injury reporting, but only operator effect was significant in both models (injunction period was not a statistically significant explanatory variable despite model 4's AIC value falling within 2 of the top-ranked model). The top models for internal injury reporting predicted much higher reporting under EAS than under USACE (by a factor of more than 3). Considering models using gill, isthmus, and/or operculum injury as the dependent variable, reporting was significantly higher post-injunction (2.561, SE = 0.025) and significantly lower when EAS operated the trap (-0.454, SE = 0.021). For fish reported to have head/body missing or nearly decapitated, the top-ranked model predicted higher injury reporting post-injunction (0.745; SE = 0.034) and significantly lower reporting under EAS than USACE (-1.049, SE = 0.068).

*Table 13. Summary tables of binomial regression models fitted to RST injury records at the Fall Creek tailrace RST. Each sub-table summarizes model results when a different injury code is used for the dependent variable. A: body/fin injury, B: head injury, C: eyes missing and/or injured; D: gill, operculum, and isthmus injury, E: copepod infection, F: body/head missing or nearly decapitated, and G: internal injuries. Explanatory variables included operator and injunction effect. Each table summarizes model fits and AIC values comparisons. Model 1 is an intercept-only model, model 2 includes injunction period as an explanatory variable, model 3 includes operator as an explanatory variable, and model 4 includes both operator and injunction period as explanatory variables. In each table, the model results from the highest-ranked model(s) according to AIC are highlighted. * indicates p<0.1, ** indicates p<0.05, and *** indicates p<0.01. Number of observations = 346.*

A. Dependent variable: Proportion with body and/or fin injuries

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Injunction period:		1.677***		0.885***
Post		(0.013)		(0.014)
Operator: EAS			3.113***	2.735***
			(0.013)	(0.014)
Constant	-1.850***	-2.986***	-2.478***	-2.986***
	(0.005)	(0.012)	(0.007)	(0.012)
Log Likelihood	-66,724	-55,938	-36,777	-34,743
AIC	133,450	111,881	73,558	69,492

B. Proportion with head injuries

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Period: Post-injunction		0.479^{***}		-18.087
		(0.035)		(150.966)
Operator: EAS			2.852^{***}	20.281
			(0.036)	(150.966)
Constant	-4.571^{***}	-4.854^{***}	-5.512^{***}	-4.854^{***}
	(0.017)	(0.028)	(0.028)	(0.028)
Log Likelihood	-8,955	-8,860	-5,833	-5,017
AIC	17,912	17,724	11,669	10,040

C. Proportion with eyes missing/injured

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Period: Post-injunction		0.618^{***}		0.583^{***}
		(0.025)		(0.026)
Operator: EAS			0.435^{***}	0.172^{***}
			(0.033)	(0.034)
Constant	-3.769^{***}	-4.143^{***}	-3.822^{***}	-4.143^{***}
	(0.011)	(0.020)	(0.012)	(0.020)
Log Likelihood		-7,797	-7,464	-7,717
AIC	15,597	14,933	15,437	14,910

D. Proportion with gill, operculum, and/or isthmus damage

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Period: Post-injunction		2.486^{***}		2.561^{***}
		(0.025)		(0.025)
Operator: EAS			0.256^{***}	-0.454^{***}
			(0.021)	(0.021)
Constant	-2.604^{***}	-4.484^{***}	-2.633^{***}	-4.484^{***}
	(0.007)	(0.024)	(0.007)	(0.024)
Log Likelihood	-17,935	-8,632	-17,860	-8,372
AIC	35,871	17,269	35,725	16,749

E. Proportion with copepod infection

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Period: Post-injunction		5.087***		4.848***
		(0.057)		(0.057)
Operator: EAS			1.883***	1.041***
			(0.012)	(0.013)
Constant	-1.917***	-6.246***	-2.240***	-6.246***
	(0.005)	(0.057)	(0.006)	(0.057)
Log Likelihood	-48,142	-19,509	-37,936	-16,273
AIC	96,286	39,022	75,875	32,552

F. Proportion with body or head missing, or nearly decapitated

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Period: Post-injunction		0.745***	0.745***	0.745***
		(0.034)		(0.034)
Operator: EAS			-0.685***	-1.049***
				(0.068)
Constant	-4.391***	-4.854***	-4.339***	-4.854***
	(0.016)	(0.028)	(0.016)	(0.028)
Log Likelihood	-7,684	-7,425	-7,622	-7,271
AIC	15,370	14,855	15,248	14,549

G. Proportion with internal injuries

Explanatory variable	Model 1	Model 2	Model 3	Model 4
Period: Post-injunction		1.507***		-0.033
		(0.040)		(0.053)
Operator: EAS			3.062***	3.080***
			(0.032)	(0.043)
Constant	-4.292***	-5.342***	-5.358***	-5.342***
	(0.015)	(0.036)	(0.026)	(0.036)
Log Likelihood	-11,775	-10,823	-7,083	-7,083
AIC	23,553	21,650	14,170	14,171

TDG effects on barotrauma and mortality analysis

As shown elsewhere in this report, the captures of juvenile Chinook salmon are highly seasonal due to both run timing and dam passage opportunities (Figures A 10a, A 10b, A 11a, and A 11b). The maximum TDG observed below Big Cliff was lower in the post-injunction period compared to the pre-injunction period (Table 14, Figures A 10a and A 10b), but slightly higher in the post-injunction period at Cougar (Table 14, Figures A 11a and A 11b). The maximum spill observed at Big Cliff and Detroit and at Cougar followed the same pattern. This highlights the close relationship between TDG and spill (Figure A 9). Reservoir forebay elevation did not appear to be consistently related to TDG below the dams (Figure A 8).

Trap event duration was daily during the post-injunction period, compared to every 2 days pre-injunction at BCL and every 1.5 days at CGR-RO (Table 14). This increased the number of trap events available for analysis in the post-injunction period. Both observed and TE-adjusted total numbers of captures were higher in the post-injunction period (Table 14). The proportion of captured fish with GBD, with barotrauma injuries, or that were dead in a given trap event were all reduced in the post-injunction period (Table 14). The proportions of fish with GBD or barotrauma injuries were both higher at CGR-RO in both periods.

Table 14. Juvenile Chinook salmon trapping events at RST located in Big Cliff (BCL) and Cougar Regulating Outlet (CGR-RO) tailraces. Hydrological variables (spill discharge, reservoir forebay elevation, TDG) are the mean or maximum values across all trap events. Proportion of captured fish with a given condition (dead, with GBD, with barotrauma injury) are the mean values across all trap events.

	BCL		**CGR-RO**	
Years	2014-2016	2021-2023	2012-2016	2021-2023
Trap events[1]	190	552	256	405
Trap hours (mean±SE)	48.3 (±1.8)	24.5 (±0.2)	36.5 (±1.4)	24.0 (±0.1)
Spill (cfs, maximum)	10,580[2]	7,370[2]	2,700	3,580
Elevation (ft, mean±SE)	2,703 (±3)[2]	2,713 (±2)[2]	1,583 (±4)	1,532 (±1)
TDG (%, maximum)	134.6	127.9	117.4	119.7
Total captures	715	2,593	4,466	11,713
TE-adjusted total captures	12,406	39,307	80,742	211,768
Proportion GBD (mean±SE)	0.136 (±0.026)	0.036 (±0.008)	0.325 (±0.032)	0.187 (±0.020)
Proportion barotrauma (mean±SE)	0.294 (±0.034)	0.160 (±0.016)	0.460 (±0.034)	0.334 (±0.024)
Proportion dead (mean±SE)	0.342 (±0.035)	0.103 (±0.013)	0.206 (±0.027)	0.116 (±0.016)

[1] "Total trap events" includes those with any missing hydrological variables; these were omitted from models

[2] Spill and elevation are combined Detroit and Big Cliff values

Effects on GBD incidence

We examined the relationship between the proportion of captures with GBD and both mean TDG and maximum TDG observed during trap events to understand which might be the better predictor. Mean TDG across trap events was similar between the two periods at both sites, but maximum TDG was reduced by almost 7% in the post-injunction period (Table 14, Figure 37). The data from Big Cliff suggested there was no relationship between GBD and mean TDG during the pre-injunction period, but a significant relationship with maximum TDG seemingly driven by 100% of captures having GBD when TDG was >130%. GBD was significantly related to both mean and maximum TDG in the post-injunction period at Big Cliff and in both periods at Cougar.

The optimal model for GBD incidence included maximum TDG, mean spill, trap event duration, length, temperature, season, site, and injunction period. Several interaction effects were significant (Table 15). The maximum TDG and temperature interaction indicated there was higher GBD incidence when TDG is high and when temperature is low. We do not present the main effects of those covariates included in significant interaction effects, but the single variable relationships of all effects included in the model in addition to maximum TDG (shown in Figure 37) are provided in Figures A 12-A 15. The main injunction period effect was significant (Table 15), and β=-0.604 was interpreted to mean that the post-injunction period was associated with a 45% reduction in the relative risk of GBD. The model also indicated that GBD incidence was higher the longer that fish were held in traps and that GBD incidence was significantly lower in fall compared to spring (Table 15).

Table 15. Binomial GLM coefficients in the optimal model explaining the proportion of captured juvenile Chinook salmon that had gas bubble disease. ':' denotes interaction between variables, 'ns' denotes non-significant coefficients.

Coefficient (β)	**Estimate**	**SE**	**P(>|t|)**
Trap hours	0.018	0.003	<0.001
Season–summer	-0.649	0.409	ns
Season–fall	-0.191	0.111	0.084
Season–winter	0.165	0.125	ns
Period–post	-0.604	0.082	<0.001
TDG maximum : Temperature	-0.024	0.004	<0.001
Spill mean : Length mean	-0.00001	0.000002	<0.001
Temperature : Site–CGR-RO	0.138	0.063	0.028

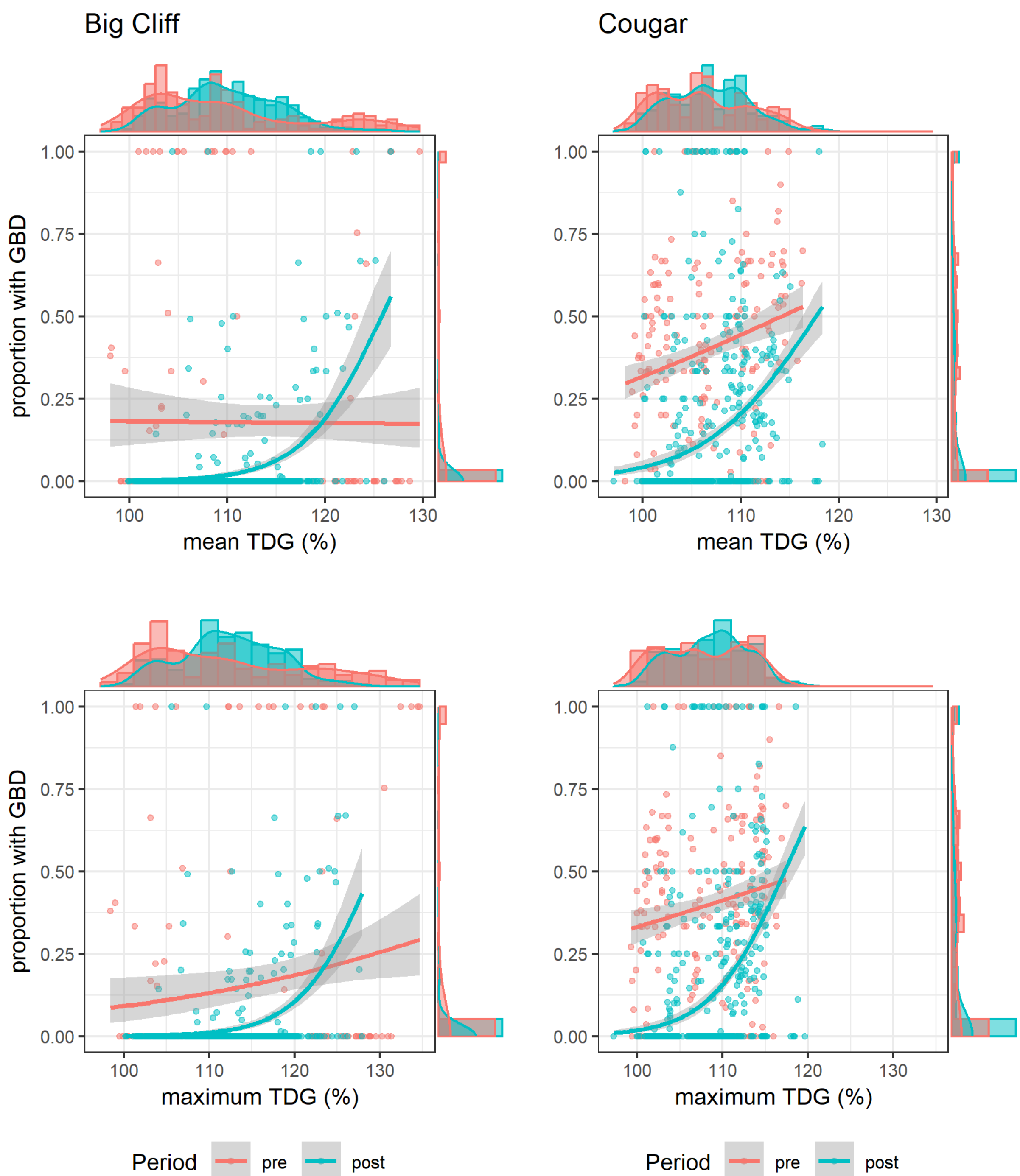

Figure 37. Relationships between the proportion of juvenile Chinook salmon captured per trap event with gas bubble disease (GBD) and mean TDG (top row) or maximum TDG (bottom row) recorded during the trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

Effects on barotrauma injury incidence

There were positive relationships of barotrauma injury rate with both mean and maximum TDG at both sites and periods (Figure 38). The optimal model for barotrauma injury incidence included mean TDG, mean spill, elevation, trap event duration, length, temperature, season, site, and injunction period. As with GBD, several interaction terms were significant (Table 16). The mean spill and length interaction indicated there was higher barotrauma when spill was high and fish were larger. We do not present the main effects of those covariates included in significant interaction effects, but the single variable relationships of all effects included in the model in addition to mean TDG (shown in Table 16) are provided in Figures A 16-A 20. The main injunction period effect was significant (Table 16), and β=-0.386 was interpreted to mean that the post-injunction period was associated with a 32% reduction in the relative risk of barotrauma injury. Barotrauma injury was significantly more likely to occur at Cougar compared to Big Cliff, supporting the data in Table 1. The probability of barotrauma injury was significantly greater as reservoir forebay elevation increased. There was a lower probability of barotrauma injury in summer compared to spring; this may be a size effect but there was no significant interaction between season and length.

Table 16. Binomial GLM coefficients in the optimal model explaining the proportion of captured juvenile Chinook salmon that had barotrauma injury. ':' denotes interaction between variables, 'ns' denotes non-significant coefficients.

Coefficient (β)	**Estimate**	**SE**	**P(>|t|)**
Elevation	0.148	0.056	0.009
Season–summer	-0.837	0.247	<0.001
Season–fall	-0.123	0.123	ns
Season–winter	0.129	0.140	ns
Site–CGR-RO	1.401	0.131	<0.001
Period–post	-0.386	0.095	<0.001
TDG mean : Temperature	0.018	0.003	<0.001
TDG mean : Trap hours	-0.001	0.0005	0.026
Spill mean : Length mean	-0.000009	0.000001	<0.001

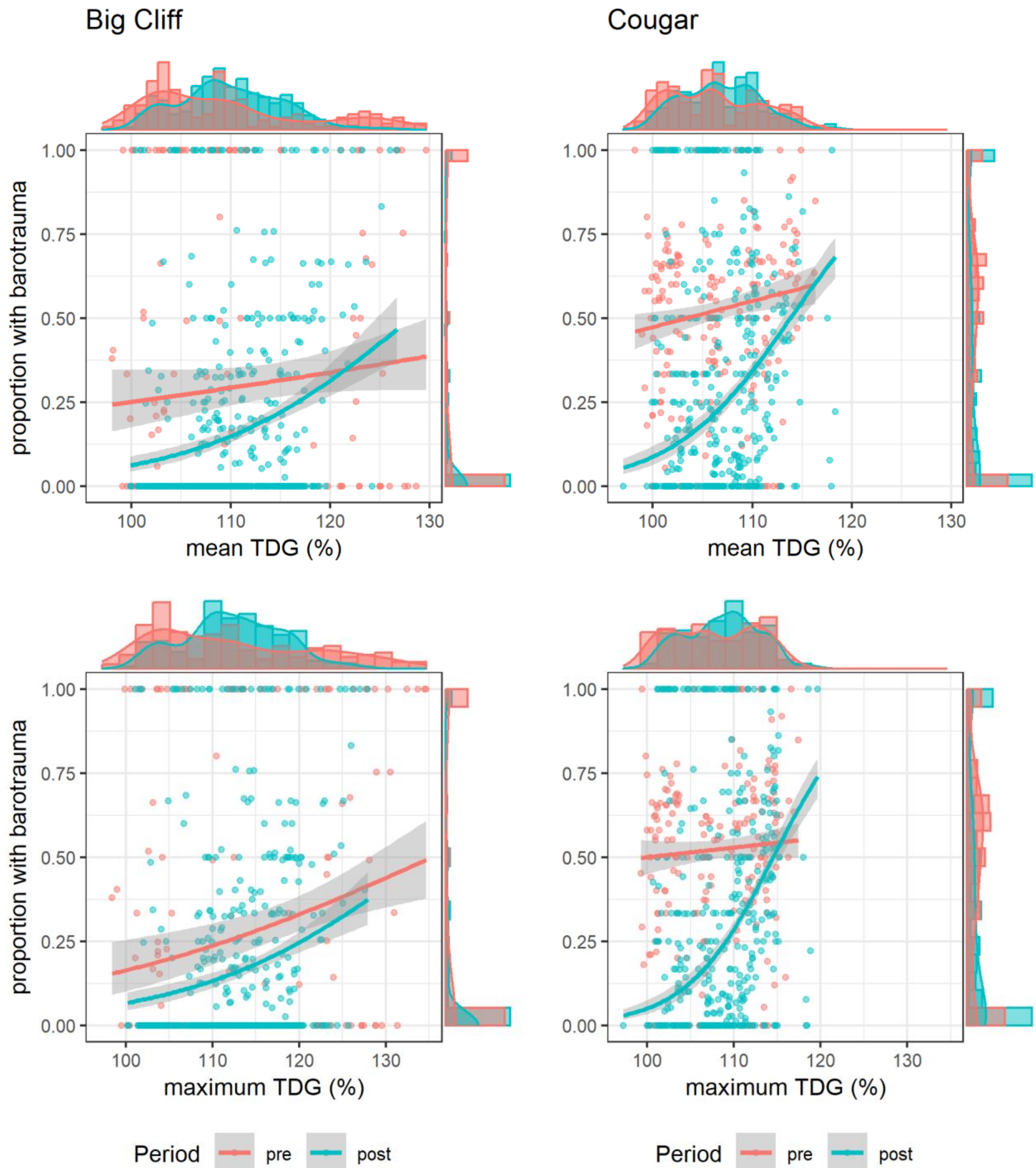

Figure 38. Relationships between the proportion of juvenile Chinook salmon captured per trap event with barotrauma injuries and mean TDG (top row) or maximum TDG (bottom row) recorded during the trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

Effects on mortality rate

The optimal model for mortality rate included maximum TDG, mean spill, length, temperature, season, site, and injunction period. Two interaction terms were significant (Table 17). As with barotrauma injury, the mean spill and length interaction indicated there was increased mortality when spill was high and fish were larger. The site and temperature interaction indicated that when the river was cooler, mortality rate was lower below Cougar but higher below Big Cliff. We do not present the main effects of those covariates included in significant interaction effects, but the single variable relationships of all effects included in the model in addition to maximum TDG and mean spill (shown in Figure 39) are provided in Figures A 21 and A 22.

Although weakly significant, the effect of TDG on mortality rate was not clear. Overall, there appeared to be no relationship between mortality rate and maximum TDG (Figure A 23), but this was both site and period specific (Figure 39). Similar inconsistent relationships were present between spill and mortality rate; overall there was a significant increase in mortality rate with mean spill (Figure A 24), but this was also site and period specific (Figure 39). The main injunction period effect was significant (Table 17), and β=-1.108 was interpreted to mean that the post-injunction period was associated with a 67% reduction in the relative risk of mortality. Mortality rate was also significantly reduced outside of spring.

Table 17. Coefficients in the optimal model explaining the proportion of captured juvenile Chinook salmon that were dead. ':' denotes interaction between variables, 'ns' denotes non-significant coefficients.

Coefficient (β)	**Estimate**	**SE**	**P(>|t|)**
TDG maximum	0.016	0.008	0.039
Season–summer	-0.808	0.282	0.004
Season–fall	-0.486	0.108	<0.001
Season–winter	-0.448	0.126	<0.001
Period–post	-1.108	0.076	<0.001
Spill mean : Length mean	-0.000009	0.000001	<0.001
Temperature : Site–CGR-RO	0.153	0.040	<0.001

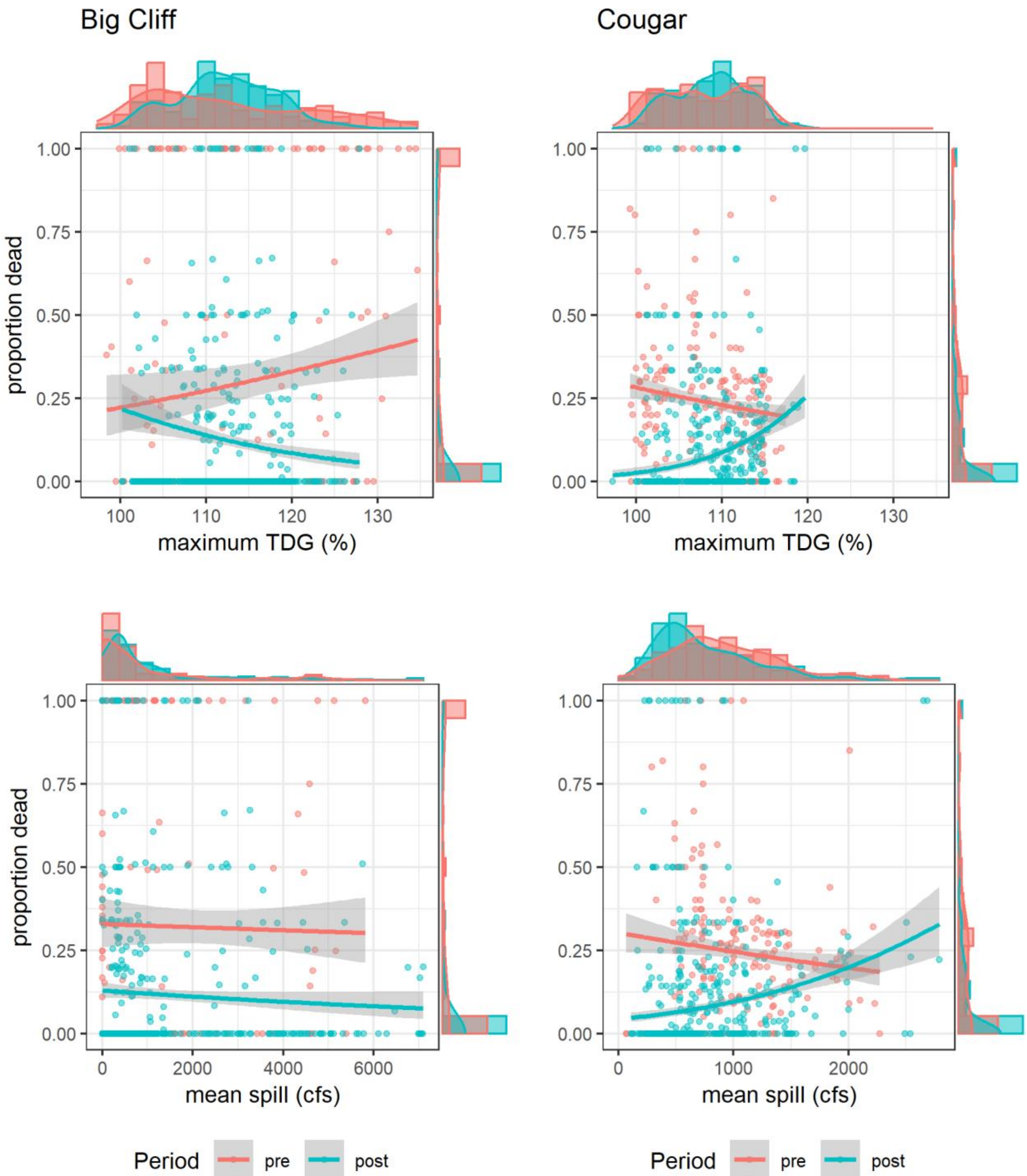

Figure 39. Relationships between the proportion of juvenile Chinook salmon captured per trap event that were dead and maximum TDG (top row) or mean spill (bottom row) recorded during the trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

Project passage efficiency

Cougar PPE

At Cougar dam, project passage efficiency—the ratio of average catch rate per week at a project tailrace to the average catch rate over the year at the HOR—peaked in the spring (Figure 40). Meanwhile, subyearling migrants tended to migrate late in the year. While the run timing was relatively consistent between years, the magnitude of PPE varied by year for both migrant types.

We evaluated several candidate models to describe how PPE varies in response to injunction period (i.e., before or after injunction measures were implemented) while accounting for run timing.

In the most inclusive fitted model, one including water year type and weekly run timing information, estimated a positive injunction effect on catch rate ratio (estimated increase of log catch rate after the injunction = 0.880, SE = 0.202; Table 18). Confidence intervals on this estimate did not overlap with zero, suggesting a significant positive injunction effect on catch rate ratios. Translated from log-space, the post-injunction catch rate was estimated to increase by 2.41 times. This model predicted run timing peaks at approximately week 13 (the same as what is predicted from the model including only weekly run timing). See Figure 41 for predictions from the global model.

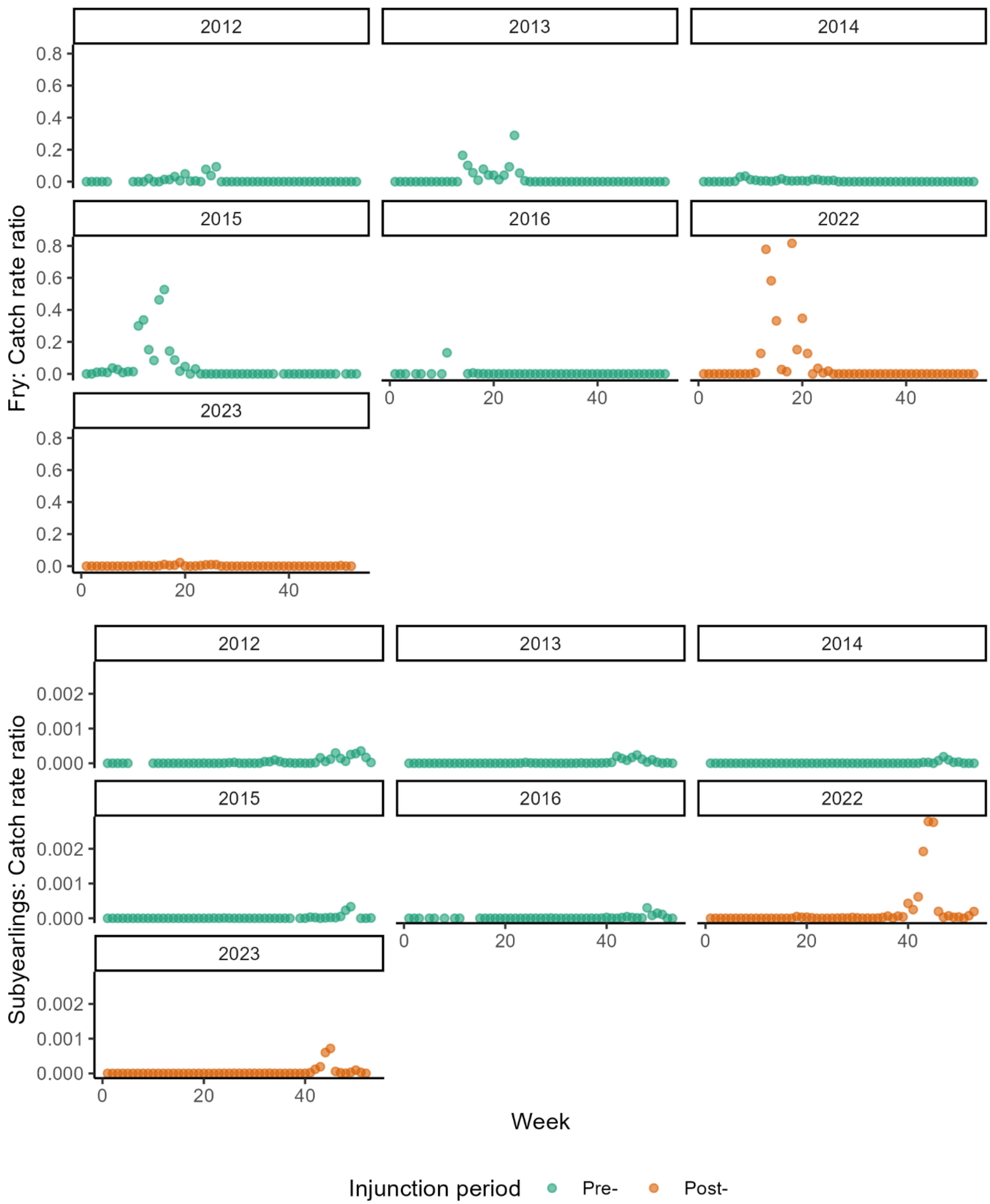

Figure 40. Catch rate ratio of fry migrant types and subyearling types across years and injunction periods at Cougar Dam. Catch rate ratio is the ratio of the catch rate (the average number of fish per hour caught in a given week of RST trapping, combining all below-dam RSTs at Cougar) divided by the average annual catch rate at the head-of-reservoir in that year. Note that the y-axis limits vary by year.

Table 18. Table of estimated intercepts, coefficients, parameter standard errors (in parentheses), and 95% confidence intervals (in brackets) estimated by non-linear estimation to model PPE of wild Chinook fry migrants passing Cougar Dam. Intercepts and coefficient values represent the expected effect on ln(catch rate ratio).

Explanatory variable	**Week**	**Week-Inj**	**Null**
Global intercept	-2.093 (0.134) [-2.31:-1.87]	-2.472 (0.184) [-2.78: 2.17]	-3.872 (0.221) [-4.23:-3.51]
Week of peak run timing (h_{week})	12.929 (0.523) [12.07:13.79]	13.291 (0.483) [12.49:14.09]	
Spread in run timing (a_{week})	0.0435 (0.015) [0.019:0.068]	0.0401 (0.01) [0.02:0.06]	
Post-injunction		0.8803 (0.202) [0.55:1.21]	
Log Likelihood	400.33	410.33	367.57

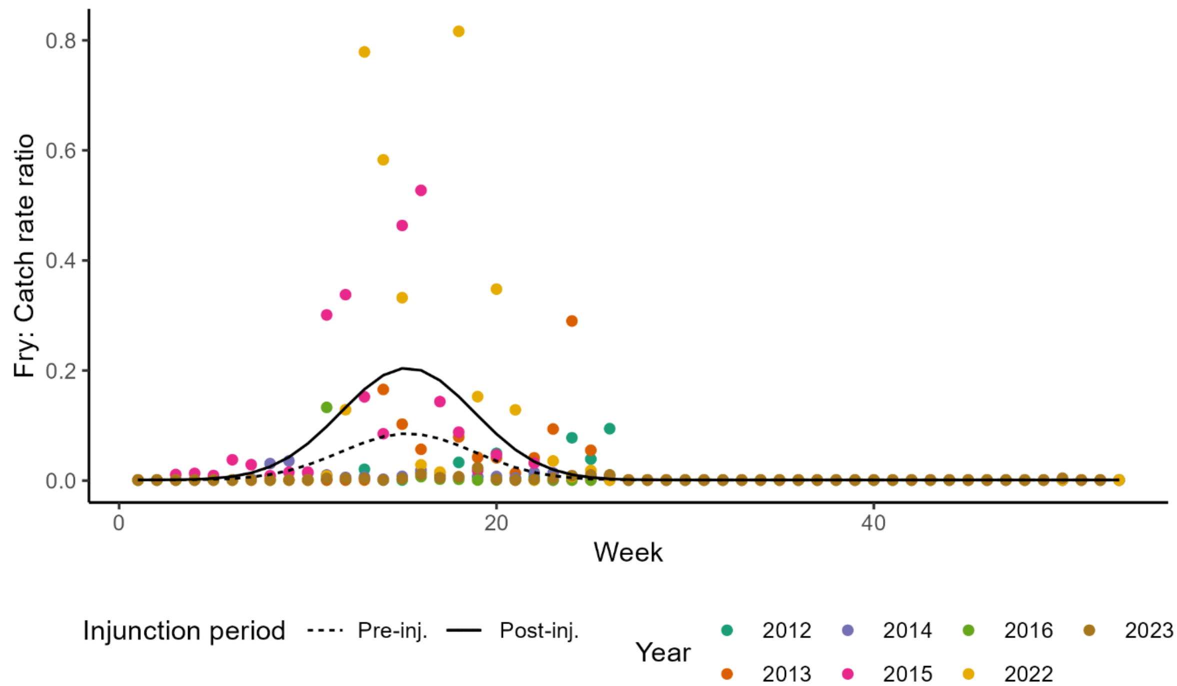

Figure 41. Model-predicted (lines) and observed (points) catch rate ratios of fry passing through the Cougar project. Predictions from the global model including weekly run timing and injunction effect.

We found similar results when modelling observations of subyearling type migrants. Fitted models that included weekly run timing estimated that the peak week of capture at the below-dam RSTs occurred around week 44. Models including both weekly run timing effects and hydrological or temperature variables failed to converge for similar reasons as reported above for fry; results from these models are not reported here.

In the global model results, the estimated effect of the injunction was large with confidence intervals not overlapping with zero. Compared to the pre-injunction period, post-injunction log-catch ratios were predicted to be higher by 3.047 (when translated out of log-transformed catch rate ratios, this corresponds to a multiplicative increase of more than 21 times; Table 19). See Figure 42 for predictions from the global mode, including injunction effects.

Table 19. Table of estimated intercepts, coefficients, parameter standard errors (in parentheses), and 95% confidence intervals (in brackets) estimated by non-linear estimation to model PPE of wild Chinook subyearling migrants passing Cougar Dam. Intercepts and coefficient values represent the expected effect on ln(catch rate ratio).

Explanatory variable	Week	Week-Inj	Null
Global intercept	-7.49 (0.125) [-7.92:-7.05]	-9.31 (0.531) [-10.19:-8.43]	-9.94 (0.265) [-10.38:-9.5]
Week of peak run timing (h_{week})	44.23 (0.176) [43.94:44.52]	44.2 (0.063) [44.1:44.3]	
Spread in run timing (a_{week})	0.303 (0.097) [-0.13:0.74]	0.435 (0.049) [0.35:0.52]	
Post-injunction		3.047 (0.534) [2.17:3.93]	
Log Likelihood	2648.3	2513.0	2473.2

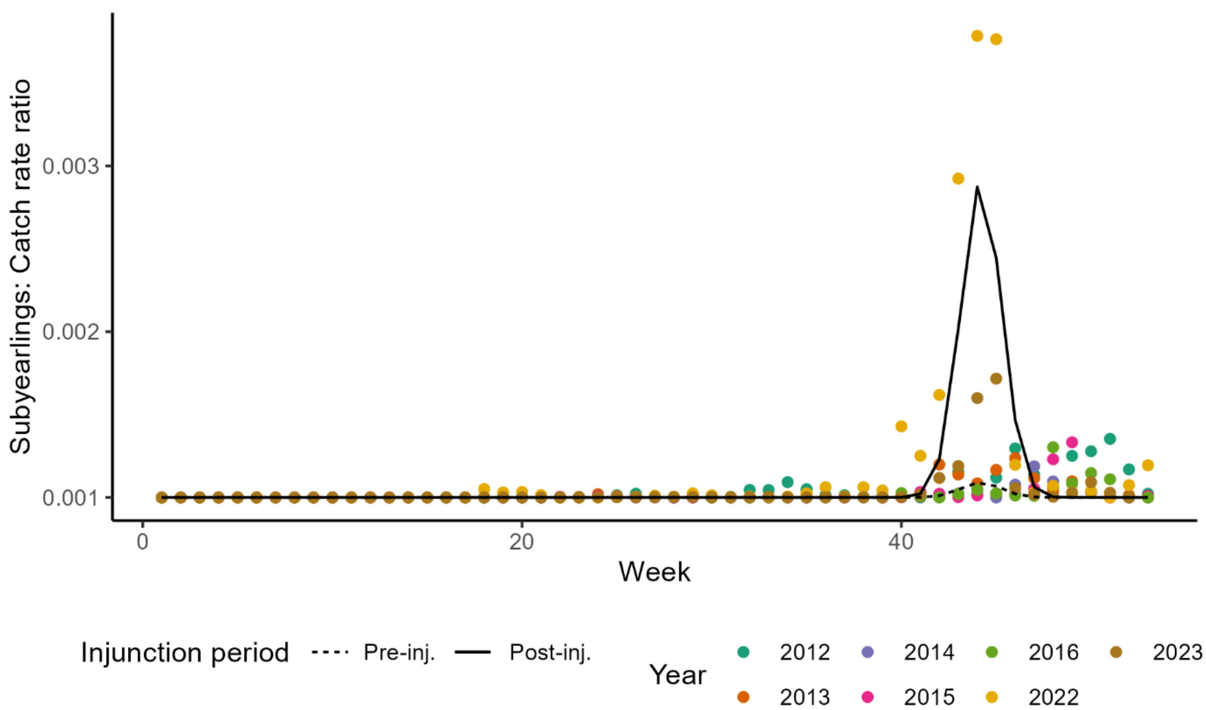

Figure 42. Model-predicted (lines) and observed (points) catch rate ratios of subyearlings passing through the Cougar project. Predictions from the global model including weekly run timing and injunction effect.

Fall Creek PPE

All Fall Creek, the catch rate ratio was highly variable between weeks, especially when compared to what was observed at the Cougar project (see Figure 43.). As a result, models did not easily converge and several models failed to fit to the data. There were no captures of any fry or subyearling migrants at the tailrace or head-of-reservoir traps in 2022. Owing to the lack of captures of fry or subyearlings in 2022, we fitted and compared only models with a) a water-year-type intercept and weekly run timing but no injunction measures, or b) a global intercept (and some combination of other explanatory variables) to provide a first-pass assessment of whether the injunction period had a notable effect on PPE. We include the results of all successfully converged models in Table 20. The model including an injunction effect was successfully fitted to the Fall Creek fry catch rate ratios; this model estimated a strong positive effect of injunction measures but with very low certainty (the model predicted that PPE increased by a factor of 5.28 post-injunction compared to pre-injunction records, but with a very large estimated SE = 75.2 and the 95% confidence interval was quite broad, suggesting a non-significant or unidentifiable injunction effect). The model including both a global intercept and an injunction effect was also unable to estimate the global intercept with certainty owing to very high correlation between the estimated global intercept and injunction effect (correlation between these variables was greater than 99% according to model fit results). Due to the high degree of uncertainty in predicted model results stemming from limited data, we do not show model predictions of catch rate ratios for fry passing Fall Creek.

Fitting models of PPE to observations of wild Chinook subyearling migrants passing Fall Creek was also difficult. Few models were able to converge on reasonable parameter estimates, and model results were highly sensitive to starting conditions used during non-linear estimation (examination of model fitting results suggests this is the result of high correlation between estimated parameters; even in successfully fitted models, the estimated parameters had correlation coefficients all above 96%). Owing to issues fitting any models to the observations of subyearling PPE at Lookout Point, we do not show results for subyearling PPE at Fall Creek in this report.

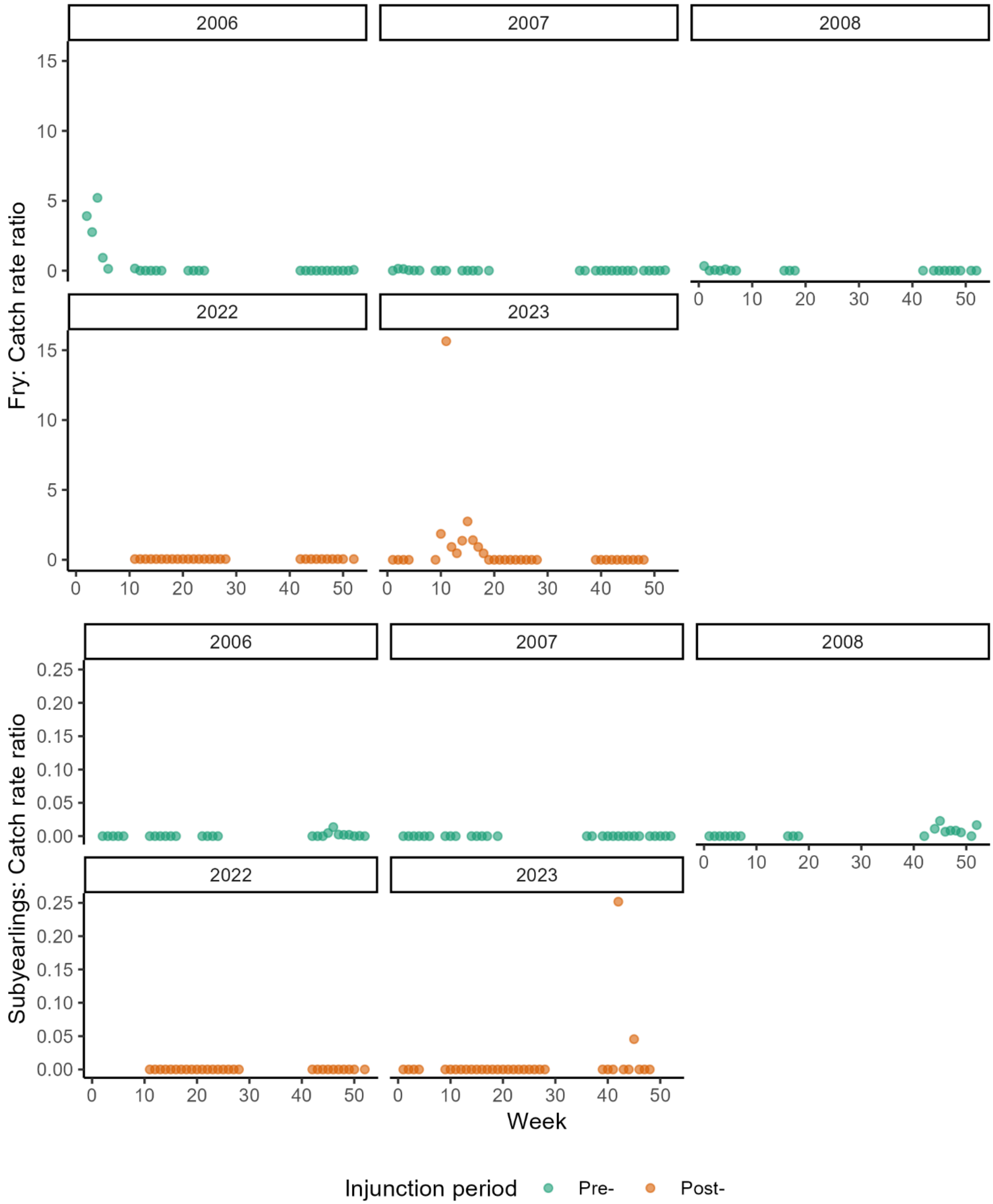

Figure 43. Catch rate ratio of fry migrant types and subyearling types across years and injunction periods at Fall Creek Dam. Catch rate ratio is the ratio of the catch rate at the tailrace RST (the average number of fish per hour caught in a given week of RST trapping) divided by the average annual catch rate at the head-of-reservoir in that year. To show differences between years, observations are split by year.

Table 20. Table of estimated intercepts, coefficients, parameter standard errors (in parentheses), and 95% confidence intervals (in brackets) estimated by non-linear estimation to model PPE of wild Chinook fry migrants passing Fall Creek project. Intercepts and coefficient values represent the expected effect on ln(catch rate ratio).

Explanatory variable	Week	Week-Inj	Null
Global intercept	0.323 (0.351) [-0.26:0.91]	-3.168 (75.2) [-127.74:121.4]	-1.193 (0.42) [-1.89:-0.49]
Week of peak run timing (h_{week})	9.42 (1.447) [7.0:11.8]	10.84 (0.168) [10.6:11.1]	
Spread in run timing (a_{week})	0.028 (0.023) [-0.01:0.07]	2.106 (0.904) [0.61:3.6]	
Post-injunction		5.28 (75.2) [-119.3:129.9]	
Log Likelihood	-241.51	-214.13	-246.82

Lookout Point PPE

At Lookout Point, the most long-term timeseries of RST records below-dam came from the PH1 RST trap; we limit our analysis to include only fry which passed this outlet channel during downstream migration. Fry migrants passing Lookout Point reservoir and dam were typically caught during early spring, while subyearlings passing Lookout Point tended to migrate in a prolonged pulse from early summer to early winter (Figure 44). Despite several years of data, there were relatively few weeks in RST records where wild spring Chinook fry or subyearlings were captured in the Lookout Point PH1 RST trap. Records from 2014 were removed because there were only records for two weeks, each of which with zero-captures.

Statistical models of PPE fitted to Lookout Point data were difficult to fit. Even in simple models including only a global intercept with weekly run timing effects, models often failed to converge on reasonable parameter estimates. We could only fit three candidate models to these data: a global intercept model, a global intercept with a weekly run timing effect, and a global intercept model with weekly run timing and injunction effects (Table 21). Due to the relatively poor fit of weekly run timing parameters, we also included a model where only the global intercept and injunction effect were included as explanatory variables.

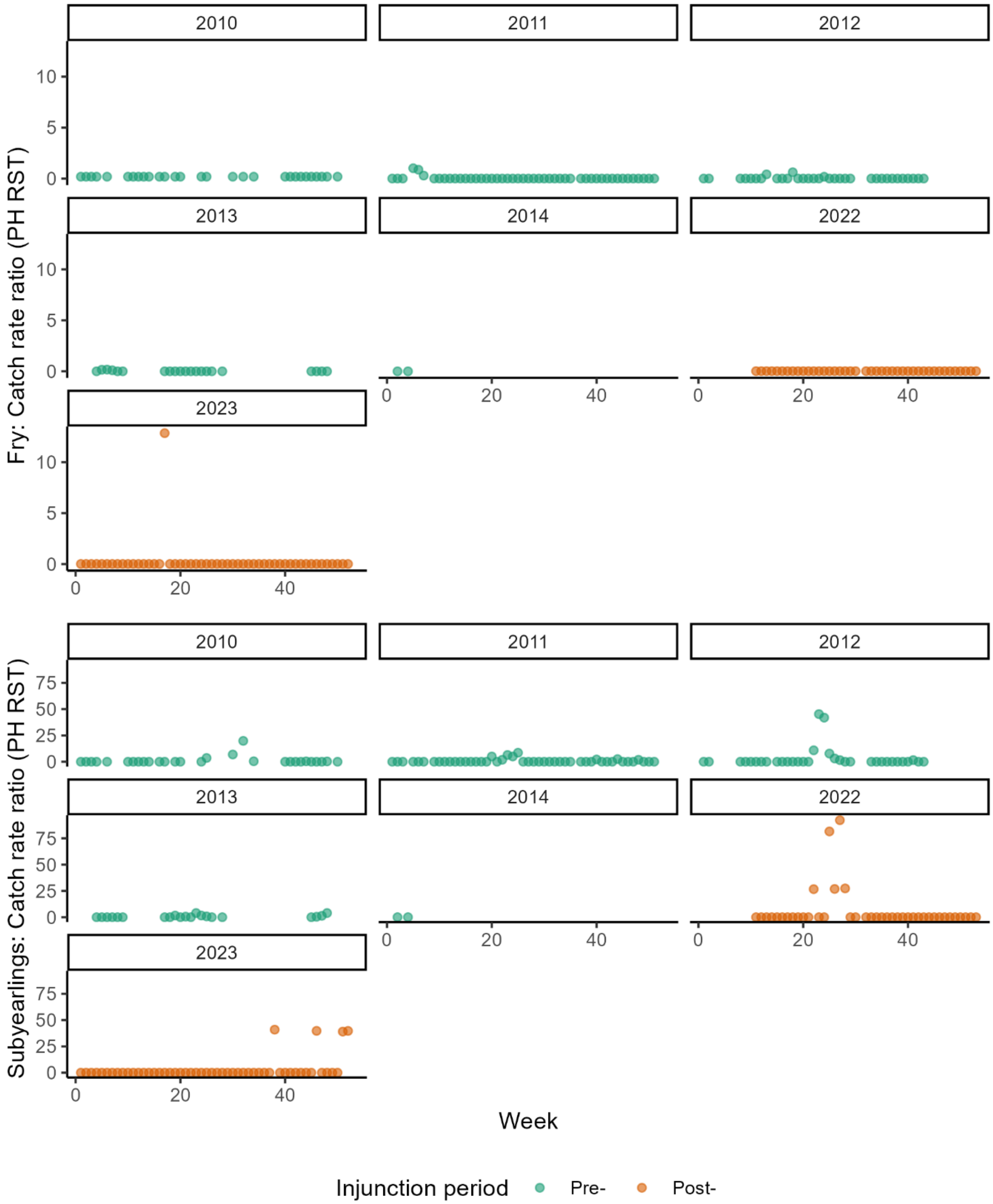

Figure 44. Catch rate ratio of fry migrant types and subyearling types across years and injunction periods at Lookout Point Dam. Catch rate ratio is the ratio of the catch rate (the average number of fish per hour caught in a given week of RST trapping, considering the powerhouse channel RST) divided by the average annual catch rate at the head-of-reservoir in that year. Data from 2014 are included in this figure but were excluded from analysis.

Table 21. Table of estimated intercepts, coefficients, parameter standard errors (in parentheses), and 95% confidence intervals (in brackets) estimated by non-linear estimation to model PPE of wild Chinook fry migrants passing Lookout Point project. Intercepts and coefficient values represent the expected effect on ln(catch rate ratio).

Explanatory variable	Week	Week-Inj	Inj	***Null***
Global intercept	0.799 (0.352) [0.22:1.37]	-3.067 (7.148) [-4.81:-1.31]	-2.655 (1.931) [-4.4:-0.9]	-2.272 (0.307) [-3.19:-1.36]
Week of peak run timing (h_{week})	17.08 (0.553) [16.18:17.98]	17.00 (2.44) [12.85:19.16]		
Spread in run timing (a_{week})	3.368 (4.259) [-3.57:10.31]	5.861 (58.88) [-19.66:31.38]		
Post-injunction		4.919 (5.987) [-5.95:15.79]	0.755 (1.692) [-1.25:2.76]	
Log Likelihood	-266.59	-211.19	-285.65	-285.885

A model including a global intercept, weekly run timing effects, and an injunction effect was successfully fitted. However, in this model, no parameter was estimated with precision, despite models converging and showing relatively low sensitivity to starting parameters. Here, the mean week of peak passage was estimated at week 17 without a sharp peak (the spread in run timing parameter, a_{week}, was estimated to be quite high and highly uncertain). In this model, there was a mean positive effect of the injunction (with log catch rates predicted to be higher by a factor of 4.919 post-injunction; equivalent to multiplying pre-injunction catch rates by 136.9 times) but the estimate of the injunction effect was also highly uncertain (SE = 5.987) and 95% confidence intervals included zero. A model including only the injunction effect and a global intercept also included a highly uncertain injunction effect. In this model, there was a strong negative correlation between the estimated global intercept and the injunction effect (correlation between these estimated parameters = -0.833) and a strong negative correlation between mean the two weekly run timing effect parameters (estimated correlation = -0.785). This model shows signs of being overfitted to the large catch rate ratio observed in 2023 (see model predictions in Figure 45).

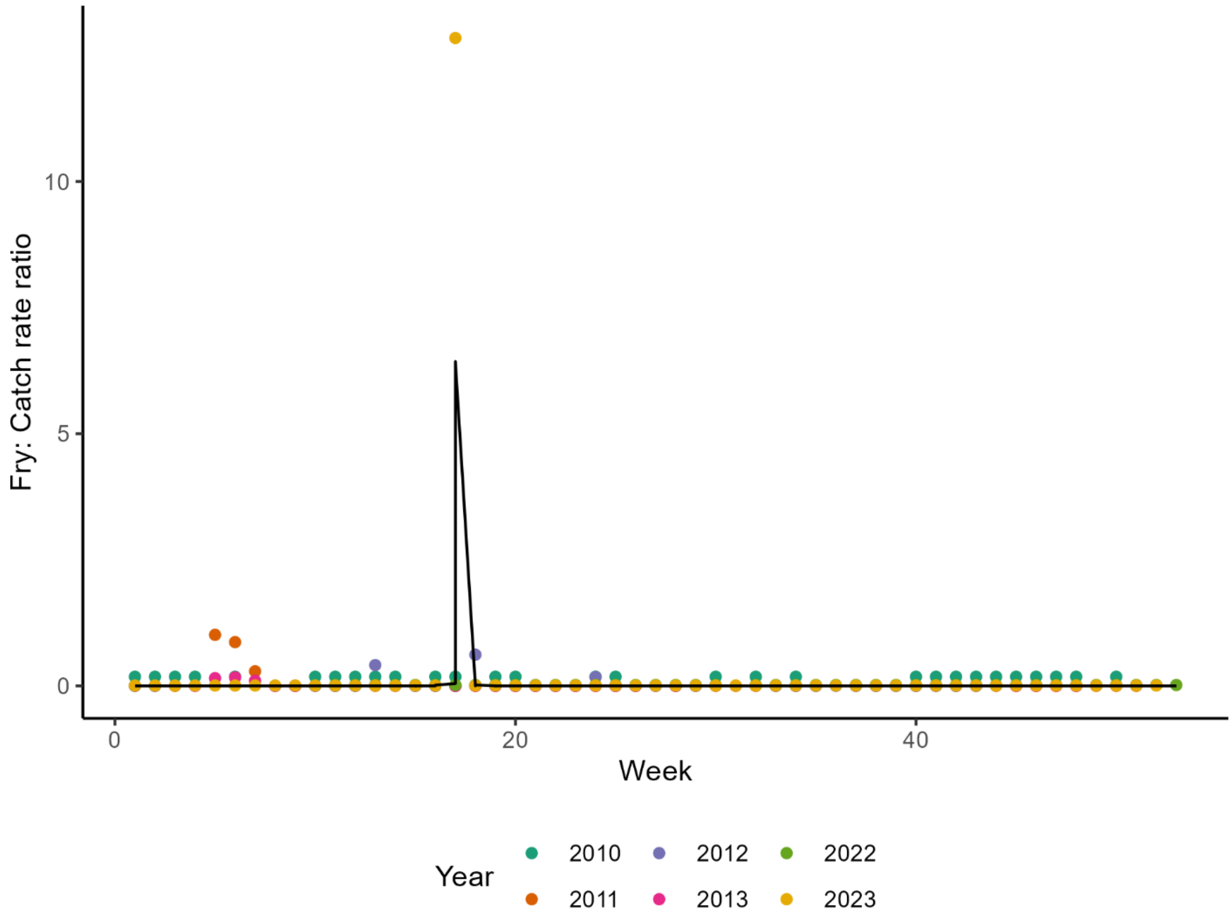

Figure 45. Model-predicted (black line) and observed (points) fry project passage efficiency through the Lookout Point project and passing through one powerhouse RST. Predictions are from the model including weekly run timing effects. Years are differentiated by colored points.

Similar to PPE estimation for fry passing Lookout Point, analysis of PPE for subyearling migrants was limited by the number of RST trap records which captured live wild Chinook. Many models which included a weekly run timing effect or annually varying intercept failed to converge on reasonable parameter estimates and were highly sensitive to starting points used during non-linear optimization. Models including annually varying intercepts did not converge. Models including an intercept varying by water year type converged in some cases, but parameter estimates were sensitive to starting values. A summary of fitted model results is shown in Table 22 .

The most parameterized model, that including weekly run timing effects, an injunction effect, and a global intercept, could be successfully fitted to observations of subyearlings passing Lookout Point project. Subyearling run timing was estimated to peak between weeks 30-32. Both of the fitted models predicted a reduction in PPE post-injunction, but with 95% confidence intervals overlapping with zero by a large margin (Table 22). Both models that included a weekly run timing effect also had poor ability to estimate the amount of spread in run timing, with broad confidence intervals. Due to the relatively poor model fit and uncertainty in parameter estimates, we do not show a figure of model-predicted catch rate ratio from these models as only the intercept was estimated with precision.

Table 22. Table of estimated intercepts, coefficients, parameter standard errors (in parentheses), and 95% confidence intervals (in brackets) estimated by non-linear estimation to model PPE of wild Chinook fry migrants passing Lookout Point project. Intercepts and coefficient values represent the expected effect on ln(catch rate ratio).

Explanatory variable	Week	Week-Inj	Inj	Null
Global	-2.655	-3.024	-5.706	-6.12
intercept	(0.881)	(0.776)	(0.514)	(0.601)
	[-2.92:-2.4]	[-2.21:-1.73]	[-6.53:-4.84]	[-7.1:-5.12]
Week of peak run timing	31.97	30.02		
(h_{week})	(2.24)	(3.59)		
	[30.66:33.32]	[28.37:35.64]		
Spread in run timing	5.65	5.40		
(a_{week})	(22.51)	(37.70)		
	[-6.85:15.87]	[-53.05:66.39]		
Post-		-5.84	-1.78	
injunction		(69.82)	(3.65)	
		[-48.76:36.43]	[-7.84:4.26]	
Log Likelihood	596.85	575.30	571.14	570.60

Time did not permit for analysis of PPE for yearling migrant types at any projects in this Phase 1 report.

Discussion and Conclusions

We could confidently perform statistical tests for injunction effects on fish passage metrics where several years of RST data were available and there were at least two years of RST data post injunction (Table 23). In the few RST sites where this was the case, some positive results on injunction effects were obtained for some metrics; however, we did not identify significant effects for all metrics. Moreover, especially for non-TDG related injury reporting, many categories of injuries were reported at higher rates after injunction measures were implemented (this may also be an artefact of the fact that RST operators changed in the post-injunction period at all below-dam sites, see below for further discussion). Even then, with the high degree of variability in the RST records, we expect the statistical power of our hypothesis tests to be low, and power could be expected to improve with additional years of RST sampling.

Caveats to Phase 1 Analyses

There was as considerable amount of variability between trapping events and between-years variability in the RST catch records and there were only two years of post-injunction data and for some locations, e.g., below Foster, no RST records available for this period. The very large amount of variability in the RST records, and relatively few years and locations where RST records are available both pre and post injunction, created challenges for the assessment of potential injunction effects in the WVS and quantitative characterization of juvenile salmonid growth and run timing. Due to the low number of projects with both pre and post injunction RST records, statistical analysis could be done for relatively few of the WVS projects. And for projects with both pre- and post-injunction records, statistical power in the hypothesis tests could be expected to be very low due to the relatively few years of available data, especially post implementation and large variability in the RST records. It thus remains plausible that for many of the statistical tests carried out, possible actual injunction effects were not statistically detectable and not detected.

Different organizations have operated RSTs over a period of decades. There may be differences in how RSTs were operated and maintained and how often they were checked which creates further challenges for statistical interpretation of the RST records. Operator effects were found in the reporting of different injury categories and when operators changed between pre- and post-injunction periods, this led to confounding between potential injunction and operative effects on the estimated incidence of injuries in captured fish. We avoided carrying out statistical tests for injuries in these circumstances. However, for instances where the same operator provided records both pre- and post-injunction, i.e., USACE at Fall Creek, there were still other operators who provided data post-injunction (EAS), and this still created challenges for accounting for potential joint effects of operator and injunction on the incidence of reported injuries.

The large amount of variability in the TE estimates from TE experiments at WVS RSTs made it challenging to quantitatively characterize TE for these RSTs. Only for the RST which had considerably more TE experiments over a very wide range of mean flows, i.e., Cougar Head of Reservoir, was it possible to obtain a reasonable amount of confidence in developing a predictive model for TE based on mean flow. In only three other of the 16 RSTs for which there were sufficient data for fitting models based on mean flow, could a fitted model be selected over simple models based on means of the sampled TEs. Use of TE sample means only for TE adjustment for RSTs provides only a relatively crude adjustment of RST data for TE and there likely remains a considerable amount of sampling error in the

WVS TE adjusted records due to the observed TEs for each RST sampling event deviating possibly considerably from the actual TE. Further investigation of data from the TE experiments using additional covariates such as mean trap rotation rate, river channel bathymetry and width, gage height, and mean size of fish released for each experiment could help to further improve the accuracy of approaches for TE adjustments to the RST records.

Table 23. Summary of statistical results on trap efficiency (TE), migration timing, reported injury rate, total dissolved gas (TDG) effects, and project passage efficiency (PPE). Growth metrics could not be statistically assessed due to data limitations and are not included here. TE results summarize the top-model identified to describe trap efficiency at that location (Exp. = exponential; where TE was found not to be related to flow, the sample mean TE at the RST site was applied; when the sample means were significantly different pre and post injunction, the sample mean TE from each period, respectively, was applied). Migration timing results show stage-specific results of Kolmogorov-Smirnov tests (significant results indicate the distribution of TE-adjusted catch rates are significantly different in the post-injunction period; non-reported migrant stages had too few data for analysis). Injury rate results indicate which injury categories were reported at a significantly different rate between pre- and post-injunction periods (+ indicates higher reporting post-injunction, - indicates lower reporting; decap. = decapitated, cope. = copepod infection). TDG and PPE results summarize significant injunction period effects. Results for fry are indicated with F, subyearlings with S, yearlings with Y, and for all pooled together with "All". n.s. = not significant, NA = not assessed due to data limitations. Blue cells indicate tests where injunction effects were significant and in line with what was hypothesized, yellow cells indicate significant results in mixed directions relative to hypothesized, orange cells indicate significant results in the opposite direction to hypothesized, and gray cells indicate non-significant results. Table continues on the following page.

RST location	Trap efficiency	Migration timing	Injury rate	TDG effects	PPE
Detroit HOR	Exp. decay with flow			*NA*	*NA*
Big Cliff TR	Exp. decay with flow	F; S; Y; All	Body +; head +; gill +; eye +; internal -	GBD, barotrauma, mortality all lower post injunction	
Foster TR (pre only)	*NA*		*NA*	*NA*	*NA*
Green Peter TR (post only)	TE not related to flow		*NA*	*NA*	
Cougar HOR	Exp. decay with flow			*NA*	F and S: PPE higher post-injunction
Cougar TR (RO)	TE not related to flow	F-n.s S; All	Body +; head +; decap. -; eye +; gill +; cope. +; internal -	GBD, barotrauma, mortality all lower post injunction	
Cougar TR (PH)	Exp. decay with flow	F	Body +; head +; descale +; eye +; gill +; cope. +; internal +	*NA*	
Fall Creek HOR	TE not related to flow			*NA*	F and S: n.s.
Fall Creek TR	TE lower post injunction		Body +; eye +; gill +; cope. +; internal +	*NA*	

RST location	Trap efficiency	Migration timing	Injury rate	TDG effects	PPE
Hills Creek HOR	TE lower post injunction			*NA*	*NA*
Hills Creek TR (RO)	TE not related to flow	Y-n.s.	n.s.	*NA*	
Hills Creek TR (PH)	TE not related to flow		Body +; head +; eye +; gill +; cope. +; internal +	*NA*	
Lookout Point HOR	TE not related to flow			*NA*	F and S: n.s.
Lookout Point TR (PH1)	TE lower post injunction	S; Y; All	Body +; decap. +; eye +; gill +; internal +	*NA*	
Lookout Point TR (PH2)	TE lower post injunction	S All-ns	Body +; internal +	*NA*	*NA*
Lookout Point TR (spillway)	TE not related to flow	All S-ns; Y-ns	Body +	*NA*	*NA*
Dexter TR (post only)	TE not related to flow		*NA*	*NA*	*NA*

Summary of TE results

As might be expected due to site-specific differences, TE estimates varied markedly between RST sites; but they also varied markedly between experiments at a given RST site. TE trial operators have changed between periods and at some RST sites the specific locations and trap sizes deployed were not constant over time. With the information currently available, it has remained challenging to explain these large variations in TE estimates at given RST sites and between different RST sites.

Due to the greater availability of records of mean flow with TE experiments, only mean flow was considered as a potential explanatory variable and covariate in this analysis. At four RST sites, mean TEs were found to decrease markedly after injunction measures were implemented, with the differences in mean TE significantly different between pre- and post-injunction periods. At two of these sites (LOP PH1 and LOP PH2) the trap locations have not been constant over time (David Trachtenbarg, pers. commn), which could explain some of this difference in mean TE. In four of the 16 RST sites where there were sufficient data to fit a TE model, either the exponential or exponential plus constant models were found to be more suitable than other options considered. In no cases were the beta regression model selected based on model diagnostics. The exponential and exponential plus constant models provided apparently better fits to the data than the beta regression model when fitted models were selected over the models based on sample means for TE.

A few potential reasons for the commonly observed large variability between TE estimates at a given RST site are mentioned here. Origin could be a one factor; most of the TE trials were conducted with hatchery-origin fish as there were typically not enough captures of natural-origin fish to conduct run-of-river TE trials. Hatchery-origin fish may not always be similarly motivated to migrate, which could affect TE as RSTs are likely to capture fish rearing in a reach at a much lower rate. Juvenile salmonids also typically move in schools. TE studies have sometimes made attempts to release tagged fish in small groups across river channels to prevent schooling behaviour (e.g., EAS 2024b). Tagged salmonids from a given release event could thus either migrate in groups within the area of vulnerability to the RST or not, depending on factors impacting downstream movement. It is also possible that the presence of salmonid predators upstream of RSTs could reduce the abundance of tagged fish vulnerable to capture either by direct predation or through predator avoidance responses in the tagged fish. This could contribute to increased variance between trapping events, depending on the presence, abundance and effectiveness of predators in the vicinity of RSTs. Mean catchability in RSTs could potentially vary with mean size of the juvenile salmonids released in TE studies with larger fish potentially being less vulnerable due to potentially advanced abilities in larger sized fish to avoid objects such as RSTs. Finally, river channel bathymetry could also influence the mean TE of a given RST site. For example, an RST may be located in a very wide river channel where river width remained relatively invariant to changes in river flow. Such a location could have numerous potential downstream routes for downstream migrating juvenile salmon across the width of the river surrounding the RST, which could lead to lower mean TEs than RST sites located in narrower river channels.

Future analyses of TE records for WVS RST sites could potentially consider mean trap rotation rate (RPM) and mean length of tagged fish released as covariates. However, for 14 RST sites, EAS (2024b) found only one site where a model with RPM as a covariate was preferred over other models and that in 3 of the sites, a model with both RPM, mean flow plus interaction effect was preferred. In 5 of the 14 sites the correlation coefficient between mean flow and RPM was either negative or relatively small, i.e., < 0.5 but larger than 0.69 in the rest of the sites. This suggests that mean flow and trap rotation rate may either work synchronously or at odds with each other depending on the RST site. In the Sacramento River Basin, Voss and Poytress (2020) computed the percentage of discharge volume sampled in each RST trapping event and found that TE for juvenile winter Chinook salmon per trapping event could be explained by % discharge volume sampled with a 70% R-squared in 79 trapping events. This suggests that it may also be worthwhile assembling hydrological and bathymetric information for each RST trapping event to assess potential relationships between TE and % discharge volume sampled per trapping event at RST sites. It is also important to consider specific site conditions. For example, the Dexter tailrace trap was moved in 2023 due to conflicts with Dexter fish facility construction, and the LOP tailrace PH traps were slightly realigned in 2023 (David Trachtenbarg, pers. commn). However, statistical tests of whether such modifications affected mean TE at a given site could only be valid with at least two years of TE trials on either side of these modifications. Alternative likelihood functions to the normal likelihood could also be considered, especially given the potential heteroskedasticity in model fit residuals.

Summary of fish size and timing of passage analysis

The figures shown in the “Run timing and fork length analyses” section show how much data was collected at each site. This can improve the understanding of the opportunities and difficulties of using the RST data sets. Having reasonably long-term data sets is useful, but not every site was observed every year, and the data was collected by different operators. It is quite likely that traps were not operated in a completely consistent manner from year to year and observer to observer. The placement of the trap may also not have been exactly the same each year due for example to variation in hydrological conditions between years.

One possible line of future research is to develop a model that uses age structure in a time structured model. For example, sub-yearlings were fry that did not migrate in the previous season. However, such a model was not considered or developed for this report.

After TE adjustments have been applied to RST data, it has been assumed that catch rate is proportional to abundance. However, due to high variability in observed TEs for given RSTs, it remains possible that the catch rates for a trap may not correlate very well with abundance of fish passing, even after adjustments for trap efficiency have been made. While we focus catch rates, this may have limited usefulness as an index of the abundance of fish passing. For many analyses in this report the use of catch rates is probably valid since we are relating run timing to growth, survival, and other metrics of interest. However, it is important to note that raw counts, counts adjusted by trap efficiency, and catch rates (adjusted by trap efficiency and hours of trap operation) may all be poorly associated with actual number of fish passing WVS RSTs.

Summary of analysis of injunction effects on fish growth patterns

Growth analysis proved challenging owing to limited ranges of observed fish length across a wide range of dates. We caution that interpretation of the growth curves estimated in this report are limited by the relative absence of large-bodied individuals due to RSTs being located in areas where young juvenile fish reside. While this limitation was expected, it hampered our ability to estimate growth rate and asymptotic size as the majority of fish captured were much smaller than the maximum fish size estimated from growth models. Only for a few combinations of site and injunction period was it possible to fit growth curve models to observed data; as a result, it was not possible to perform statistical analysis to compare pre- and post-injunction growth rates.

Summary of analysis of injunction effects on injury reporting

Injunction effects on injury and body condition were not intuitive, considering non-TDG-related injuries. At many RST locations below dams and for many injury categories, especially those with consistent and high reporting across sites like body injury, injury rates were higher in the post-injunction period. Only a few injury categories at a few sites declined post-injunction. These included, for example, reduced incidence of decapitation at the Cougar RO trap. RO surfacing was completed in fall 2023 and is believed to reduce the risk of injury to fish passing the dam through the RO. With additional years of RST data from the Cougar RO trap, future analyses could assess if there was a statistically detectable change in post-injunction injury reporting before and after the resurfacing was completed.

We caution that these results do not indicate conclusively that true injury rates increased as a result of injunction measures. At all sites except for the tailrace trap at Fall Creek, the RST operator changed between the pre- and post-injunction periods, such that differences between operators may be obscuring an effect of injunction measures on injury rates. Supporting this is our finding that at many sites with significant differences in injury reporting pre- versus post-injunction, there was also a statistically significant effect of operator (but not in all cases). Our more in-depth analysis comparing operator and injunction effects at Fall Creek indicated that both operator and injunction period were informative to observed injury rates of all categories.

Disentangling injury reporting rates may be possible if there were additional information on the efficiency of different operators at identifying different types of injuries. This could be informed by in-the-field experiments and/or interviews with those who were responsible for trapping and injury reporting. In a follow-up analysis, we could consider a more robust statistical framework with which to account for overdispersion in catches at Fall Creek, and potentially new ways of categorizing relevant injuries. In a future analysis, we intend to account for overdispersion in our assessment of operator versus injunction effects using observations at Fall Creek by applying a quasi-binomial regression and analysis of deviance approach instead of the AIC-based model selection approach reported here. Additionally, to maximize the number of fish available with which to assess injury rates, we did not exclude hatchery fish from our analysis. However, there are several types of injuries which are likely to occur as a result of hatchery release and handling, for example descaling, not as a result of dam operations. We cannot rule out the possibility that changes to observed injury rates are related to changes in the prevalence of hatchery fish captured in RSTs between the pre and post injunction periods.

Summary of analyses incorporating effects of TDG on barotrauma and mortality

The results from statistical analysis of WVS RST data indicate that at Big Cliff and Cougar, the injunction measures have reduced GBD and barotrauma injury incidence as well as the overall mortality rate recorded in juvenile Chinook salmon captured in rotary screw traps. The mechanisms behind this are not clear, but the maximum TDG levels recorded below Big Cliff are lower in the post-injunction period. TDG is generally lower below Cougar. Maximum TDG of >130% resulted in 100% incidence of GBD, with over 50% of fish captured in those high TDG trap events being dead. This suggests that mitigation measures to reduce TDG below 130% through dam spill operations may have reduced the risks to threatened Chinook salmon populations. It appears that larger juvenile Chinook salmon are more likely to have barotrauma-related injuries or be found dead in traps under higher spill discharge conditions. This may be related to size, as the probability of fish having these conditions was higher in the spring when larger yearlings are migrating.

We cannot rule out that the lower injury incidence and mortality rates in the post-injunction period may be an operator effect, but it was not possible to test this as all RST data pre-injunction was collected by ODFW. However, both Cramer and EAS recorded lower injury incidence in the post-injunction period, indicating that the reduction was real and not a result of different injury incidence recording. As RSTs do not sample the entire population, with trap efficiency typically much lower than 10%, our results may also be dependent upon the TE adjustments made, and the assumption that healthy, injured, and dead fish are captured with the same efficiency. While this assumption may be a simplification and refinements could be made to the TE adjustments, we note that similar results, including the injunction effects detected, were obtained when numbers captured per trap event were not adjusted for trap efficiency. We also caution that these results are only from two sites and may not be replicated below all projects. Indeed, as seen in the previous section, Big Cliff and Cougar were the only sites where there were positive effects of the injunction measures on internal injuries; at the other dams the reported internal injury rate had increased post-injunction. From these two sites alone, we found evidence of site-specific effects in how TDG affects GBD, as although TDG was lower below Cougar, the GBD incidence was greater. Data recording of TDG below the other dam projects is required in the future to further examine these effects and understand if they are consistent across all sites.

Finally, we note that although this is the case in both pre- and post-injunction periods, captured fish are held close to the surface in the trap box. This means that the use of RST data to understand GBD incidence may reflect a worst-case scenario. Furthermore, there was a higher proportion of captured fish with GBD the longer they were held in traps where the potential exposure time to TDG is increased, as was the case during the pre-injunction period where trap event duration was up to two days compared to only one day post-injunction. This is intuitive given the inability to depth compensate; the ability to move to a depth of 1m would reduce the TDG experienced by 9.7% compared to the TDG at the surface (Pleizier et al. 2020b).

Summary of analysis of injunction effects on PPE

We also did not consistently detect a statistically significant injunction effect on project passage efficiency. Results of models of PPE at Cougar dam indicated a positive and strong increase in PPE after injunction measures were put in place. For fry passing Cougar dam, PPE post-injunction was estimated to increase by a factor of 2.4 times; for subyearlings, the estimated increase was even higher at 21-times pre-injunction estimates. At the other two locations where PPE analysis was possible—Fall Creek and Lookout Point—our ability to fit reasonable models was impeded by few years of data and years where zero fish of a given migrant type were captured either above- or below-dams. At these sites, injunction effects were estimated with poor precision and wide confidence intervals. Models that included weekly run timing effects and any of the candidate hydrological explanatory variables (i.e., temperature, depth to outlet, and outflow) would not converge and could not be assessed. Interannual variability, which can obscure injunction effects, was also likely to be high (e.g., at Fall Creek, where the number of adults outplanted above the dams for spawning has been variable and quite low in some years). While our analysis attempted to account for relative juvenile abundance by comparing the ratio of catches at a dam tailrace to that at the head of reservoir, there may be additional effects of fish density that are not accounted for in the catch ratio (e.g., schooling and other density-dependent behaviors).

As was the case in the growth analysis, data limitations and limited contrast in catch rate data impeded model fitting and assessment of injunction effects, with many years dominated by weeks with zero live catches of wild Chinook migrants. Future analysis will seek to better represent migrant run timing, e.g., by considering multi-modal distributions and allowing for changes in run timing resulting from injunction measures. While these could improve our ability to fit models to observations of subyearling migrants at Lookout Point project, lack of overlapping RST records between HOR and tailrace RSTs at USACE projects remains a major limitation to our ability to assess PPE. Were RST records from 2024 were made available, we would have sufficient data to also assess PPE at the Detroit-Big Cliff complex and from Hills Creek. Currently, RST records are available from the Big Cliff and Detroit complex for 2014-2016 in the pre-injunction period, and 2023 for the post-injunction period. At Hills Creek, RST records are available from the head-of-reservoir and powerhouse channel RST from 2013 and 2015 (with records from the RO RST available only from 2015).

Potential refinements for future analysis

We list briefly below some potential additional areas of analysis to further refine assessment of potential effects of injunction measures on fish passage metrics. Future analyses will depend on the availability of additional data (from RST and other sources), data cleaning required, and on the research activities of other groups that are responsible for collecting and analysing new active tag data (e.g., U.S. Geological Survey and Pacific Northwest National Laboratory).

- Possible refinements to TE analyses
    1. What are the potential effects of size of fish released for TE experiments, channel width, channel bathymetry, RST RPM, gage height, trap operator on TE?
    2. What are the causes of the marked pre-post injunction changes in TE for the four RSTs where this was found when there were no accompanying changes in mean flow?
    3. How important is fish behaviour, e.g., schooling, predator avoidance, in determining TE?
- Identifying where TE adjustments to the RST records could be expected to make a difference in statistical tests for injunction effects on fish passage metrics and providing some additional statistical tests with and without the application of TE adjustments to characterize where TE adjustments made and did not make differences in results of statistical tests.
- Testing for injunction effects in the active tagging study results in the WVS projects
- Initiation of Project Passage Efficiency analysis for yearlings
- Statistical power analysis in tests for effects of injunction measures on project passage metrics
- If available and in suitable condition for timely analysis, incorporate available RST records from spring 2024.

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Appendices

Appendix A: Summary tables of RST observations.

In this Appendix we report the number of observations at each site, pre- and post-injunction, with tables for each migrant type. We include all observations of natural- and hatchery-origin Chinook, except for the fish used for trap efficiency studies.

Also, the mean week of passage, median week of passage, mean fork length, and median fork length was computed. The values in these tables are not corrected by trap efficiency. The p-values are from a boot strap test to compare the mean week of passage pre and post injunction and mean fork length pre and post injunction raw counts by week. These tables were produced for Fry, sub yearlings, and yearlings and record just the results from the observed captures. Figures are not adjusted by trap efficiency or the numbers of hours that a trap was operating.

Table A 1. Summary table of observations of Chinook Fry pre and post injunction. These are raw counts and show the number of observations pre injunction, the mean and median week of passage, mean and median fork length in mm, p-values from testing if mean week of passage is different pre vs post injunction, p-values from testing if mean fork length is different pre vs post injunction. Med: median, FL: fork length. Table continues on following page.

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
All	30302	15	15	37	37	16282	20	21	36	35	1.0 E-4	1.0 E-4	-4.4	0.41
BCL	45	9.5	8	37	37	131	9.8	8	37	36	0.739	0.706	-0.3	0.24
BRE	4088	13	12	36	36	20	25	25	51	52	-	-	-12	-16
CGR PH	879	17	16	40	40	401	16	14	39	38	4.0 E-4	0.004	0.86	1.1
CGR RO	96	16	16	40	40	42	18	18	41	39	0.054	0.53	-2.2	-0.72
BRZ	14	19	18	38	38	0	-	-	-	-	-	-	-	-
DET PH	0	-	-	-	-	0	-	-	-	-	-	-	-	-
FOS 5FT	1	47	47	36	36	0	-	-	-	-	-	-	-	-
FOS 8FT	474	11	9	39	39	0	-	-	-	-	-	-	-	-
HCR HOR	255	13	12	36	36	91	21	22	43	43	1.00E-4	1.0 E-4	-8.5	-6.4
NFMF	570	11	11	36	36	0	-	-	-	-	-	-	-	-
LOP HOR	3491	14	14	37	37	146	14	12	41	37	0.507	1.0 E-4	-0.37	-4
DET HOR	4632	17	17	37	37	9120	21	21	36	35	1.0 E-4	1.0 E-4	-4.1	1
CGR HOR	13962	17	17	36	36	5137	20	21	36	36	1.0 E-4	0.954	-3.1	-0.0033
FOS HOR	1076	9.6	8	36	36	589	10	11	36	36	0.0064	0.345	-0.84	0.12
HCR PH	17	7.9	9	36	36	220	13	12	36	36	-	-	-4.9	0.35
FCR HOR	406	11	11	35	35	141	8.9	10	35	34	1.0 E-4	0.264	2.4	-0.29
FCR	264	6.5	7	38	38	59	12	11	40	37	1.0 E-4	0.0018	-5.6	-2.6

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
LOP PH1	27	9.4	6	40	40	1	17	17	52	52	-	-	-7.6	-12
HCR RO	2	13	13	38	38	125	12	12	36	35	-	-	0.56	1.9
LOP PH2	2	18	18	46	46	6	16	16	42	36	-	-	1.3	3.2
LOP SP	1	20	20	47	47	3	29	20	43	44	-	-	-9	3.7
DEX	0	-	-	-	-	4	25	26	51	52	-	-	-	-
GPR	0	-	-	-	-	25	19	20	52	55	-	-	-	-
GPR HOR	0	-	-	-	-	21	19	19	36	36	-	-	-	-

Table A 2. Summary table of observations of Chinook subyearlings pre and post injunction. These are raw counts and show the number of observations pre injunction, the mean and median week of passage, mean and median fork length in mm, p-values from testing if mean week of passage is different pre vs post injunction, p-values from testing if mean fork length is different pre vs post injunction. Wk: weekly; med: median, FL: fork length. Table continues on following page.

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
All	23497	41	43	120	120	11335	40	43	110	110	1.0 E-4	1.0 E-4	0.66	7.3
BCL	873	35	30	140	140	1179	34	30	130	130	0.0578	1.0 E-4	0.68	4.4
BRE	93	37	40	80	80	356	38	38	89	90	0.168	2.0 E-4	-1.2	-9.5
CGR PH	4740	43	44	120	120	807	39	40	120	120	1.0 E-4	2.0 E-4	3.8	3.4
CGR RO	7733	45	46	130	130	5830	44	44	120	120	1.0 E-4	1.0 E-4	1.3	6.7
DET BRZ	191	44	46	150	150	0	-	-	-	-	-	-	-	-
DET PH	187	43	45	160	160	0	-	-	-	-	-	-	-	-
FOS 5FT	4	44	42	130	130	0	-	-	-	-	-	-	-	-

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
FOS 8FT	77	31	28	110	110	0	-	-	-	-	-	-	-	-
HCR HOR	122	39	41	91	91	5	24	25	69	72	-	-	14	23
NFMF	216	40	42	97	97	0	-	-	-	-	-	-	-	-
LOP HOR	263	27	24	76	76	75	30	25	79	77	0.0422	0.274	-2.4	-2.9
DET HOR	1195	37	38	82	82	1022	39	42	76	79	1.0 E-4	1.0 E-4	-1.5	6.2
CGR HOR	4403	34	33	64	64	1356	33	31	61	58	0.0036	1.0 E-4	0.5	3.9
FOS HOR	141	31	29	97	97	129	42	46	100	100	1.0 E-4	0.0354	-11	-3.9
HCR PH	1048	44	47	170	170	123	45	47	170	180	0.0652	0.66	-0.92	1.1
FCR HOR	17	19	19	72	72	6	20	20	77	80	-	-	-0.82	-4.9
FCR	1912	44	43	180	180	85	42	42	180	180	1.0 E-4	0.0246	1.3	4.9
LOP PH1	242	28	24	100	100	20	36	30	130	120	-	-	-8.6	-28
HCR RO	8	47	44	130	130	69	48	49	160	180	-	-	-1.8	-31
LOP PH2	22	42	48	120	120	41	42	50	110	110	-	-	0.3	6.8
LOP SP	10	26	24	110	110	61	42	50	120	110	-	-	-16	-4.7
DEX	0	-	-	-	-	85	34	27	110	110	-	-	-	-
GPR	0	-	-	-	-	82	23	21	75	72	-	-	-	-
GPR HOR	0	-	-	-	-	4	46	45	110	100	-	-	-	-

Table A 3. Summary table of observations of Chinook yearlings pre and post injunction. These are raw counts and show the number of observations pre injunction, the mean and median week of passage, mean and median fork length in mm, p-values from testing if mean week of passage is different pre vs post injunction, p-values from testing if mean fork length is different pre vs post injunction. Wk: weekly; med: median, FL: fork length. Table continues on following page.

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
All	7650	27	22	180	180	2693	18	16	150	150	1.0 E-4	1.0 E-4	9.1	27
BCL	163	26	23	180	180	614	17	17	160	160	1.0 E-4	1.0 E-4	9.2	14
BRE	3	5.3	6	95	95	0	-	-	-	-	-	-	-	-
CGR PH	1439	11	11	130	130	397	11	9	120	120	0.0594	1.0 E-4	-0.73	11
CGR RO	1364	18	16	150	150	1232	18	15	150	150	0.149	0.756	0.69	-0.43
DET BRZ	62	13	8	170	170	0	-	-	-	-	-	-	-	-
DET PH	18	36	45	180	180	0	-	-	-	-	-	-	-	-
FOS 5FT	1	3	3	120	120	0	-	-	-	-	-	-	-	-
FOS 8FT	46	22	25	140	140	0	-	-	-	-	-	-	-	-
HCR HOR	66	15	15	92	92	0	-	-	-	-	-	-	-	-
NFMF	73	14	14	100	100	0	-	-	-	-	-	-	-	-
LOP HOR	99	11	10	91	91	29	11	12	97	96	-	-	-0.028	-5.6
DET HOR	64	12	11	97	97	0	-	-	-	-	-	-	-	-
CGR HOR	61	10	11	91	91	68	11	11	90	89	0.475	0.748	-0.4	0.69
FOS HOR	10	11	11	110	110	28	12	12	110	110	-	-	-1.1	-2.4
HCR PH	1181	26	34	200	200	83	38	49	210	210	1.0 E-4	0.107	-13	-8.3
FCR HOR	5	11	11	120	120	8	10	11	140	130	-	-	1.1	-22
FCR	2618	44	45	220	220	9	19	14	130	120	-	-	25	83
LOP PH1	293	14	7	170	170	30	16	18	160	160	0.249	0.637	-2.1	4.1
HCR RO	57	36	45	230	230	76	40	48	220	220	0.125	0.134	-4.8	7.8
LOP PH2	23	19	19	160	160	10	29	25	180	180	-	-	-11	-15
LOP SP	4	28	24	190	190	43	20	19	160	160	-	-	7.5	32

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
DEX	0	-	-	-	-	66	22	21	150	160	-	-	-	-
GPR	0	-	-	-	-	0	-	-	-	-	-	-	-	-
GPR HOR	0	-	-	-	-	0	-	-	-	-	-	-	-	-

Table A 4. Summary table of observations of Chinook all migrant types pre and post injunction. These are raw counts and show the number of observations pre injunction, the mean and median week of passage, mean and median fork length in mm, p-values from testing if mean week of passage is different pre vs post injunction, p-values from testing if mean fork length is different pre vs post injunction. Table continues on following page.

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
All	62391	27	21	85	85	30456	27	22	74	41	1.0 E-4	1.0 E-4	-0.49	11
BCL	1094	32	30	140	140	1943	27	29	140	140	1.0 E-4	0.019	5.5	3.6
BRE	4185	13	12	37	37	376	38	38	87	89	1.0 E-4	1.0 E-4	-25	-50
CGR PH	7068	33	42	110	110	1621	26	23	98	100	1.0 E-4	1.0 E-4	6.6	15
CGR RO	9196	41	45	130	130	7106	39	44	130	120	1.0 E-4	1.0 E-4	1.8	4.5
DET BRZ	270	35	42	150	150	0	-	-	-	-	-	-	-	-
DET PH	205	42	45	160	160	0	-	-	-	-	-	-	-	-
FOS 5FT	6	37	42	110	110	0	-	-	-	-	-	-	-	-
FOS 8FT	598	15	10	56	56	0	-	-	-	-	-	-	-	-
HCR HOR	443	20	14	60	60	96	22	22	44	44	0.0484	1.0 E-4	-1.3	16
NFMF	860	19	13	57	57	0	-	-	-	-	-	-	-	-
LOP HOR	3856	15	14	41	41	252	19	21	59	52	1.0 E-4	1.0 E-4	-4	-18
DET HOR	5892	21	18	47	47	10143	23	21	40	35	1.0 E-4	1.0 E-4	-1.8	6.9

Trap	Pre Count	Pre Mean Week	Pre Med Week	Pre Mean FL	Pre Med FL	Post Count	Post Mean Week	Post Med Week	Post Mean FL	Post Med. FL	Week Test	FL test	Week diff	FL diff
CGR HOR	18429	21	18	43	43	6638	23	21	42	37	1.0 E-4	1.0 E-4	-1.7	1.3
FOS HOR	1227	12	9	44	44	749	16	12	50	36	1.0 E-4	1.0 E-4	-3.9	-6.2
HCR PH	2322	34	45	190	190	438	27	16	110	42	1.0 E-4	1.0 E-4	7	78
FCR HOR	428	12	11	37	37	156	9.4	10	42	34	1.0 E-4	0.0054	2.2	-5
FCR	5567	42	44	190	190	155	29	42	120	150	1.0 E-4	1.0 E-4	13	72
LOP PH1	605	19	20	130	130	53	25	22	150	140	0.002	0.0314	-6.4	-14
HCR RO	73	36	45	210	210	275	30	16	120	100	0.0168	1.0 E-4	6.8	91
LOP PH2	52	31	27	140	140	57	37	47	120	110	0.041	0.014	-6.3	22
LOP SP	15	26	24	130	130	109	33	27	130	120	-	-	-7.1	-3.1
DEX	0	-	-	-	-	157	29	25	130	120	-	-	-	-
GPR	0	-	-	-	-	107	22	21	70	67	-	-	-	-
GPR HOR	0	-	-	-	-	25	23	19	47	37	-	-	-	-

Appendix B: Trap efficiency

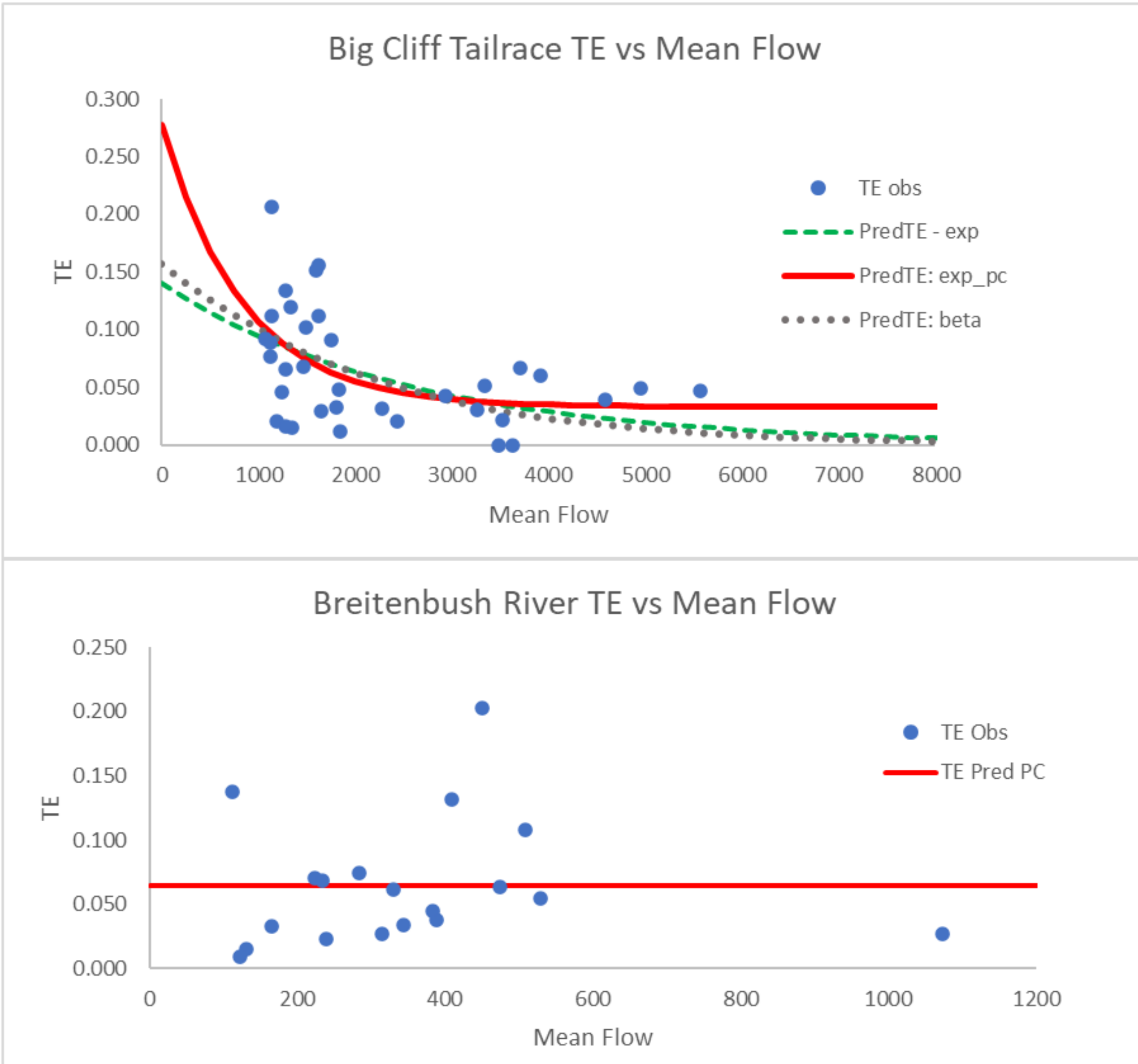

Figure A 1. Plots of observed TE (TE obs) versus mean flow for RSTs at the Big Cliff Tailrace and Breitenbush River. Mean flow is in cfs. TEs predicted from fitted exponential (exp), exponential plus constant (exp_pc), and beta regression models are also plotted where fits of these models were obtainable. Where a flat curve is shown, e.g., for Breitenbush River, the fitted models predicted a constant TE.

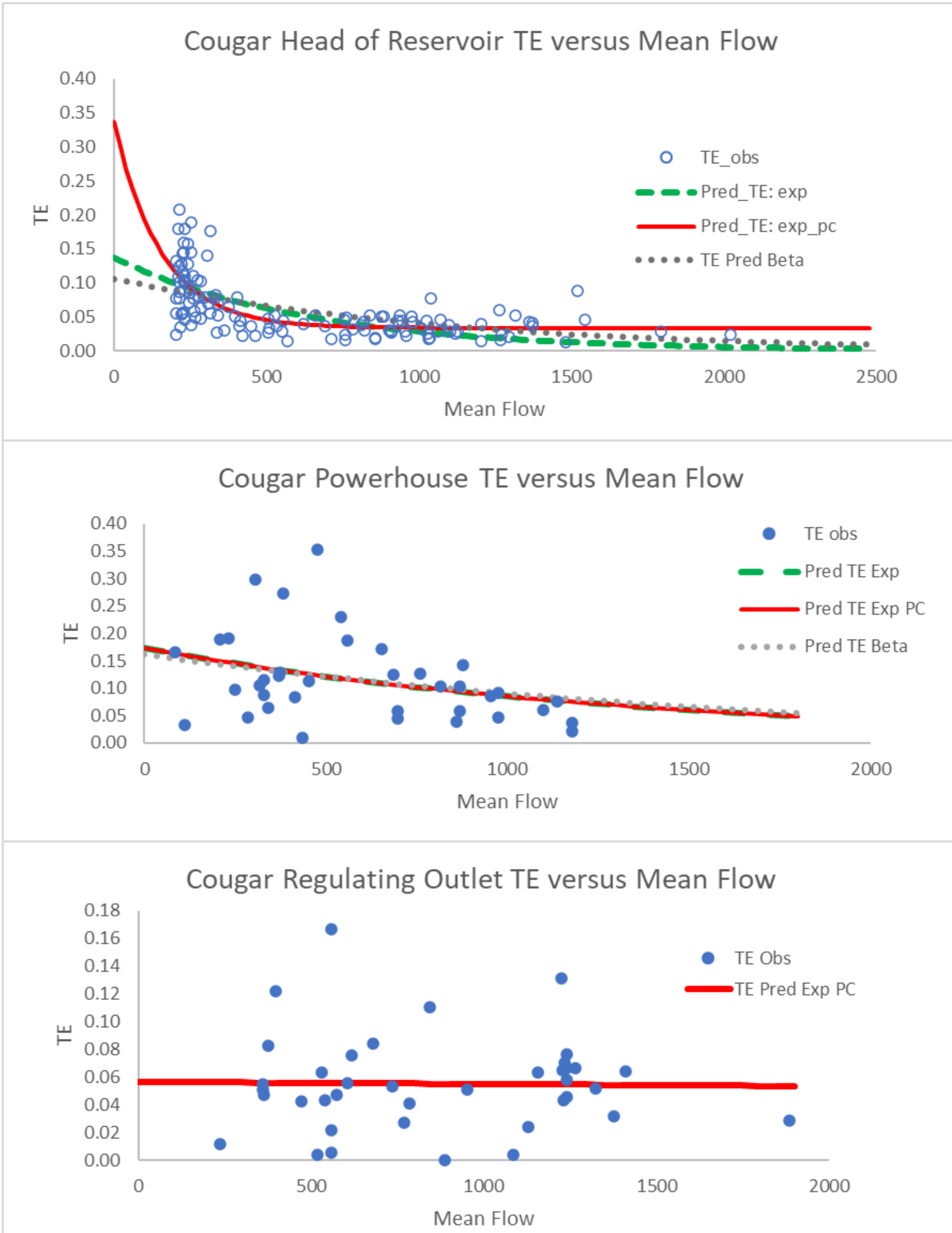

Figure A 2. Plots of observed TE (TE obs) versus mean flow for RSTs at the Cougar Head of Reservoir, Cougar Powerhouse and Cougar Regulating Outlet. Mean flow is in cfs. TEs predicted from fitted exponential (Exp), exponential plus constant (Exp_PC), and beta regression models are also plotted where fits of these models were obtainable. Where a flat curve is shown, the fitted models predicted a constant TE.

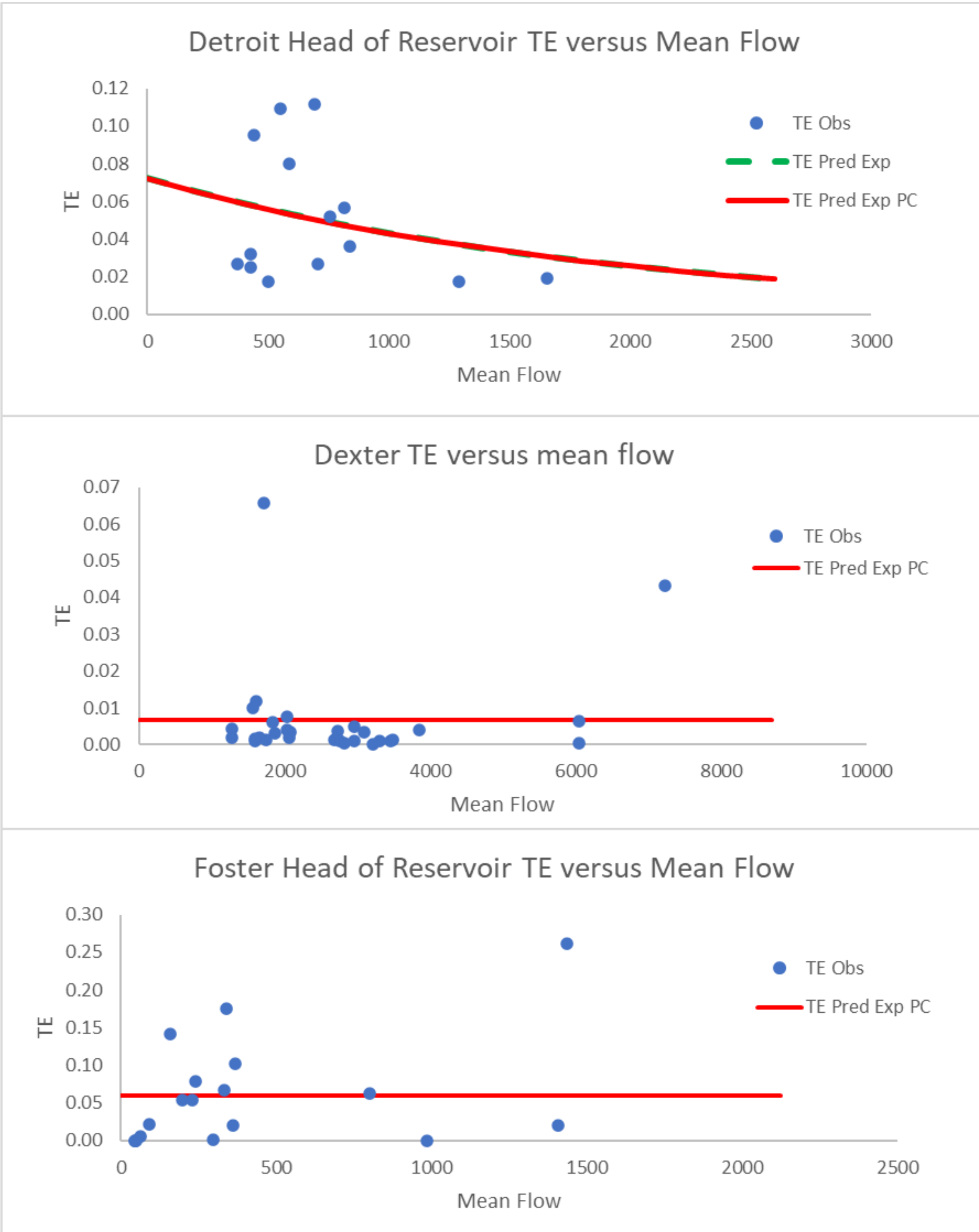

Figure A 3. Plots of observed TE (TE obs) versus mean flow for RSTs at the Detroit Head of Reservoir, Dexter and Foster Head of Reservoir. Mean flow is in cfs. TEs predicted from fitted exponential (exp), exponential plus constant (Exp_PC) are also plotted for the Detroit HOR RST site. A fit of the beta regression model was not obtainable for these three RST sites. Where a flat curve is shown, the fitted models predicted a constant TE.

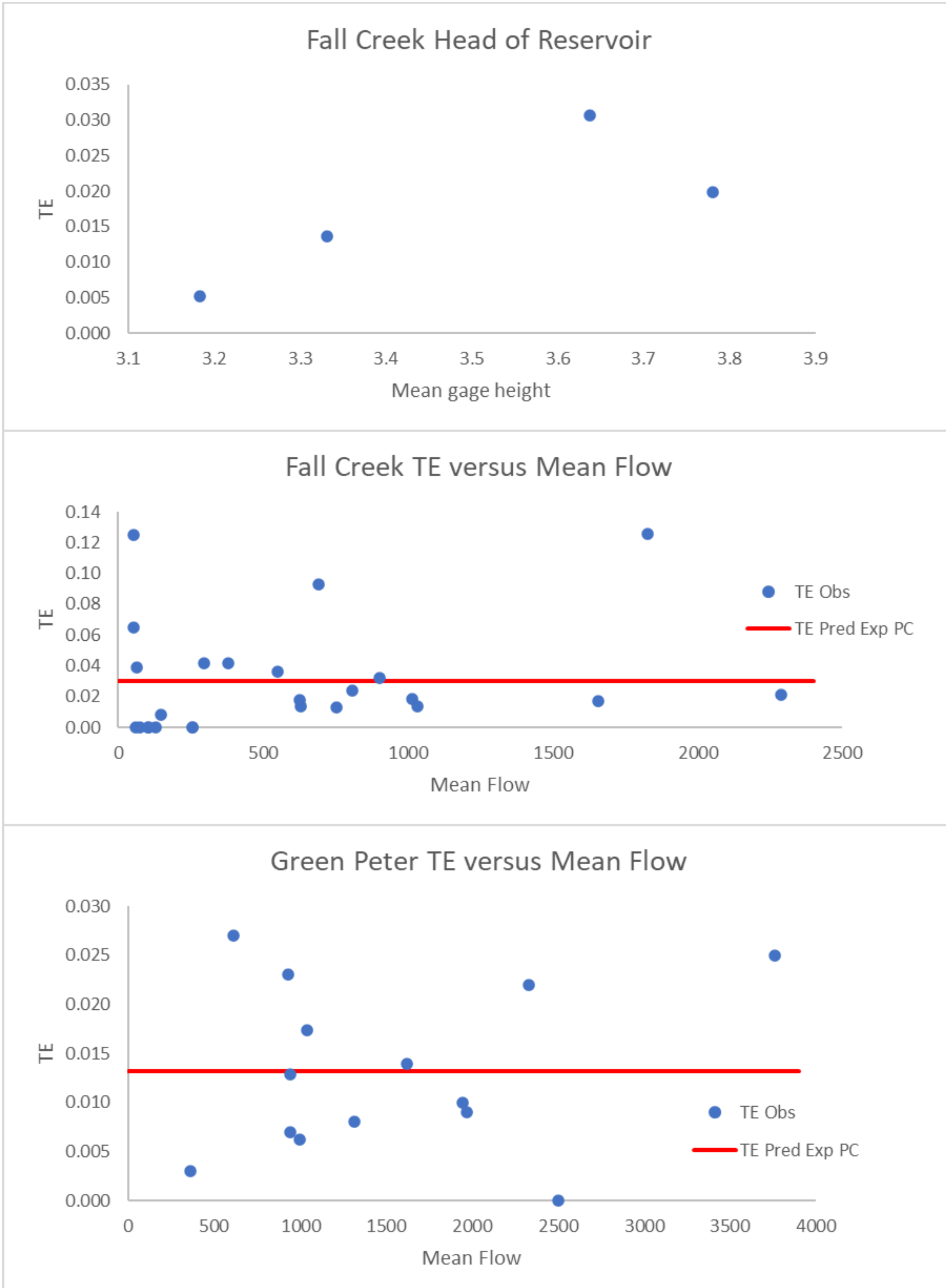

Figure A 4. Plots of observed TE (TE obs) versus mean gage height / flow for RSTs at the Fall Creek Head of Reservoir, Fall Creek Tailrace and Green Peter Tailrace. Mean flow is in cfs. Mean gage height is in feet. TEs predicted from fitted exponential (exp), exponential plus constant (Exp_PC), and beta regression models are also plotted where fits of these models were obtainable. Where a flat curve is shown, the fitted models predicted a constant TE.

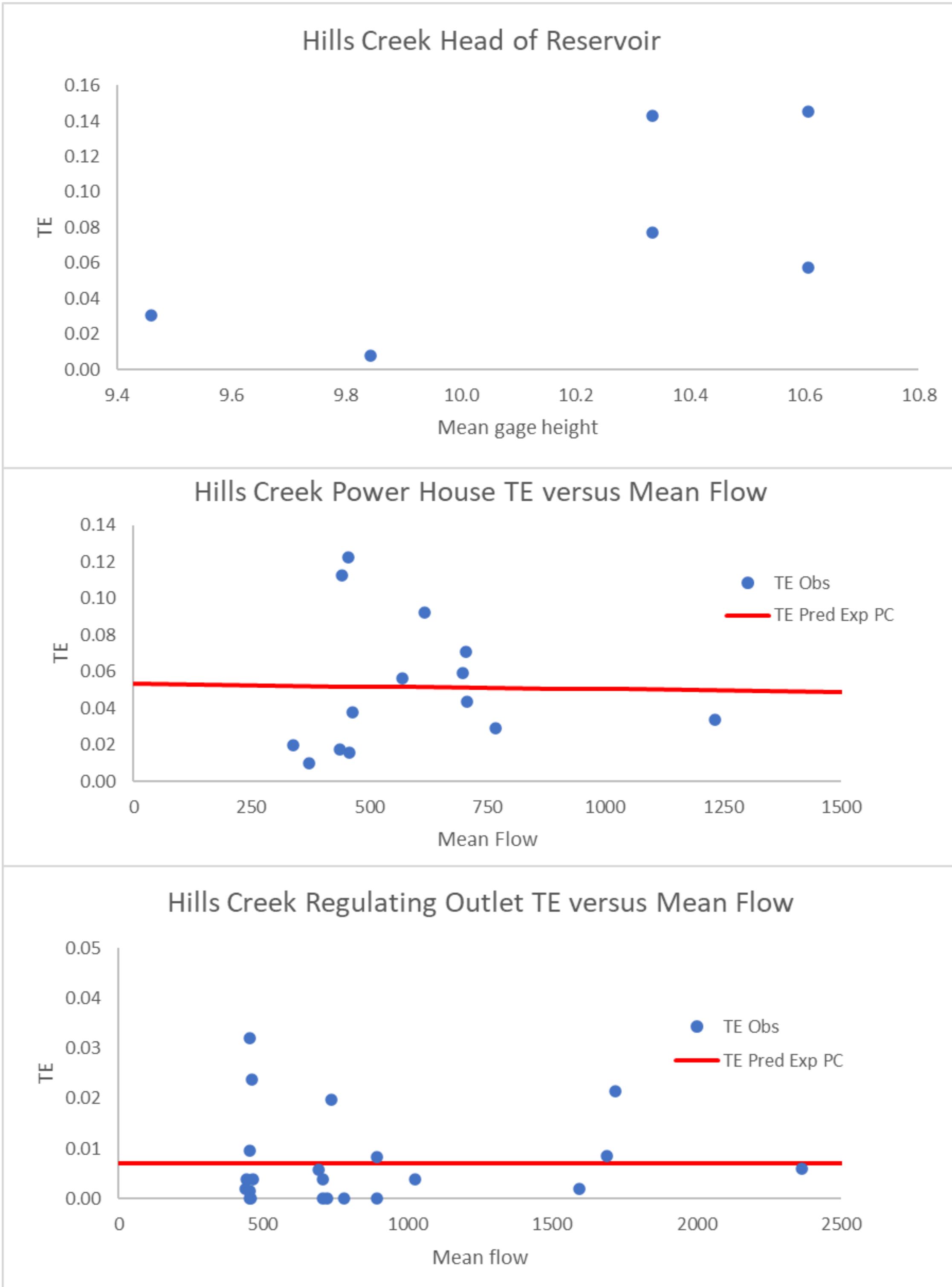

Figure A 5. Plots of observed TE (TE obs) versus mean gage height/ flow for RSTs at the Hills Creek Head of Reservoir, Hills Creek Power House and Hills Creek Regulating Outlet. Mean flow is in cfs. Mean gage height is in feet. TEs predicted from fitted exponential (exp), exponential plus constant (Exp_PC), and beta regression models are also plotted where fits of these models were obtainable. Where a flat curve is shown, the fitted models predicted a constant TE.

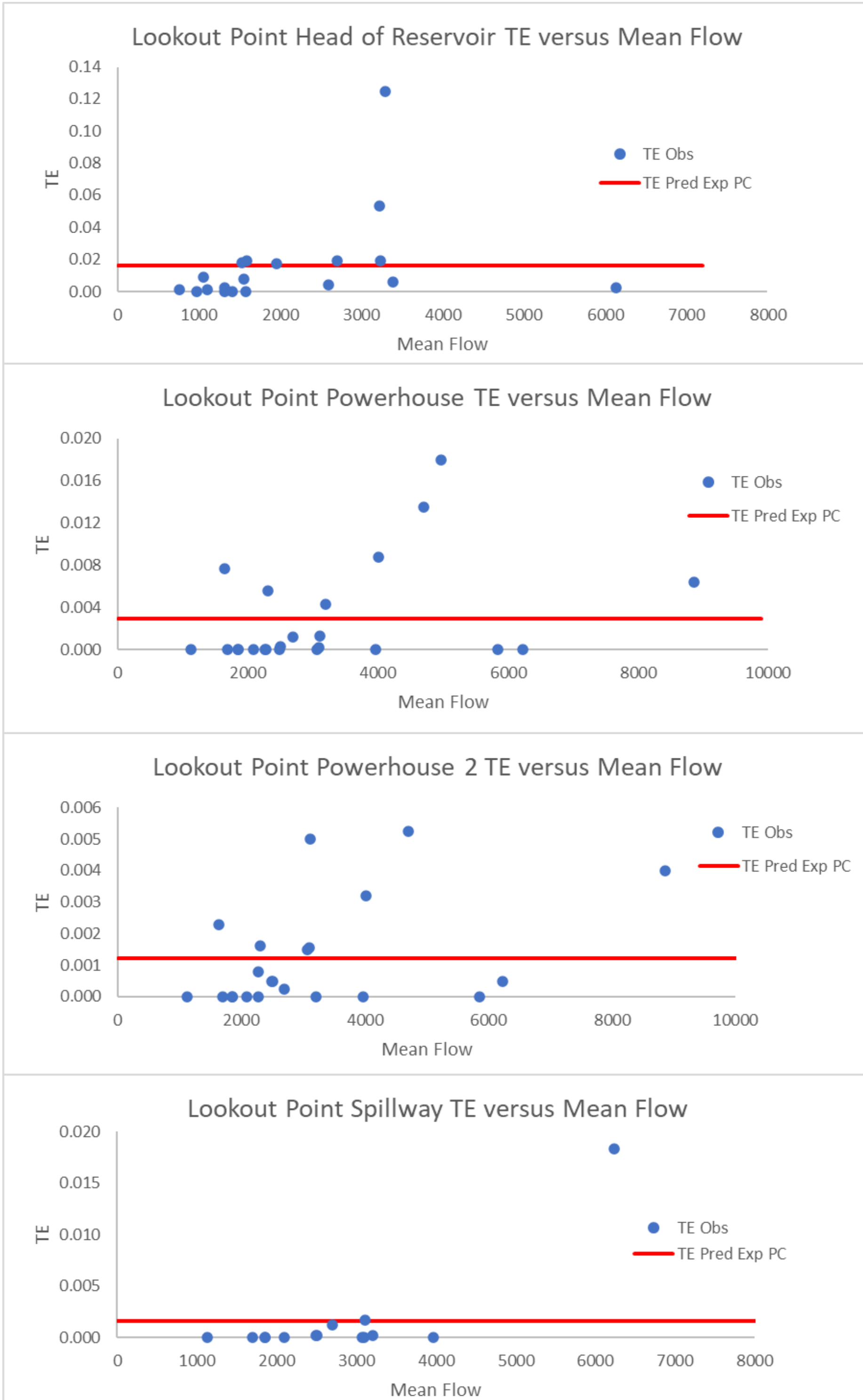

Figure A 6. Plots of observed TE (TE obs) versus mean flow for RSTs at the Lookout Point Head of Reservoir, Power Houses 1 and 2, and Spillway. Mean flow is in cfs. TEs predicted from fitted exponential (exp), exponential plus constant (Exp_PC), and beta regression models are also plotted where fits of these models were obtainable. Where a flat curve is shown, the fitted models predicted a constant TE.

Appendix C: Estimated growth parameters from above- and below-dam RSTs

Table A 5. Estimated parameters of the logistic growth model for juvenile Chinook salmon, with each row representing a specific site and year combination for the data from above dam RSTs. The parameters include the asymptote length (L_u), and growth rate (B). The 95% confidence intervals (lower and upper bounds; abbreviated "lb" and "ub" respectively) for each parameter, calculated using bootstrap resampling, are also provided.

Site	Year	L_u	B	L_u (lb)	L_u (ub)	B (lb)	B (ub)
BRE	2016	169.263	0.013	134.374	193.904	0.009	0.018
Above HCR	2015	118.805	0.017	109.569	138.738	0.009	0.025
Above MF	2016	118.026	0.031	112.843	124.367	0.024	0.038
Above MF	2015	119.662	0.020	114.130	126.985	0.012	0.028
Above LOP	2010	169.213	0.018	118.281	199.996	0.010	0.029
Above LOP	2011	156.276	0.008	132.558	169.647	0.002	0.011
Above LOP	2012	181.161	0.012	148.807	200.000	0.008	0.017
Above LOP	2013	138.337	0.015	109.802	165.270	0.009	0.025
Above LOP	2014	149.912	0.011	109.796	188.940	0.006	0.022
Above LOP	2023	174.198	0.012	110.083	199.998	0.008	0.027
Above LOP	2022	150.075	0.008	96.151	182.654	0.000	0.023
Above DET	2016	128.751	0.019	115.693	134.792	0.017	0.025
Above DET	2015	130.069	0.017	126.762	132.083	0.016	0.018
Above DET	2011	133.572	0.016	127.905	138.071	0.014	0.019
Above DET	2012	127.461	0.031	119.307	135.267	0.024	0.035
Above DET	2013	138.837	0.017	128.249	144.426	0.016	0.020
Above DET	2014	125.930	0.023	114.530	129.815	0.020	0.031
Above CGR	2016	141.068	0.010	120.226	175.950	0.000	0.018
Above CGR	2015	164.370	0.016	127.064	200.000	0.012	0.020
Above CGR	2010	173.168	0.020	139.314	199.992	0.011	0.025
Above CGR	2011	149.988	0.026	110.454	191.073	0.010	0.037
Above CGR	2012	146.534	0.020	112.217	179.007	0.013	0.025
Above CGR	2014	158.606	0.020	112.305	192.287	0.013	0.028
Above FOS	2016	127.615	0.026	116.709	136.307	0.022	0.033
Above FOS	2015	105.520	0.031	83.727	116.940	0.014	0.050
Above FOS	2010	117.820	0.027	114.940	120.843	0.025	0.031
Above FOS	2012	128.234	0.016	110.001	138.684	0.004	0.021
Above FOS	2013	116.098	0.025	102.460	128.212	0.018	0.038
Above FOS	2014	120.306	0.024	107.196	133.197	0.016	0.039
Above FOS	2023	122.557	0.023	109.957	138.266	0.012	0.032
Above NS	2023	136.884	0.018	124.845	164.138	0.014	0.022

Table A 6. Estimated parameters of the logistic growth model for juvenile Chinook salmon, with each row representing a specific site and year combination for the data above dams. The parameters include the lower asymptote (L_l), scaling parameter (q), and Shape parameter (V). The 95% confidence intervals (lower and upper bounds, lb and ub) for each parameter, calculated using bootstrap resampling, are also provided.

Site	Year	L_l	q	V	L_l (lb)	L_l (ub)	q (lb)	q (ub)	V (lb)	V (ub)
BRE	2016	43.197	0.399	0.016	33.826	50.000	0.132	1.000	0.004	0.060
Above HCR	2015	32.486	0.794	0.092	29.762	40.898	0.365	1.000	0.035	0.100
Above MF	2016	31.785	0.909	0.012	30.610	33.215	0.836	0.977	0.004	0.026
Above MF	2015	32.156	0.795	0.088	28.125	35.682	0.307	0.954	0.027	0.100
Above LOP	2010	42.455	0.402	0.012	30.566	49.995	0.101	1.000	0.003	0.056
Above LOP	2011	41.666	0.416	0.080	38.650	46.038	0.203	0.572	0.063	0.100
Above LOP	2012	45.837	0.334	0.030	37.872	50.000	0.088	1.000	0.005	0.100
Above LOP	2013	36.581	0.688	0.069	29.981	43.604	0.421	1.000	0.028	0.100
Above LOP	2014	39.194	0.551	0.076	29.976	47.594	0.138	1.000	0.020	0.100
Above LOP	2023	42.767	0.385	0.040	28.563	49.996	0.098	1.000	0.009	0.100
Above LOP	2022	40.211	0.492	0.091	29.960	46.439	0.180	1.000	0.034	0.100
Above DET	2016	35.409	0.746	0.018	34.453	36.366	0.682	0.806	0.007	0.025
Above DET	2015	34.542	0.764	0.032	34.141	34.894	0.737	0.789	0.029	0.038
Above DET	2011	34.816	0.807	0.019	34.001	35.552	0.721	0.845	0.011	0.026
Above DET	2012	33.686	0.812	0.004	31.534	35.433	0.727	0.909	0.002	0.009
Above DET	2013	36.674	0.676	0.017	35.568	37.624	0.619	0.761	0.012	0.023
Above DET	2014	34.170	0.766	0.008	33.610	35.063	0.331	0.827	0.002	0.011
Above CGR	2016	37.497	0.655	0.050	32.105	46.296	0.263	0.939	0.020	0.100
Above CGR	2015	35.598	0.663	0.019	18.205	50.000	0.107	1.000	0.001	0.045
Above CGR	2010	43.714	0.418	0.005	30.635	50.000	0.071	1.000	0.001	0.036
Above CGR	2011	32.807	0.637	0.006	3.248	42.623	0.242	0.988	0.000	0.042
Above CGR	2012	26.910	0.769	0.013	11.385	43.167	0.277	0.986	0.001	0.031
Above CGR	2014	32.728	0.644	0.012	10.825	46.178	0.131	0.993	0.000	0.037
Above FOS	2016	35.387	0.761	0.039	33.435	36.753	0.676	0.861	0.017	0.066
Above FOS	2015	31.528	0.586	0.052	0.000	38.664	0.121	0.952	0.004	0.100
Above FOS	2010	31.752	0.913	0.020	31.092	32.461	0.879	0.947	0.010	0.027
Above FOS	2012	36.033	0.680	0.035	33.808	36.637	0.497	0.726	0.017	0.100
Above FOS	2013	34.561	0.823	0.038	32.741	36.296	0.686	1.000	0.007	0.069
Above FOS	2014	34.733	0.836	0.020	31.696	37.533	0.641	1.000	0.002	0.045
Above FOS	2023	33.285	0.830	0.032	29.994	38.479	0.539	1.000	0.009	0.083
Above NS	2023	34.402	0.756	0.015	30.107	43.181	0.525	0.926	0.007	0.021

Table A 7. Estimated parameters of the logistic growth model for juvenile Chinook salmon, with each row representing a specific site and year combination for the data from below-dam RSTs. The parameters include the asymptote length (L_u), and growth rate (B). The 95% confidence intervals (lower and upper bounds; abbreviated "lb" and "ub" respectively) for each parameter, calculated using bootstrap resampling, are also provided. Table continues on following page.

Site	Year	L_u	B	L_u (lb)	L_u (ub)	B (lb)	B (ub)
Below FCR	2006	191.731	0.030	186.029	198.436	0.005	0.050
Below FCR	2007	187.500	0.023	176.359	197.498	0.002	0.050
Below FCR	2008	197.445	0.018	191.977	200.000	0.005	0.029
Below FCR	2013	194.628	0.028	190.454	200.000	0.012	0.050
Below FCR	2014	188.434	0.028	183.873	198.421	0.004	0.050
Below FCR	2018	194.381	0.017	187.975	198.027	0.007	0.024
Below HCR	2013	194.679	0.017	187.653	199.106	0.004	0.026
Below HCR	2023	195.941	0.014	186.765	198.905	0.004	0.021
Below LOP	2010	180.851	0.017	164.620	193.067	0.008	0.028
Below LOP	2011	184.761	0.020	174.533	195.841	0.016	0.022
Below LOP	2012	138.286	0.029	126.968	157.922	0.025	0.033
Below LOP	2022	152.411	0.019	118.747	173.346	0.010	0.033
Below LOP	2023	189.828	0.020	180.725	197.794	0.005	0.029
Below MF	2007	147.360	0.013	121.648	183.209	0.007	0.023
Below BCL	2014	191.970	0.012	183.728	197.878	0.004	0.019
Below BCL	2016	186.967	0.015	173.497	197.320	0.006	0.019
Below BCL	2021	180.554	0.011	171.774	193.175	0.003	0.015
Below BCL	2022	183.555	0.012	174.705	193.178	0.003	0.017
Below BCL	2023	153.742	0.019	149.111	169.789	0.011	0.023
Below CGR	2013	157.703	0.016	151.747	165.134	0.014	0.017
Below CGR	2014	183.599	0.010	168.182	193.806	0.005	0.015
Below CGR	2010	178.979	0.012	169.585	188.538	0.010	0.014
Below CGR	2011	188.100	0.007	177.165	191.400	0.006	0.009
Below CGR	2012	175.982	0.014	166.342	183.128	0.010	0.017
Below CGR	2016	156.732	0.017	152.293	161.500	0.015	0.018
Below CGR	2015	179.841	0.010	166.708	190.919	0.004	0.014
Below CGR	2021	137.511	0.021	135.985	139.470	0.018	0.021
Below CGR	2022	181.900	0.009	173.602	194.171	0.005	0.011
Below CGR	2023	141.011	0.018	137.161	145.447	0.016	0.020
Below DET	2013	190.916	0.014	182.392	196.852	0.006	0.019
Below DET	2011	189.254	0.013	172.671	197.133	0.003	0.021
Below FOS	2013	144.193	0.029	133.748	154.805	0.024	0.035
Below FOS	2014	139.351	0.021	131.099	148.344	0.016	0.028
Below FOS	2012	167.002	0.030	148.759	182.807	0.027	0.035
Below FOS	2015	154.659	0.030	110.003	187.749	0.006	0.050
Below BRE	2023	110.791	0.027	108.303	114.484	0.024	0.030
Below DEX	2022	124.452	0.021	93.455	176.699	0.008	0.029
Below DEX	2023	187.206	0.014	182.335	191.335	0.013	0.016
Below GPR	2023	164.438	0.014	129.680	190.236	0.010	0.021

Site	Year	L_u	B	L_u (lb)	L_u (ub)	B (lb)	B (ub)
Below NS	2013	193.236	0.014	184.783	199.396	0.010	0.018
Below NS	2014	197.217	0.010	189.135	199.734	0.008	0.015
Below NS	2011	191.241	0.012	174.316	197.384	0.003	0.020
Below NS	2012	182.324	0.018	163.874	199.999	0.005	0.025
Below NS	2016	184.411	0.015	170.531	199.929	0.012	0.018
Below NS	2015	182.513	0.028	176.771	199.130	0.015	0.050

Table A 8. Estimated parameters of the logistic growth model for juvenile Chinook salmon, with each row representing a specific site and year combination for the data below dams. The parameters include the lower asymptote (L_l), scaling parameter (q), and Shape parameter (V). The 95% confidence intervals (lower and upper bounds, ub and lb respectively) for each parameter, calculated using bootstrap resampling, are also provided. Table continues on following page.

Site	Year	l_l	q	V	l_l (lb)	l_l (ub)	q (lb)	q (ub)	V (lb)	V (ub)
Below FCR	2006	48.686	0.234	0.046	40.295	50.000	0.000	1.000	0.005	0.100
Below FCR	2007	46.811	0.440	0.045	34.995	50.000	0.000	1.000	0.005	0.100
Below FCR	2008	48.226	0.305	0.032	32.980	50.000	0.029	0.943	0.003	0.098
Below FCR	2013	49.586	0.184	0.030	46.678	50.000	0.000	0.738	0.002	0.100
Below FCR	2014	47.186	0.177	0.052	31.873	50.000	0.000	0.694	0.002	0.100
Below FCR	2018	39.309	0.373	0.035	20.322	50.000	0.074	0.874	0.004	0.098
Below HCR	2013	28.838	0.464	0.038	5.023	50.000	0.039	0.947	0.004	0.097
Below HCR	2023	24.835	0.529	0.045	9.194	50.000	0.041	0.830	0.014	0.098
Below LOP	2010	33.887	0.531	0.055	14.269	50.000	0.207	0.826	0.007	0.098
Below LOP	2011	43.785	0.256	0.011	25.850	48.626	0.121	0.632	0.006	0.034
Below LOP	2012	28.777	0.861	0.017	19.616	34.038	0.797	0.949	0.009	0.029
Below LOP	2022	39.345	0.534	0.042	31.844	44.142	0.295	0.905	0.014	0.076
Below LOP	2023	42.547	0.389	0.026	19.759	50.000	0.088	0.743	0.003	0.098
Below MF	2007	39.629	0.620	0.056	33.019	50.000	0.198	1.000	0.011	0.100
Below BCL	2014	38.651	0.291	0.059	21.433	50.000	0.042	0.616	0.007	0.097
Below BCL	2016	45.320	0.265	0.022	27.040	50.000	0.136	0.613	0.011	0.098
Below BCL	2021	39.177	0.360	0.067	29.265	50.000	0.097	0.549	0.037	0.098
Below BCL	2022	35.951	0.392	0.063	25.590	50.000	0.103	0.593	0.029	0.098
Below BCL	2023	39.639	0.519	0.037	38.536	40.750	0.332	0.574	0.020	0.073
Below CGR	2013	40.571	0.478	0.023	39.180	42.253	0.394	0.547	0.017	0.030
Below CGR	2014	37.863	0.364	0.066	27.577	50.000	0.146	0.534	0.020	0.097
Below CGR	2010	44.830	0.271	0.032	36.510	47.458	0.151	0.485	0.013	0.066
Below CGR	2011	49.543	0.271	0.096	44.013	50.000	0.189	0.381	0.079	0.097
Below CGR	2012	41.270	0.353	0.024	23.075	46.055	0.209	0.659	0.009	0.084
Below CGR	2016	40.386	0.495	0.032	39.387	41.442	0.435	0.563	0.023	0.043
Below CGR	2015	37.302	0.383	0.067	25.212	50.000	0.112	0.619	0.023	0.097
Below CGR	2021	36.118	0.698	0.040	35.703	36.605	0.672	0.713	0.029	0.074
Below CGR	2022	43.783	0.242	0.083	38.036	50.000	0.123	0.335	0.056	0.097
Below CGR	2023	36.898	0.659	0.032	36.037	37.935	0.603	0.704	0.023	0.050
Below DET	2013	37.331	0.421	0.046	25.108	50.000	0.127	0.571	0.011	0.097

Site	Year	l_l	q	V	l_l (lb)	l_l (ub)	q (lb)	q (ub)	V (lb)	V (ub)
Below DET	2011	32.021	0.418	0.046	10.606	50.000	0.069	0.807	0.004	0.097
Below FOS	2013	37.075	0.628	0.016	35.301	39.097	0.527	0.732	0.008	0.029
Below FOS	2014	36.906	0.678	0.021	35.346	38.362	0.579	1.000	0.007	0.037
Below FOS	2012	39.480	0.477	0.005	34.441	44.684	0.268	1.000	0.003	0.009
Below FOS	2015	40.861	0.397	0.014	35.302	46.468	0.143	1.000	0.001	0.100
Below BRE	2023	30.242	0.988	0.010	29.825	31.033	0.950	1.000	0.006	0.015
Below DEX	2022	34.774	0.758	0.035	29.998	43.751	0.319	1.000	0.017	0.100
Below DEX	2023	45.987	0.167	0.009	40.455	47.824	0.111	0.271	0.006	0.013
Below GPR	2023	40.272	0.438	0.045	27.414	47.712	0.119	0.809	0.012	0.100
Below NS	2013	45.504	0.593	0.054	31.086	50.000	0.125	1.000	0.007	0.100
Below NS	2014	49.589	0.346	0.097	47.631	50.000	0.151	1.000	0.059	0.100
Below NS	2011	38.052	0.347	0.044	12.316	50.000	0.070	0.794	0.004	0.096
Below NS	2012	46.041	0.306	0.012	40.951	50.000	0.063	0.886	0.002	0.085
Below NS	2016	45.432	0.263	0.025	34.981	50.000	0.113	0.976	0.010	0.084
Below NS	2015	41.989	0.679	0.019	34.108	48.600	0.137	1.000	0.001	0.069

Appendix D: Injury analysis

Below, we present tables of summary results from quasi-binomial regressions of injury reports. See report section "Fish injury analysis: Testing for injunction effect on injury rates" for full details.

Injury type: Body/fin injury

*Table A 9.Summary of results of quasi-binomial regressions of body injury reporting rate against injunction period. For simplicity, we do not report estimated intercepts, only the estimated injunction effect (est.); the reported estimate is the increase in reporting under EAS compared to the previous operator. Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	**Par.**	**Est.**	**StdErr.**	**t value**	**Disp.**	**Dev. (null dev.)**
HCR_PH	Post-inj.	3.35	0.224	15***	130	3.5e+04(7.5e+04)
FCR	Post-inj.	1.68	0.26	6.45***	400	1.11e+05(1.33e+05)
LOP_PH1	Post-inj.	5.35	0.365	14.6***	831	1.07e+05(4.48e+05)
HCR_RO	Post-inj.	2.69	1.73	1.55	1.26E+03	8.66e+04(9.03e+04)
LOP_PH2	Post-inj.	3.96E+15	1.26E+14	31.4***	7.22E+16	1.21e+05(1.13e+05)
LOP_SP	Post-inj.	1.50E+15	4.06E+14	3.7***	1.37E+17	1.42e+05(6.04e+04)
CGR_PH	Post-inj.	1.52	0.144	10.5***	79.8	6.4e+04(7.26e+04)
CGR_RO	Post-inj.	1.59	0.131	12.2***	242	1.12e+05(1.51e+05)
BCL	Post-inj.	2.39	0.216	11.1***	77.2	2.69e+04(3.87e+04)

*Table A 10.Summary of results of quasi-binomial regressions of body injury reporting rate against operator during the post-injunction period. For simplicity, we do not report estimated intercepts, only the estimated operator effect (est.). Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	**Par.**	**Est.**	**StdErr.**	**t value**	**Disp.**	**Dev. (null dev.)**
FCR	Op.	2.74	0.521	5.25***	1.38E+03	4.27e+04(8.51e+04)
LOP_PH1	Op.	3.58	3.25	1.1	1.16E+03	3.73e+04(3.94e+04)
LOP_PH2	Op.	19.4	3.45E+03	0.00561	2.20E+03	3.43e+04(4.08e+04)
LOP_SP	Op.	3.87	1.48	2.62**	1.14E+03	3.79e+04(5.2e+04)
CGR_PH	Op.	3.63	0.674	5.38***	49.7	8.64e+03(1.24e+04)
CGR_RO	Op.	2.56	0.167	15.3***	123	1.06e+04(4.53e+04)
BCL	Op.	2.46	0.236	10.4***	70.3	1.33e+04(2.18e+04)

Injury type: Head injury

*Table A 11.Summary of results of quasi-binomial regressions of head injury reporting rate against injunction period. For simplicity, we do not report estimated intercepts, only the estimated injunction effect (est.). Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
HCR_PH	Post-inj.	1.64	0.262	6.25***	65.5	1.02e+04(1.29e+04)
FCR	Post-inj.	0.479	0.485	0.988	187	1.76e+04(1.78e+04)
LOP_PH1	Post-inj.	3.21	0.69	4.65***	754	7.41e+04(1.01e+05)
HCR_RO	Post-inj.	16.4	1.74E+03	0.00939	324	2.48e+04(2.57e+04)
LOP_PH2	Post-inj.	17.2	1.90E+03	0.00907	968	4.09e+04(4.6e+04)
LOP_SP	Post-inj.	-0.571	1.44	-0.395	1.01E+03	2.99e+04(3e+04)
CGR_PH	Post-inj.	0.777	0.443	1.76*	48.6	7.97e+03(8.1e+03)
CGR_RO	Post-inj.	0.434	0.189	2.29**	66.9	1.67e+04(1.7e+04)
BCL	Post-inj.	4.11	1.82	2.25**	39.8	4.85e+03(5.96e+03)

*Table A 12.Summary of results of quasi-binomial regressions of body injury reporting rate against operator during the post-injunction period. For simplicity, we do not report estimated intercepts, only the estimated operator effect (est.); the reported estimate is the increase in reporting under EAS compared to the previous operator. Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
FCR	Op.	21.3	2.36E+03	0.00901	90	2.64e+03(1.03e+04)
LOP_PH1	Op.	13.6	2.79E+03	0.00487	2.49E+03	6.01e+04(6.03e+04)
LOP_PH2	Op.	14.8	3.04E+03	0.00488	1.71E+03	4.06e+04(4.09e+04)
LOP_SP	Op.	16.4	2.63E+03	0.00622	1.03E+03	2.7e+04(2.82e+04)
CGR_PH	Op.	17.4	2.54E+03	0.00688	28.2	1.45e+03(1.56e+03)
CGR_RO	Op.	3.81	1.19	3.21***	75.6	5.66e+03(9.19e+03)
BCL	Op.	3.9	1.47	2.65***	26.3	3.78e+03(4.69e+03)

Injury type: Internal injury

*Table A 13.Summary of results of quasi-binomial regressions of internal injury reporting rate against injunction period. For simplicity, we report only the estimated injunction effect (est.). Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1. Table continues on following page.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
HCR_PH	Post-inj.	2.11	0.185	11.4***	38.6	9.31e+03(1.53e+04)
FCR	Post-inj.	1.51	0.674	2.24**	288	2.15e+04(2.34e+04)
LOP_PH1	Post-inj.	2.8	0.593	4.73***	776	7.37e+04(9.76e+04)
HCR_RO	Post-inj.	16.4	1.98E+03	0.00827	417	3.18e+04(3.27e+04)
LOP_PH2	Post-inj.	2.48E+15	8.92E+13	27.8***	3.61E+16	5.5e+04(3.02e+04)
LOP_SP	Post-inj.	15.5	4.40E+03	0.00354	841	1.1e+04(1.12e+04)

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
CGR_PH	Post-inj.	1.03	0.364	2.82***	54.4	1.04e+04(1.08e+04)
CGR_RO	Post-inj.	-0.486	0.241	-2.01**	150	3.42e+04(3.48e+04)
BCL	Post-inj.	-2.08	0.295	-7.04***	77.7	1.75e+04(2.17e+04)

*Table A 14.Summary of results of quasi-binomial regressions of internal injury reporting rate against operator during the post-injunction period. For simplicity, we do not report estimated intercepts, only the estimated operator effect (est.); the reported estimate is the increase in reporting under EAS compared to the previous operator. Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
FCR	Op.	3.08	0.925	3.33***	472	8.2e+03(1.57e+04)
LOP_PH1	Op.	13.6	2.61E+03	0.00522	2.17E+03	5.45e+04(5.47e+04)
LOP_PH2	Op.	14.3	2.44E+03	0.00587	1.10E+03	2.47e+04(2.49e+04)
LOP_SP	Op.	15.8	4.04E+03	0.00391	889	1.07e+04(1.1e+04)
CGR_PH	Op.	2	1.56	1.28	34.2	1.93e+03(2.04e+03)
CGR_RO	Op.	3.1	1.05	2.97***	96.7	7.4e+03(1e+04)
BCL	Op.	2.26	1.29	1.76*	67.3	6.53e+03(6.98e+03)

Injury type: Body/head missing or nearly decapitated

*Table A 15.Summary of results of quasi-binomial regressions of decapitation reporting rate against injunction period. For simplicity, we report only the estimated injunction effect (est.). Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
HCR_PH	Post-inj.	-0.331	0.213	-1.56	32.3	8.38e+03(8.46e+03)
FCR	Post-inj.	0.745	0.385	1.94*	128	1.46e+04(1.52e+04)
LOP_PH1	Post-inj.	2.38	0.669	3.55***	442	2.75e+04(3.42e+04)
HCR_RO	Post-inj.	-1.32	1.07	-1.24	266	1.14e+04(1.17e+04)
LOP_PH2	Post-inj.	-19.4	3.16E+03	-0.00614	192	2.91e+03(4.31e+03)
LOP_SP	Post-inj.	15.1	4.89E+03	0.00309	1.04E+03	8.58e+03(8.69e+03)
CGR_PH	Post-inj.	-0.773	0.617	-1.25	42.2	9.83e+03(9.91e+03)
CGR_RO	Post-inj.	-2	1.02	-1.97**	94.2	4.49e+03(5.01e+03)
BCL	Post-inj.	0.553	0.715	0.773	50	4.56e+03(4.59e+03)

*Table A 16.Summary of results of quasi-binomial regressions of decapitation reporting rate against operator during the post-injunction period. For simplicity, we do not report estimated intercepts, only the estimated operator effect (est.); the reported estimate is the increase in reporting under EAS compared to the previous operator. Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1. Table continues on following page. Op.: Operator effect.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
FCR	Op.	-1.05	1.42	-0.741	418	6.69e+03(7e+03)
LOP_PH1	Op.	13.4	2.76E+03	0.00486	897	1.79e+04(1.8e+04)
LOP_SP	Op.	15.4	4.50E+03	0.00342	1.10E+03	8.39e+03(8.58e+03)
CGR_PH	Op.	1.01	2.62	0.384	47.4	923(933)
CGR_RO	Op.	16.6	4.27E+03	0.00389	127	909(981)
BCL	Op.	0.393	0.974	0.403	75.2	3.94e+03(3.96e+03)

Injury type: Major descaling

*Table A 17.Summary of results of quasi-binomial regressions of reported major descaling rate against injunction period. For simplicity, we show only the estimated injunction effect (est.). Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1. Post-inj: estimated change in injury reporting post-injunction.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
HCR_PH	Post-inj.	21.3	642	0.0332	36.5	1.39e+04(5.11e+04)
FCR	Post-inj.	18.8	1.34E+03	0.014	357	6.56e+04(8.06e+04)
LOP_PH1	Post-inj.	21.5	813	0.0264	258	9.03e+04(2.61e+05)
HCR_RO	Post-inj.	16.9	1.46E+03	0.0116	618	5.79e+04(6.1e+04)
LOP_PH2	Post-inj.	18.4	1.95E+03	0.00945	1.02E+03	6.54e+04(7.94e+04)
LOP_SP	Post-inj.	16.8	1.60E+03	0.0105	826	4.39e+04(4.73e+04)
CGR_PH	Post-inj.	1.48	0.284	5.23***	78.9	2.01e+04(2.2e+04)
CGR_RO	Post-inj.	0.223	0.147	1.52	253	9.53e+04(9.59e+04)
BCL	Post-inj.	-0.259	0.181	-1.43	60	2.08e+04(2.1e+04)

*Table A 18.Summary of results of quasi-binomial regressions of reported major descaling rate against operator during the post-injunction period. For simplicity, we do not report estimated intercepts, only the estimated operator effect (est.); the reported estimate is the increase in reporting under EAS compared to the previous operator. Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1. Table continues on following page.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
FCR	Op.	21.2	2.51E+03	0.00847	750	2.34e+04(6.56e+04)
LOP_PH1	Op.	15.5	2.51E+03	0.00618	2.01E+03	8.94e+04(9.03e+04)
LOP_PH2	Op.	15	1.89E+03	0.00795	1.79E+03	6.44e+04(6.54e+04)
LOP_SP	Op.	18.1	2.35E+03	0.00769	818	3.83e+04(4.39e+04)
CGR_PH	Op.	2.61	1.52	1.71*	54.5	4.76e+03(5.16e+03)
CGR_RO	Op.	0.413	0.254	1.62	350	4.14e+04(4.24e+04)

BCL	Op.	0.95	0.289	3.28***	60.1	1.18e+04(1.26e+04)

Injury type: Copepod infection

*Table A 19.Summary of results of quasi-binomial regressions of reported copepod infection rate against injunction period. For simplicity, we report only the estimated injunction effect (est.). Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
HCR_PH	Post-inj.	7.95	0.937	8.49***	67	1.88e+04(8.74e+04)
FCR	Post-inj.	5.09	0.669	7.61***	137	3.89e+04(9.62e+04)
LOP_PH1	Post-inj.	21.3	816	0.0261	259	8.69e+04(2.34e+05)
HCR_RO	Post-inj.	18.2	1.93E+03	0.00942	1.08E+03	8e+04(8.69e+04)
LOP_PH2	Post-inj.	18.5	2.39E+03	0.00774	563	3.11e+04(3.75e+04)
LOP_SP	Post-inj.	17.3	2.15E+03	0.00805	546	2.8e+04(3.03e+04)
CGR_PH	Post-inj.	0.638	0.188	3.4***	143	1.29e+05(1.31e+05)
CGR_RO	Post-inj.	1.25	0.145	8.64***	257	1.21e+05(1.41e+05)
BCL	Post-inj.	-0.0848	0.19	-0.447	59.7	1.99e+04(2e+04)

*Table A 20.Summary of results of quasi-binomial regressions of reported copepod infection rate against operator during the post-injunction period. For simplicity, we do not report estimated intercepts, only the estimated operator effect (est.); the reported estimate is the increase in reporting under EAS compared to the previous operator. Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
FCR	Op.	1.04	0.399	2.61**	988	3.08e+04(3.73e+04)
LOP_PH1	Op.	15.3	2.52E+03	0.00607	2.02E+03	8.61e+04(8.69e+04)
LOP_PH2	Op.	15.1	2.32E+03	0.00652	990	3.06e+04(3.11e+04)
LOP_SP	Op.	1.16	1.05	1.11	586	2.71e+04(2.8e+04)
CGR_PH	Op.	0.273	0.285	0.958	49	1.02e+04(1.02e+04)
CGR_RO	Op.	0.822	0.179	4.58***	159	1.87e+04(2.19e+04)
BCL	Op.	0.021	0.219	0.0957	56.2	1.15e+04(1.15e+04)

Injury type: Eye damage/missing

*Table A 21.Summary of results of quasi-binomial regressions of reported eye injury rate against injunction period. For simplicity, we report only the estimated injunction effect (est.). Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
HCR_PH	Post-inj.	1.17	0.161	7.3***	40.3	1.02e+04(1.23e+04)
FCR	Post-inj.	0.618	0.277	2.23**	128	1.46e+04(1.53e+04)
LOP_PH1	Post-inj.	2.24	0.37	6.05***	694	1.1e+05(1.38e+05)
HCR_RO	Post-inj.	-1.02	0.664	-1.54	233	1.9e+04(1.95e+04)

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
LOP_PH2	Post-inj.	17.2	2.20E+03	0.00785	1.29E+03	5.26e+04(5.77e+04)
LOP_SP	Post-inj.	-0.571	0.982	-0.581	469	1.75e+04(1.77e+04)
CGR_PH	Post-inj.	0.824	0.327	2.52**	42.4	9.86e+03(1.01e+04)
CGR_RO	Post-inj.	0.343	0.11	3.13***	68.4	2.41e+04(2.48e+04)
BCL	Post-inj.	0.49	0.27	1.82*	37.8	8.63e+03(8.76e+03)

*Table A 22.Summary of results of quasi-binomial regressions of reported eye injury rate against operator during the post-injunction period. For simplicity, we report only the estimated operator effect (est.); the reported estimate is the increase in reporting under EAS compared to the previous operator. Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
FCR	Op.	0.172	0.674	0.255	393	4.63e+03(4.66e+03)
LOP_PH1	Op.	14.1	2.75E+03	0.00511	2.42E+03	7.13e+04(7.16e+04)
LOP_PH2	Op.	14.8	3.52E+03	0.00422	2.28E+03	5.23e+04(5.26e+04)
LOP_SP	Op.	17.4	2.85E+03	0.00608	444	1.46e+04(1.59e+04)
CGR_PH	Op.	1.72	1.27	1.35	27	1.93e+03(2.02e+03)
CGR_RO	Op.	1.25	0.209	5.97***	73.1	7.73e+03(1.12e+04)
BCL	Op.	1.05	0.39	2.7***	38.5	5.97e+03(6.33e+03)

Injury type: Gill/operculum damage

*Table A 23.Summary of results of quasi-binomial regressions of reported rates of injury to the gills, operculum, and/or isthmus against injunction period. For simplicity, we report only the estimated injunction effect (est.). Standard errors, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1. Table continues on the following page.*

RST	Par.	Est.	StdErr.	t value	Disp.	Dev. (null dev.)
HCR_PH	Post-inj.	1.68	0.156	10.8***	40.2	1.02e+04(1.52e+04)
FCR	Post-inj.	2.49	0.249	9.97***	101	1.7e+04(3.56e+04)
LOP_PH1	Post-inj.	3.67	0.566	6.49***	744	8.88e+04(1.49e+05)
HCR_RO	Post-inj.	0.921	1.26	0.733	388	3.2e+04(3.23e+04)
LOP_PH2	Post-inj.	18.5	2.39E+03	0.00774	563	3.01e+04(3.65e+04)
LOP_SP	Post-inj.	16.3	2.41E+03	0.00676	690	2.38e+04(2.47e+04)
CGR_PH	Post-inj.	1.68	0.22	7.64***	18.6	5.44e+03(6.37e+03)
CGR_RO	Post-inj.	0.981	0.11	8.95***	65.7	2.57e+04(3.17e+04)
BCL	Post-inj.	3.58	0.735	4.88***	29.3	7.7e+03(1.04e+04)

Table A 24.Summary of results of quasi-binomial regressions of reported rates of injury to the gills, operculum, and/or isthmus against operator during the post-injunction period. For simplicity, we report only the estimated operator effect (est.); the reported estimate is the increase in reporting under EAS *compared to the previous operator. Standard error, t-values, estimated dispersion (disp.), and residual and null deviance (dev.) are also reported. *** = p < 0.01, ** = p <0.05, * = p < 0.1.*

RST	**Par.**	**Est.**	**StdErr.**	**t value**	**Disp.**	**Dev. (null dev.)**
FCR	Op.	0.172	0.674	0.255	393	4.63e+03(4.66e+03)
LOP_PH1	Op.	14.1	2.75E+03	0.00511	2.42E+03	7.13e+04(7.16e+04)
LOP_PH2	Op.	14.8	3.52E+03	0.00422	2.28E+03	5.23e+04(5.26e+04)
LOP_SP	Op.	17.4	2.85E+03	0.00608	444	1.46e+04(1.59e+04)
CGR_PH	Op.	1.72	1.27	1.35	27	1.93e+03(2.02e+03)
CGR_RO	Op.	1.25	0.209	5.97***	73.1	7.73e+03(1.12e+04)
BCL	Op.	1.05	0.39	2.7***	38.5	5.97e+03(6.33e+03)

Appendix E: TDG effects on barotrauma and mortality analysis

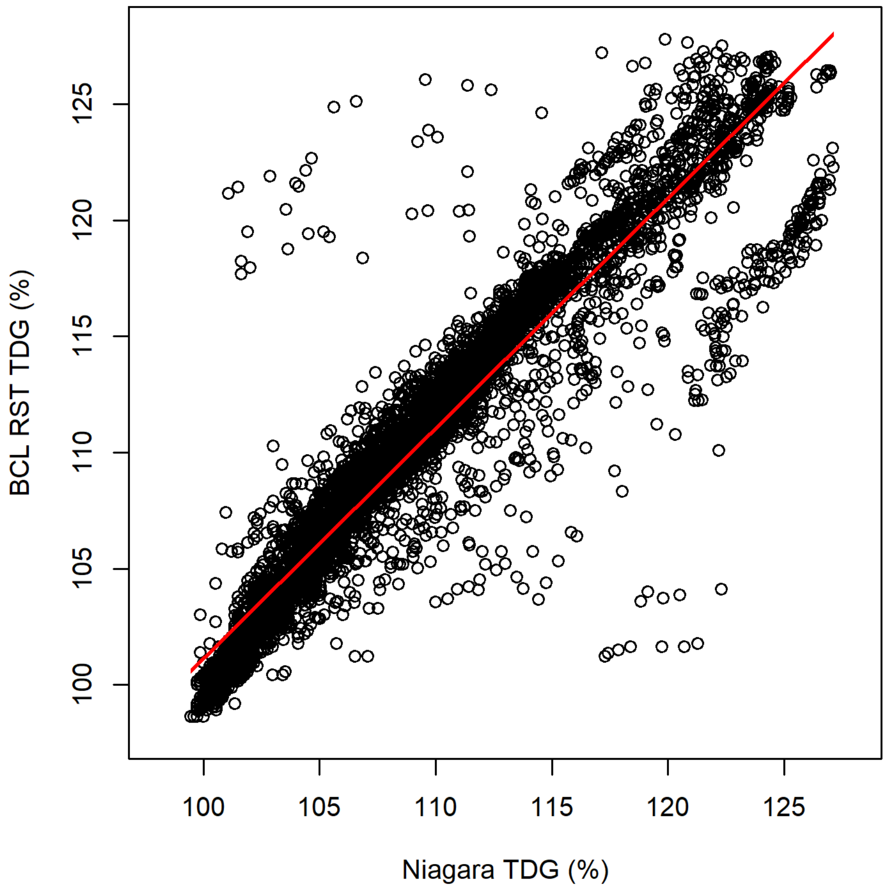

Figure A 7. Relationship of total dissolved gas (TDG) as measured directly at the RST below Big Cliff dam (BCL) with TDG measured at the Niagara USGS gage during the period 7 February 2023 to 11 February 2024. Red line shows a linear regression model fit to the data with an R^2 of 0.885.

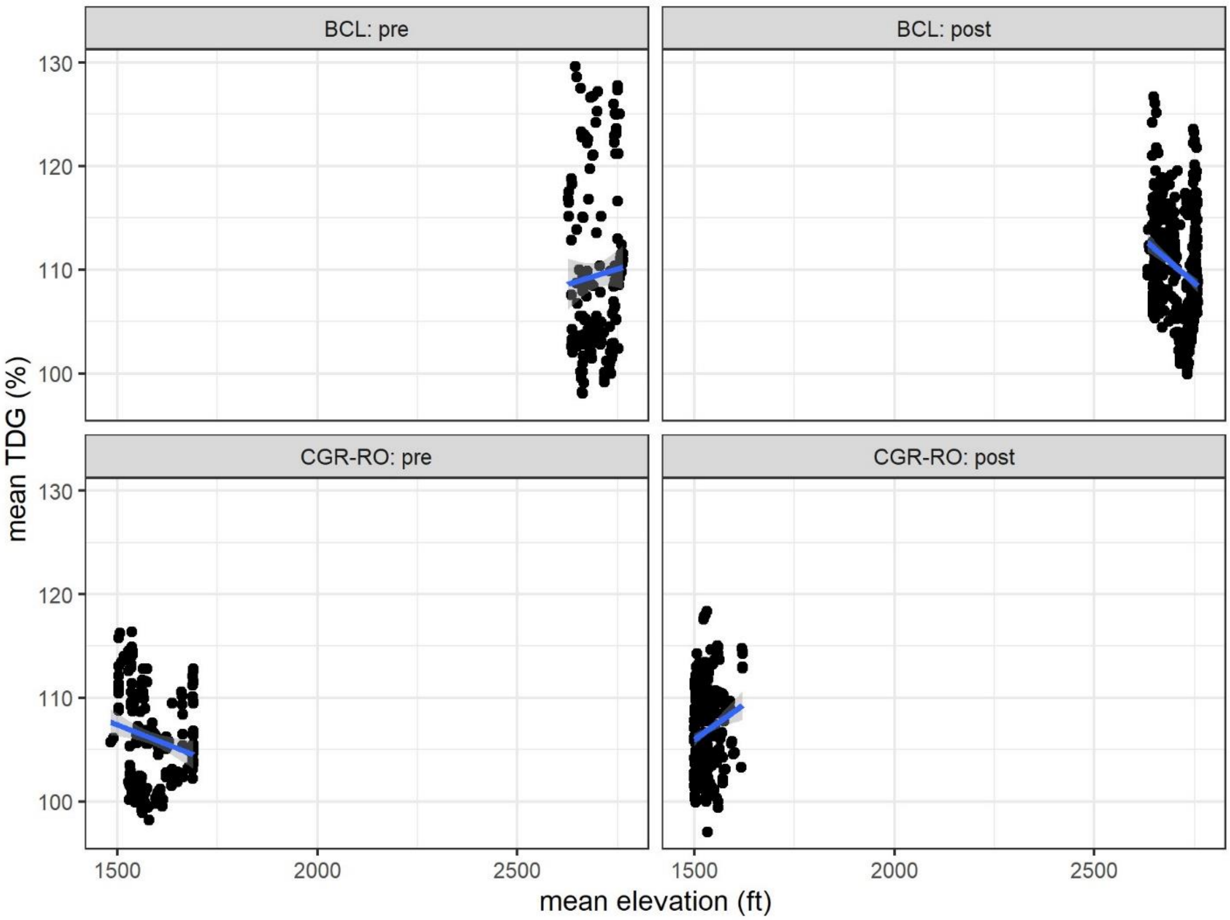

Figure A 8. Relationships of mean TDG and mean reservoir forebay elevation during RST trap events for each site and injunction period. Note that elevation at BCL is the combined elevations of Big Cliff and Detroit reservoirs. Lines show the fit of a linear regression model.

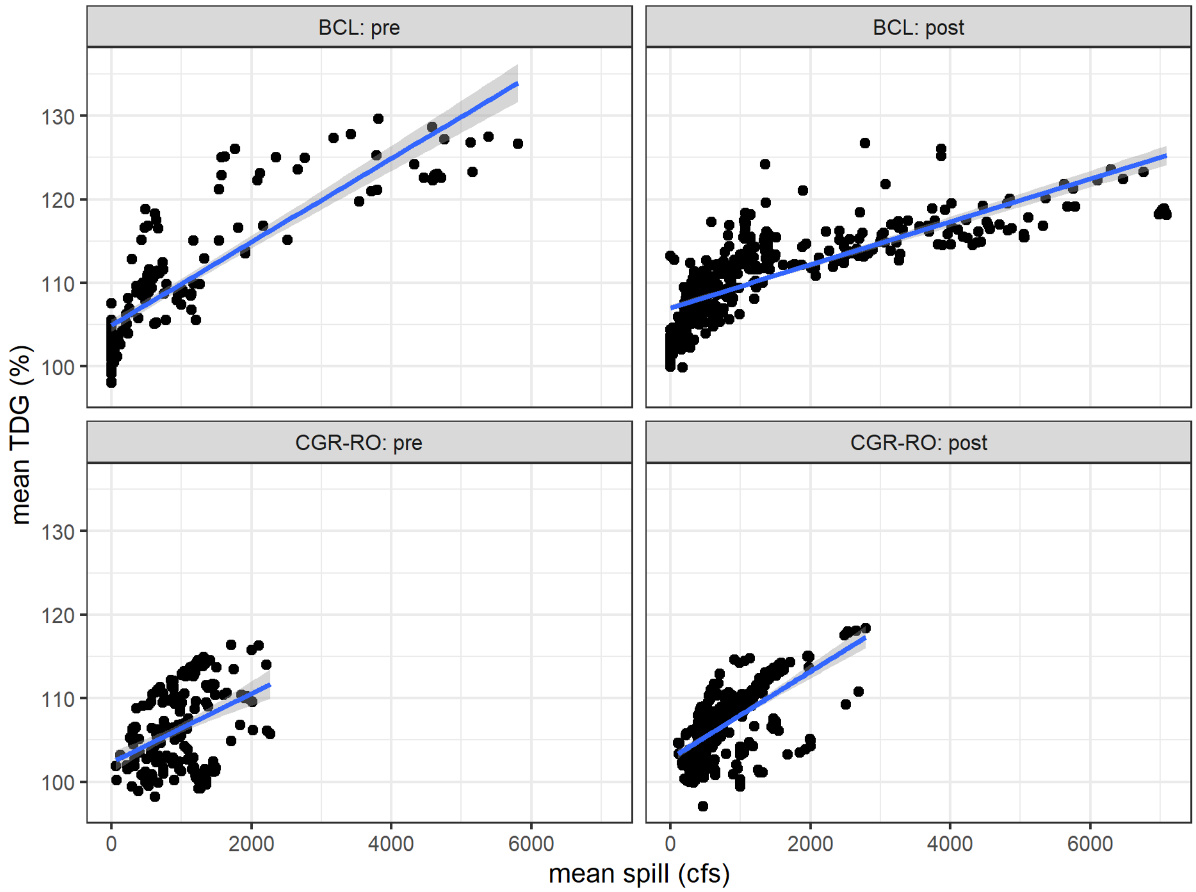

Figure A 9. Relationships of mean TDG and mean spill discharge during RST trap events for each site and injunction period. Note that spill at BCL is the combined spill discharge at Big Cliff and Detroit reservoirs. Lines show the fit of a linear regression model.

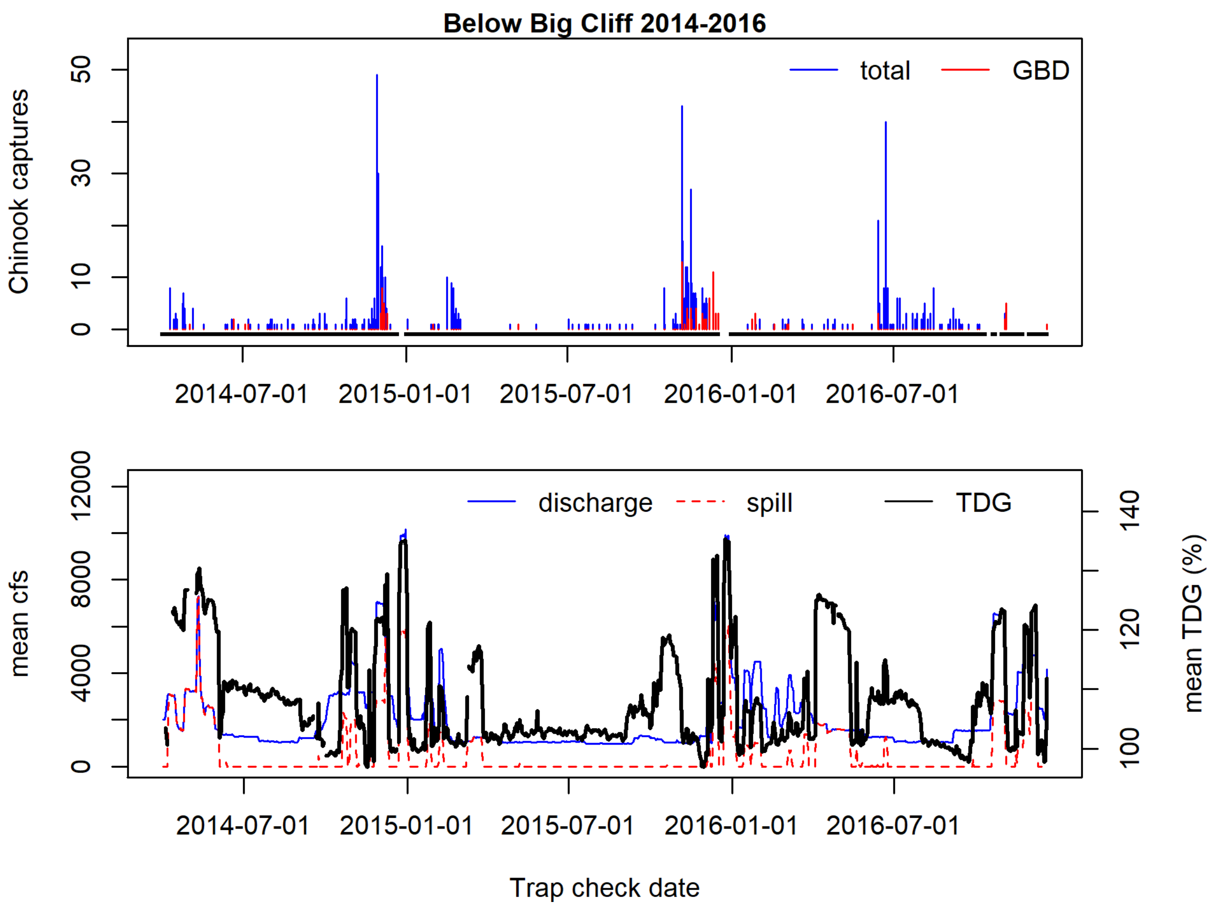

Figure A 10a. Number of juvenile Chinook salmon captured and the proportion of captured fish with gas bubble disease (GBD)per trap event at the Big Cliff RST during the pre-injunction period (top panel). Mean daily total discharge, spill discharge, and TDG are shown for comparison (bottom panel).

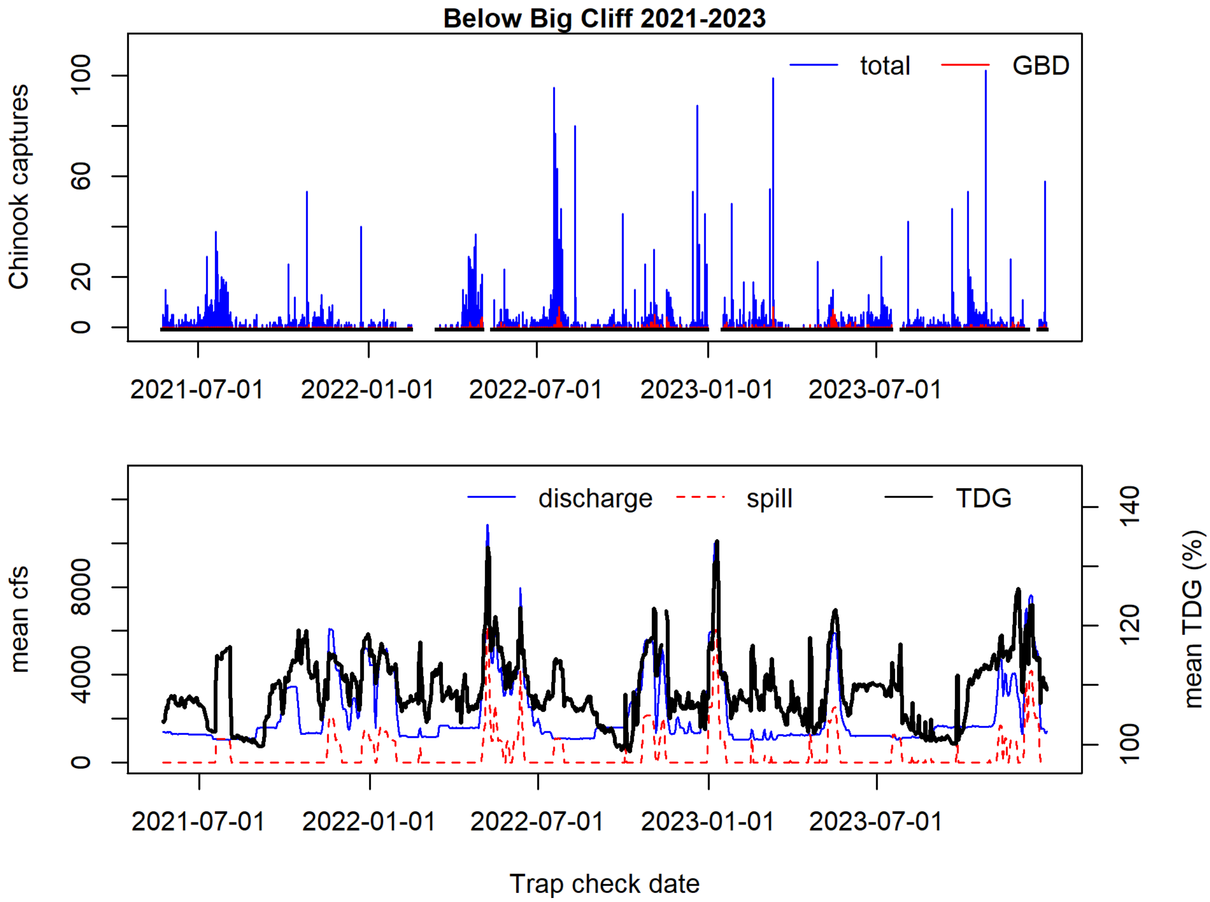

Figure A 10b. Number of juvenile Chinook salmon captured and the proportion of captured fish with gas bubble disease (GBD)per trap event at the Big Cliff RST during the post-injunction period (top panel). Mean daily total discharge, spill discharge, and TDG are shown for comparison (bottom panel).

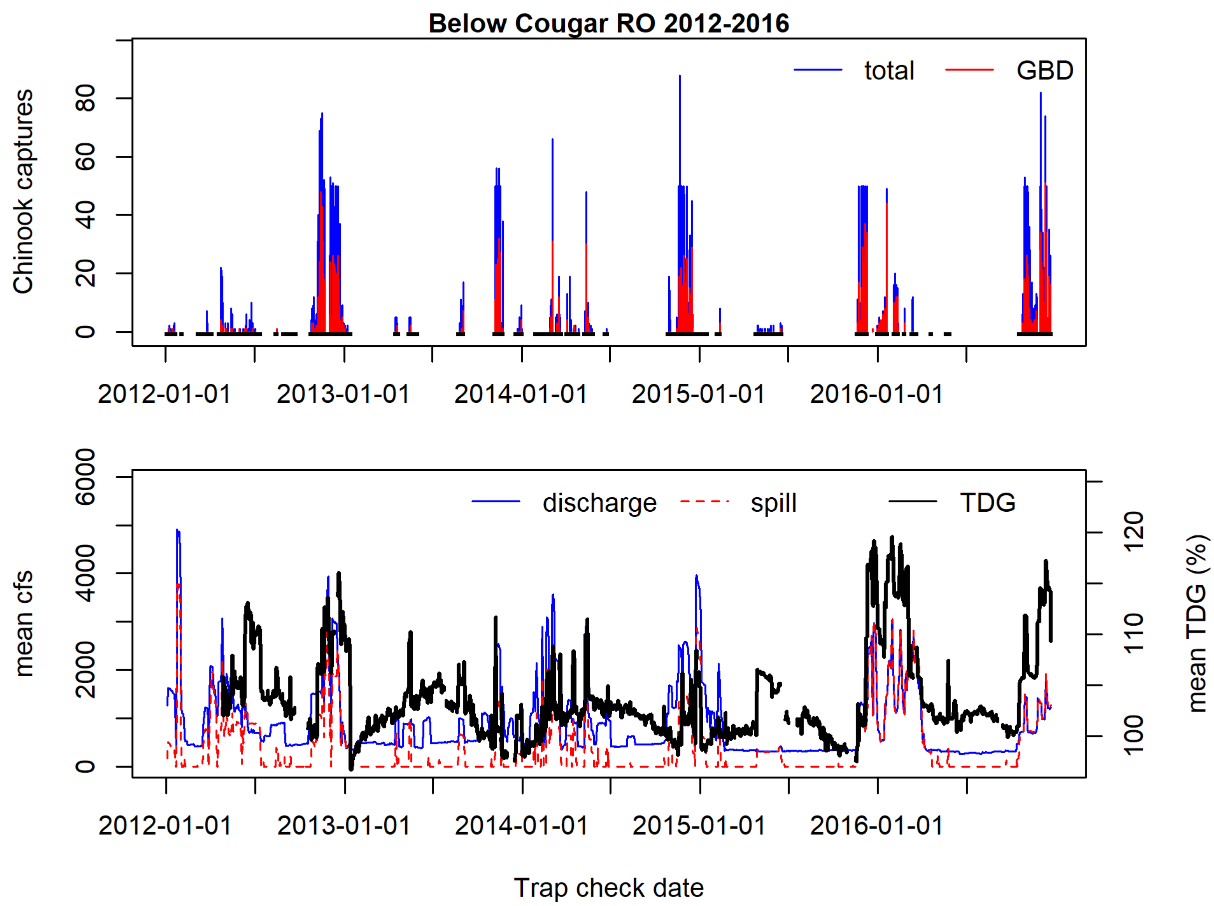

Figure A 11a. Number of juvenile Chinook salmon captured and the proportion of captured fish with gas bubble disease (GBD)per trap event at the Cougar RO RST during the pre-injunction period (top panel). Mean daily total discharge, spill discharge, and TDG are shown for comparison (bottom panel).

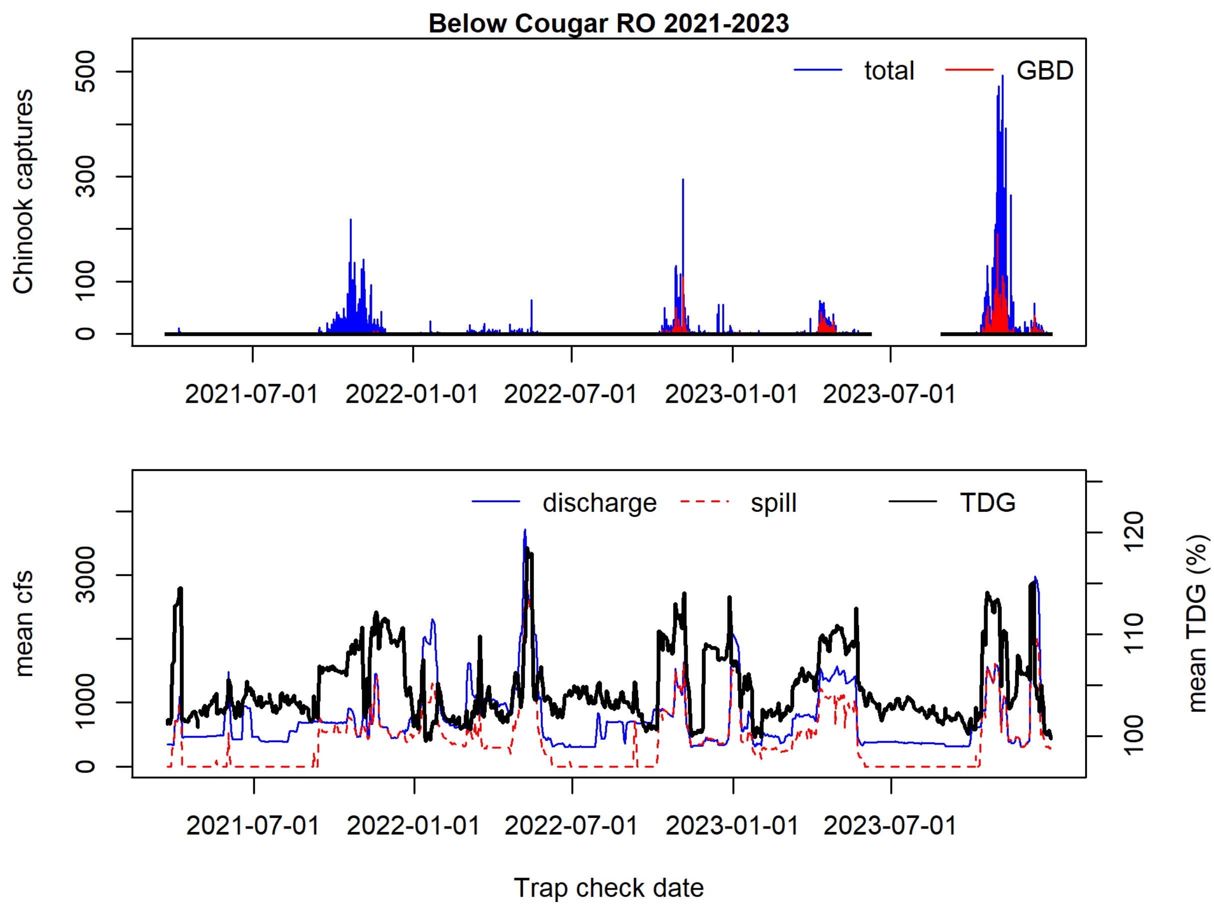

Figure A 11b. Number of juvenile Chinook salmon captured and the proportion of captured fish with gas bubble disease (GBD)per trap event at the Cougar RO RST during the post-injunction period (top panel). Mean daily total discharge, spill discharge, and TDG are shown for comparison (bottom panel).

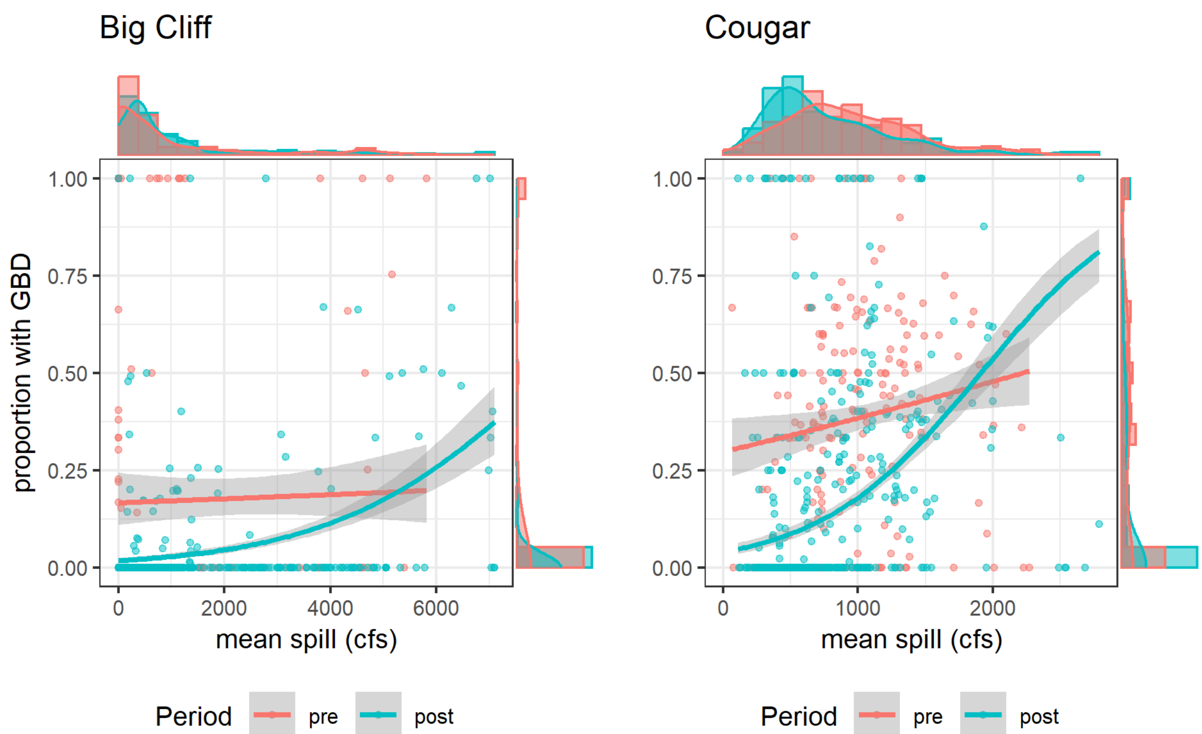

Figure A 12. Relationships between the proportion of juvenile Chinook salmon captured per trap event with gas bubble disease (GBD) and mean spill recorded during the trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

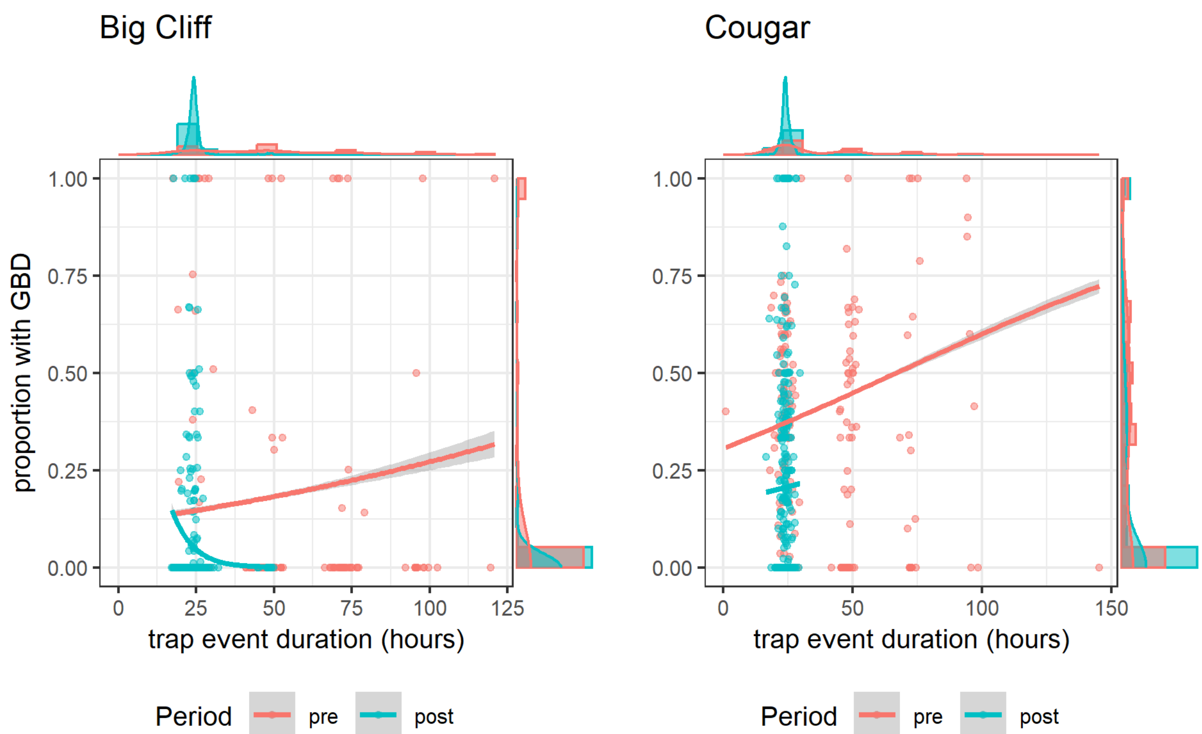

Figure A 13. Relationships between the proportion of juvenile Chinook salmon captured per trap event with gas bubble disease (GBD) and trap event duration at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

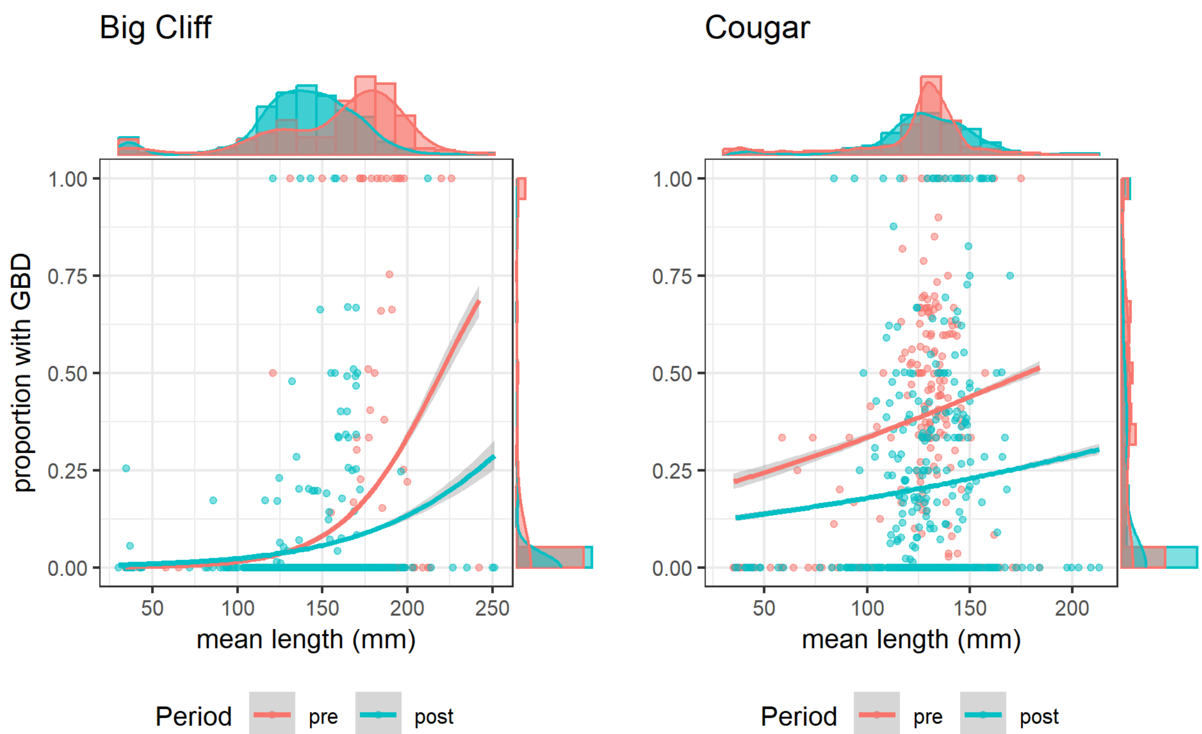

Figure A 14. Relationships between the proportion of juvenile Chinook salmon captured per trap event with gas bubble disease (GBD) and the mean length of fish caught per trap event at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

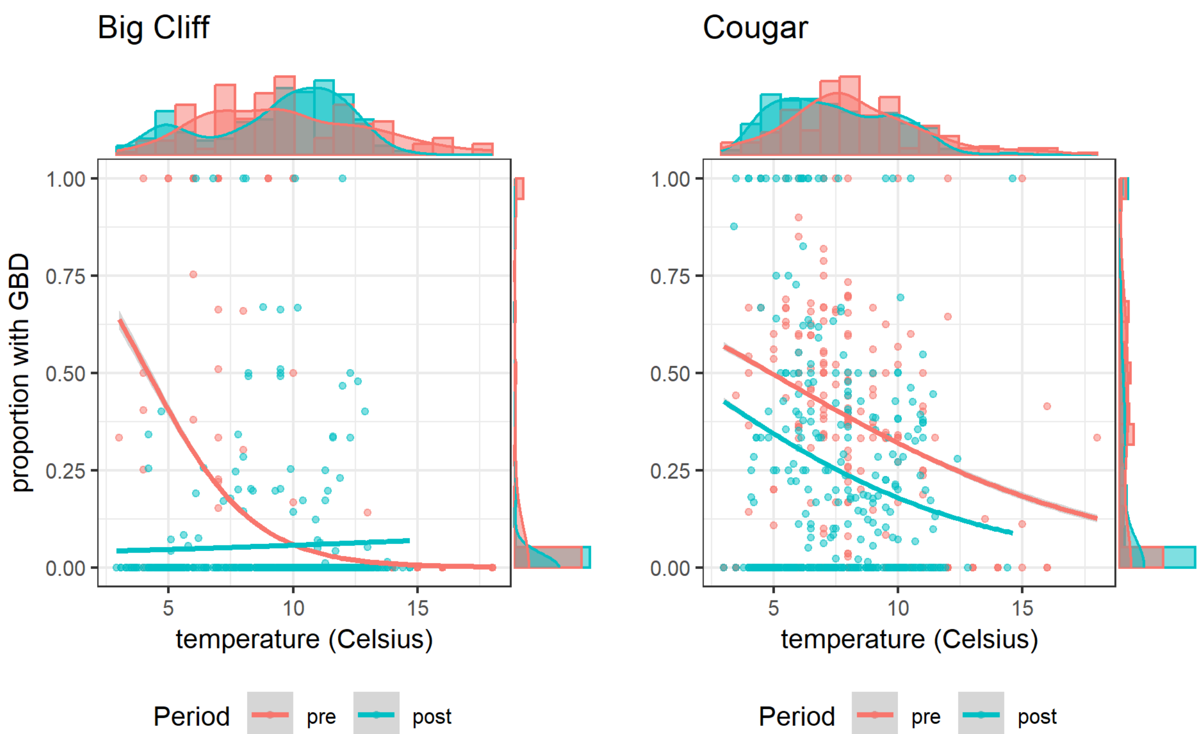

Figure A 15. Relationships between the proportion of juvenile Chinook salmon captured per trap event with gas bubble disease (GBD) and river temperature recorded during trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

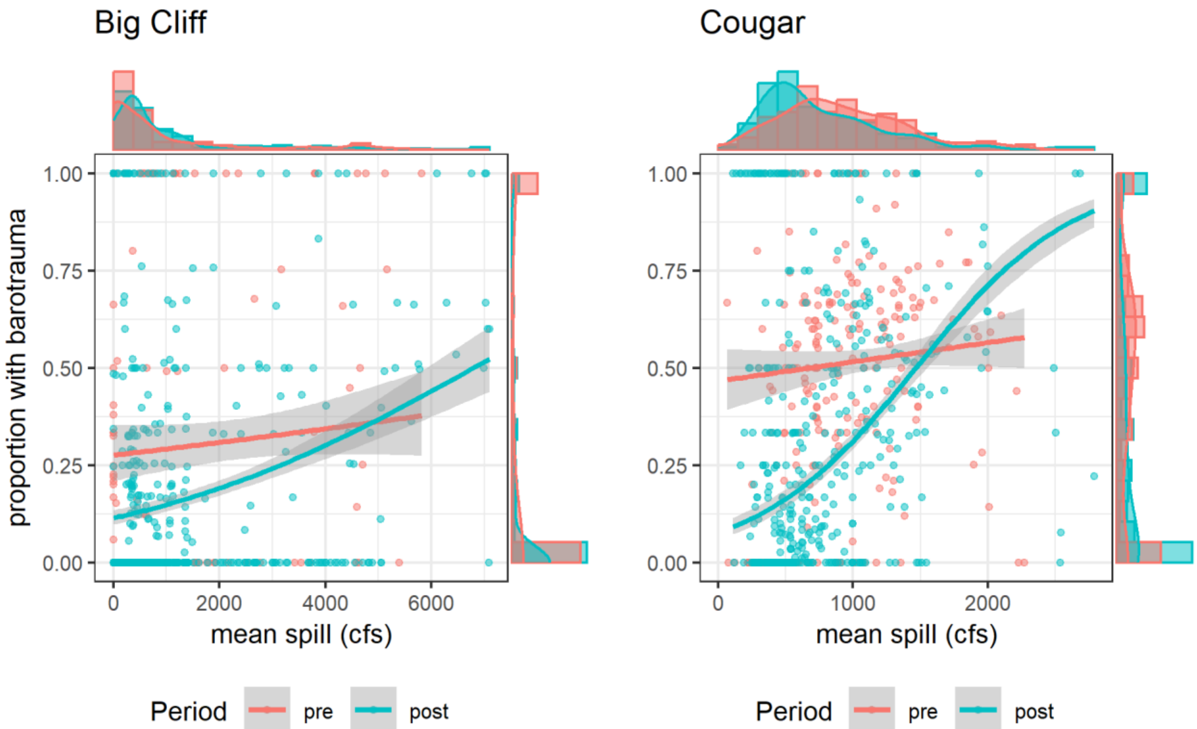

Figure A 16. Relationships between the proportion of juvenile Chinook salmon captured per trap event with barotrauma injuries and mean spill recorded during the trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

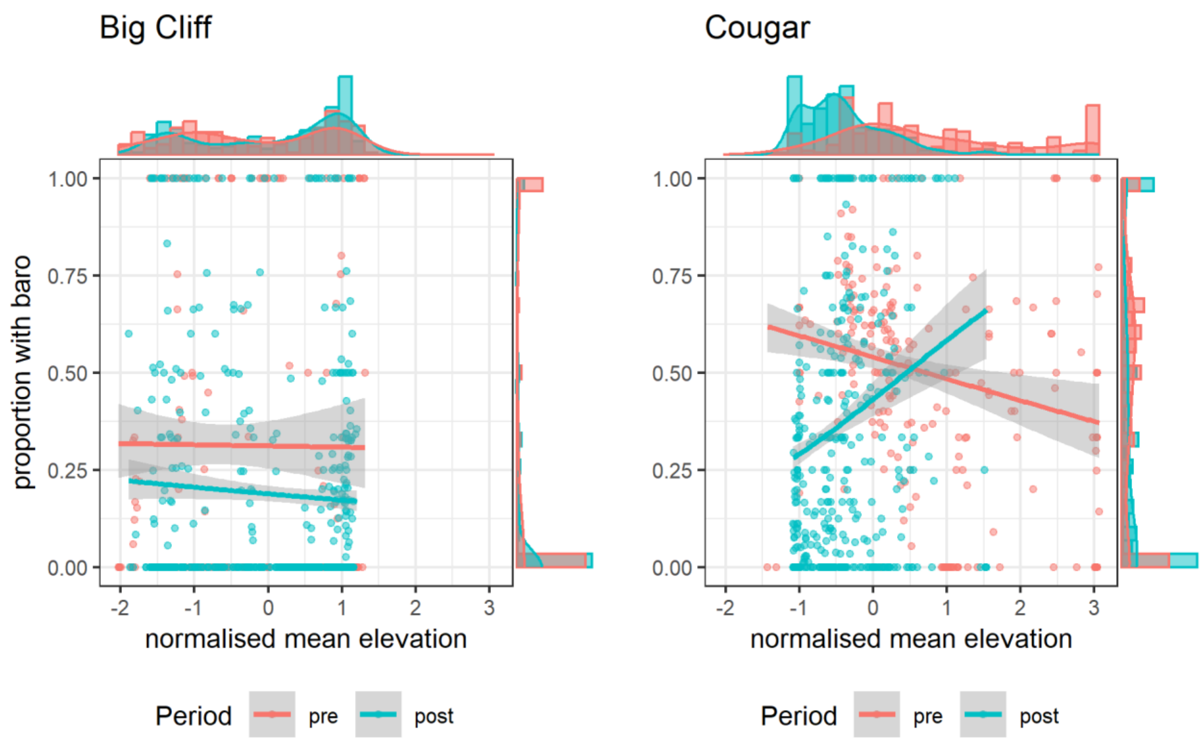

Figure A 17. Relationships between the proportion of juvenile Chinook salmon captured per trap event with barotrauma injuries and normalized mean reservoir forebay elevation recorded during the trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

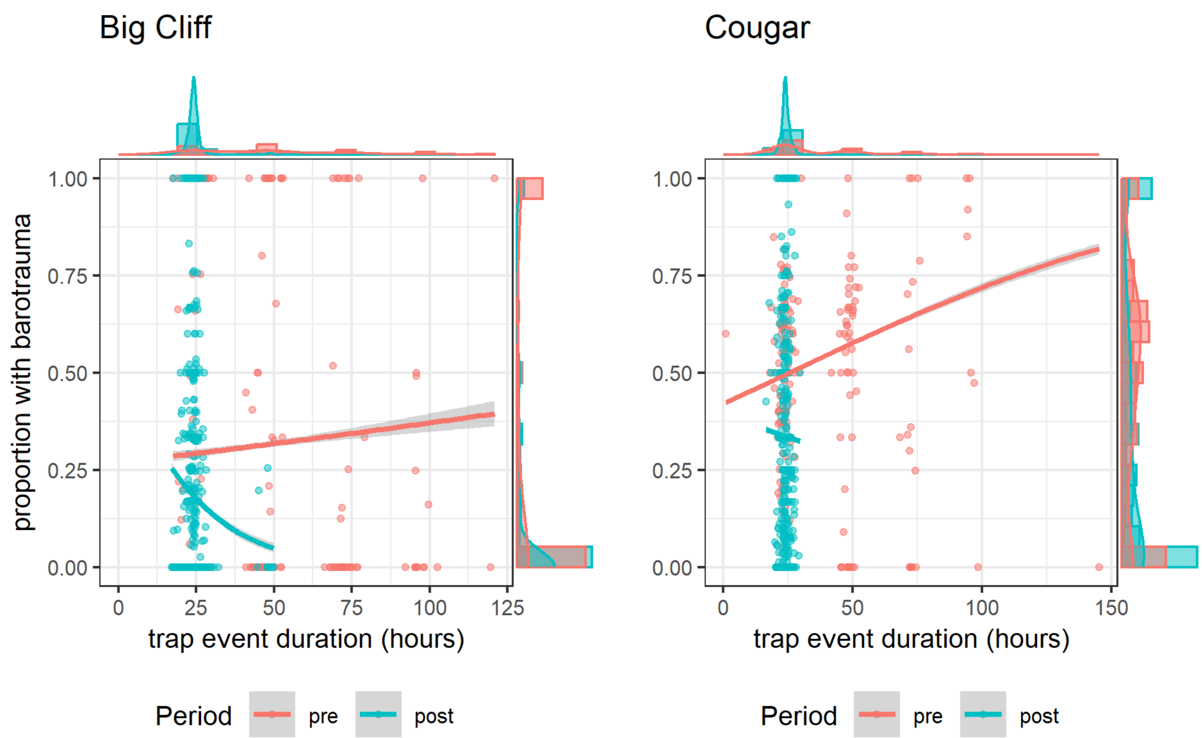

Figure A 18. Relationships between the proportion of juvenile Chinook salmon captured per trap event with barotrauma injuries and trap event duration at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

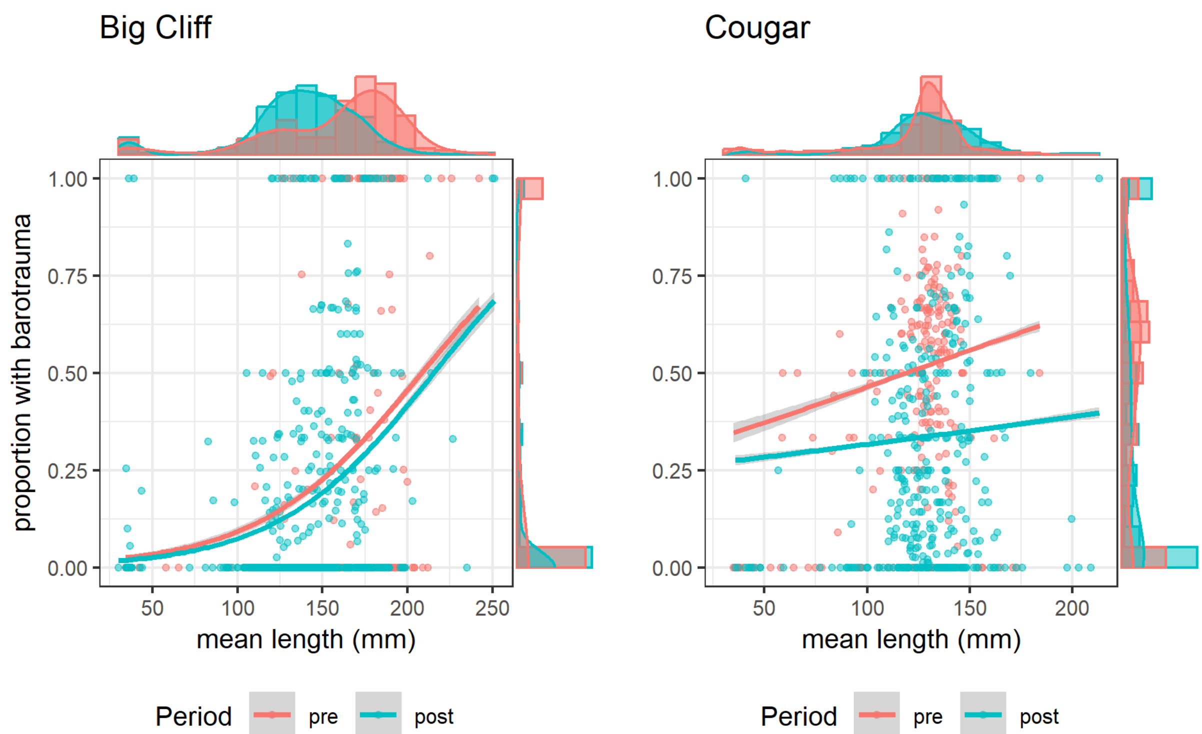

Figure A 19. Relationships between the proportion of juvenile Chinook salmon captured per trap event with barotrauma injuries and the mean length of fish caught per trap event at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

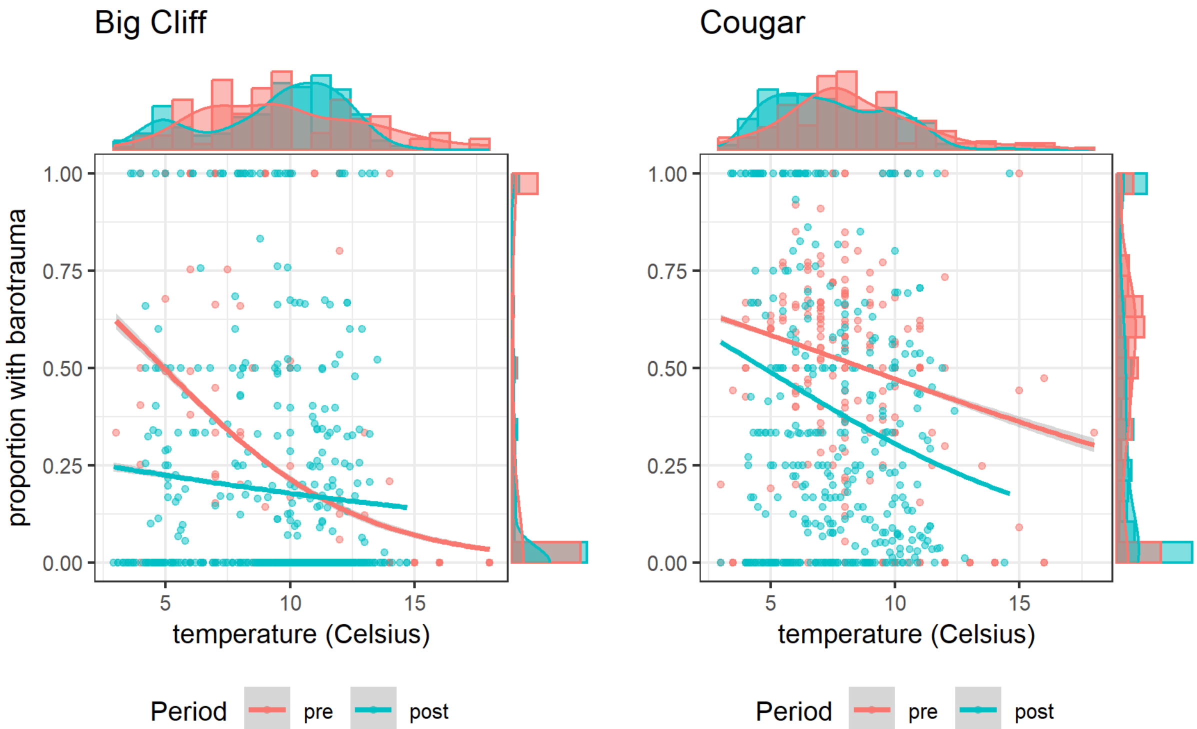

Figure A 20. Relationships between the proportion of juvenile Chinook salmon captured per trap event with barotrauma injuries and river temperature recorded during trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

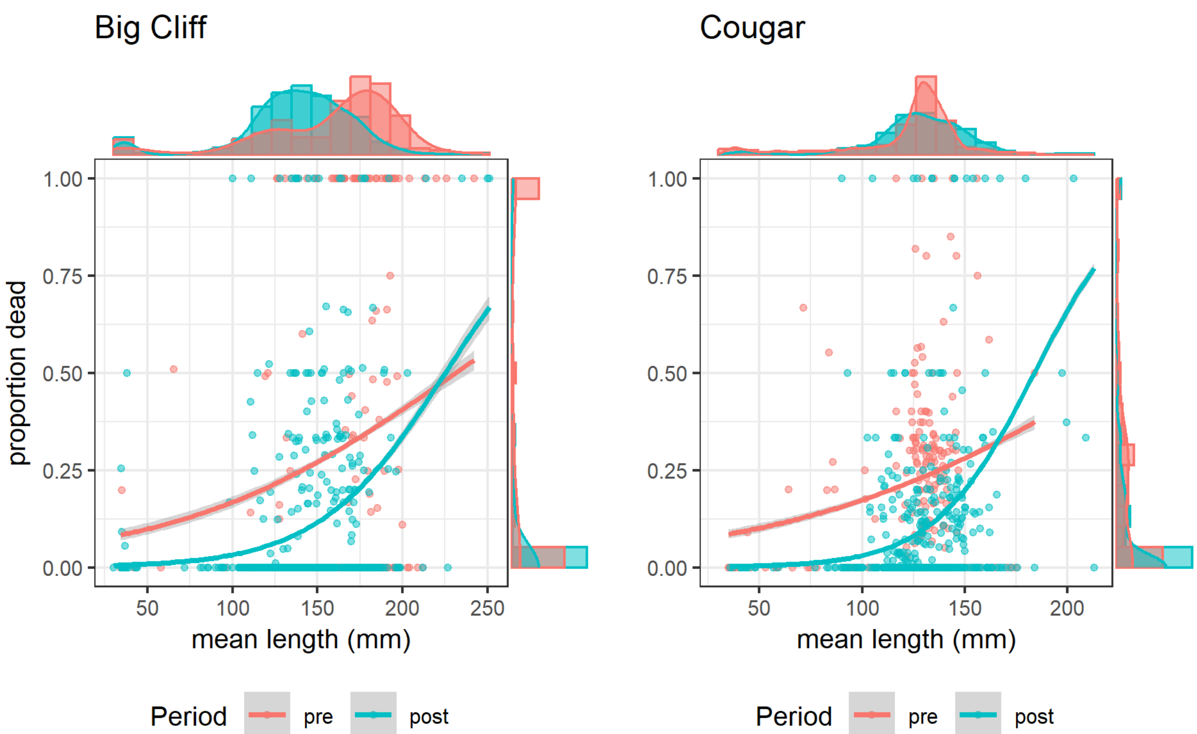

Figure A 21. Relationships between the proportion of juvenile Chinook salmon captured per trap event that were dead and the mean length of fish caught per trap event at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

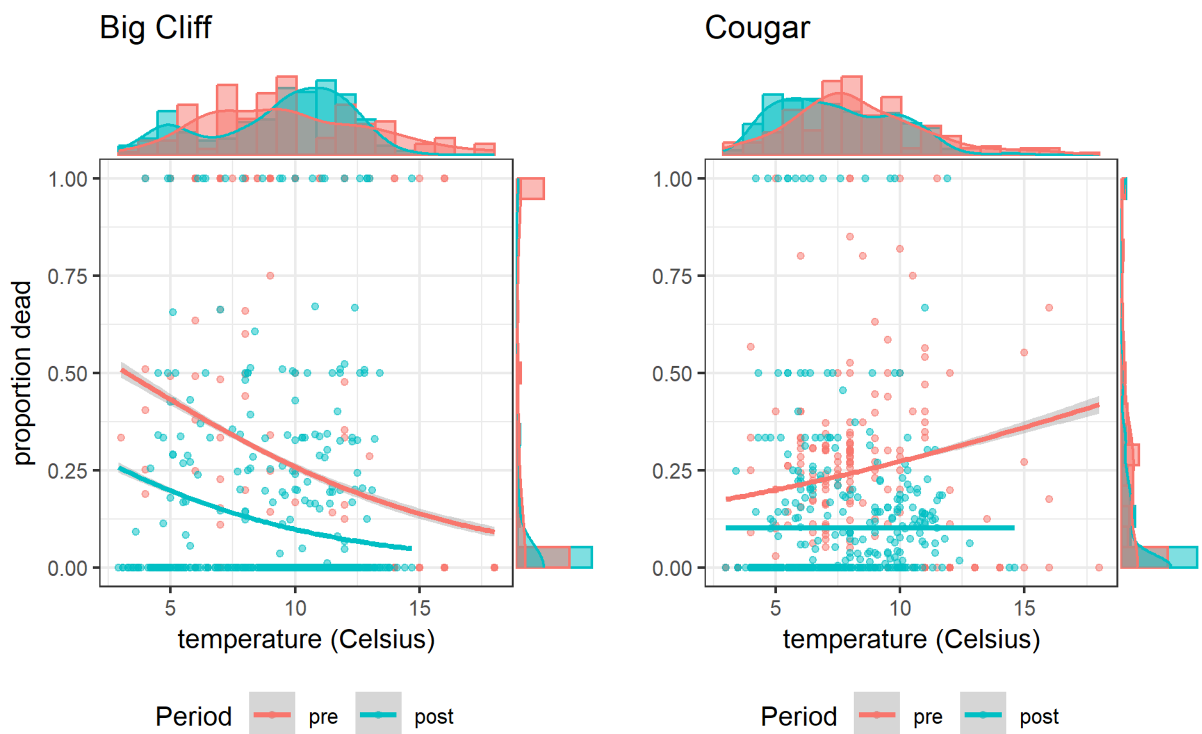

Figure A 22. Relationships between the proportion of juvenile Chinook salmon captured per trap event tat were dead and river temperature recorded during trap events at Big Cliff (left column) and Cougar RO RSTs in the pre- and post-injunction periods. Densigrams show the distribution of observations of each variable. Lines show the fit of a binomial GLM for each site and period, shading shows 95% confidence intervals.

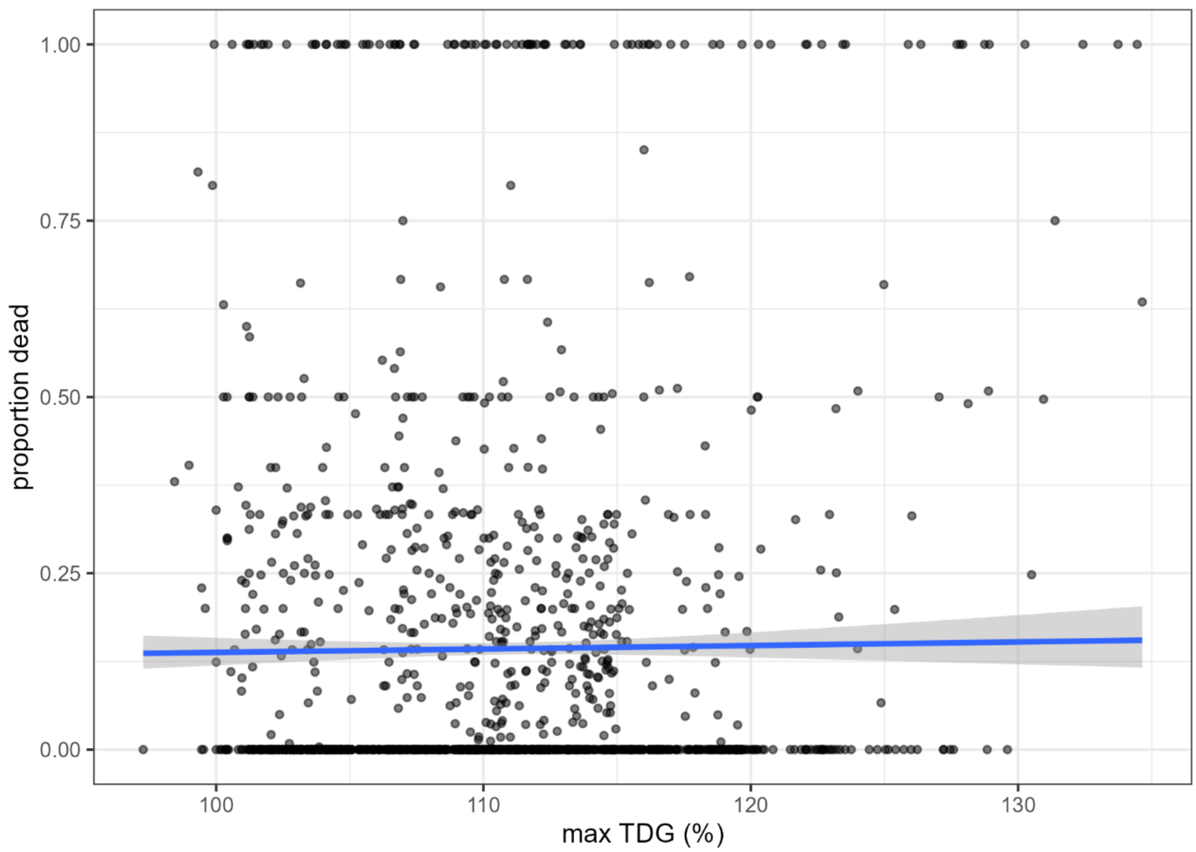

Figure A 23. Relationships between the proportion of juvenile Chinook salmon captured per trap event that were dead and maximum TDG recorded during the trap events across both Big Cliff and Cougar RO RSTs in both the pre- and post-injunction periods. Lines show the fit of a binomial GLM, shading shows 95% confidence intervals.

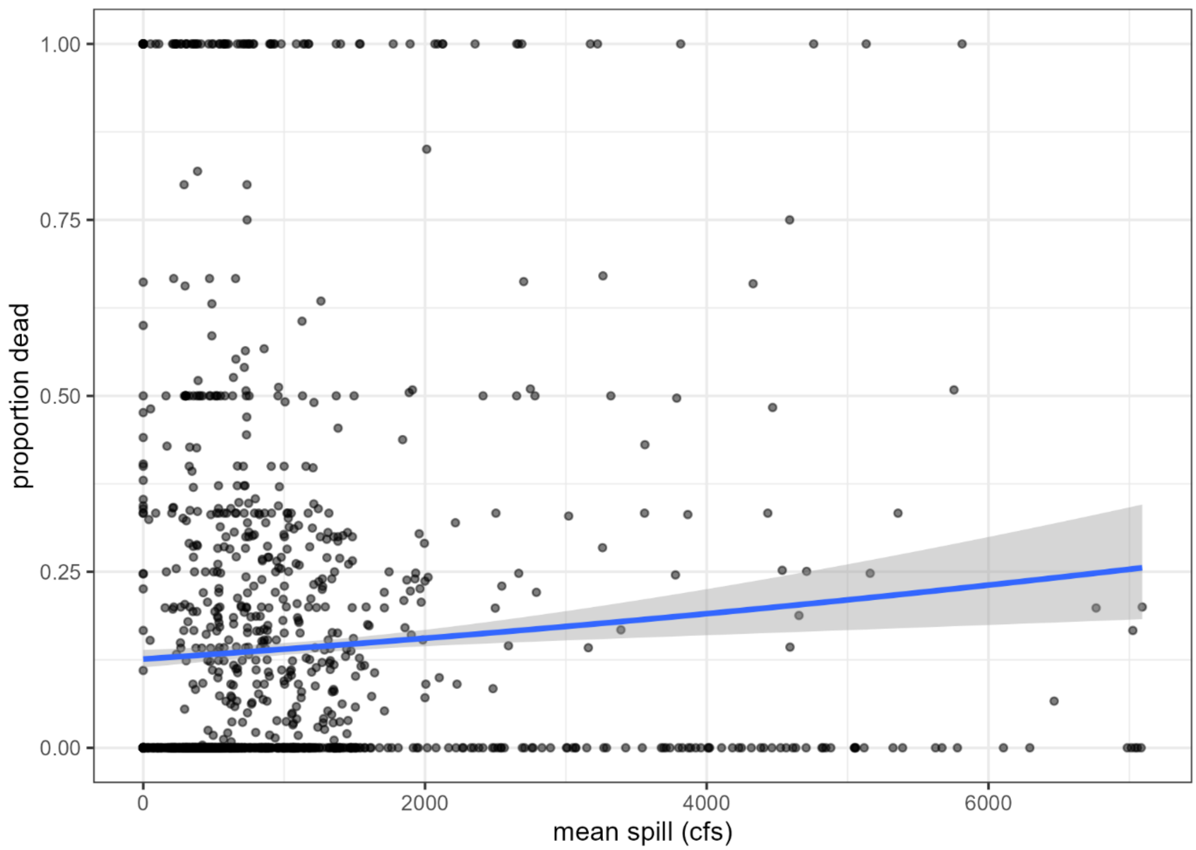

Figure A 24. Relationships between the proportion of juvenile Chinook salmon captured per trap event that were dead and mean spill recorded during the trap events across both Big Cliff and Cougar RO RSTs in both the pre- and post-injunction periods. Lines show the fit of a binomial GLM, shading shows 95% confidence intervals.

Appendix F: Project passage efficiency

Data filtering

Below Cougar and Lookout Point dams, multiple RSTs were in operation in at least one dam outlet. At Cougar, records were available from 2012-2016 and 2022-2023, when RST records indicated that a single trap was placed in each of the powerhouse (PH) and regulating outlet (RO) channel traps. We did not include data from 2010-2011 at Cougar Dam because RST operator records show multiple traps operating in the RO at this time that we could not disentangle (RO captures during this time were not differentiated by trap identity and were instead all labelled as “RO”). For PPE analysis, because we sought to capture as large a proportion of fish passing the dam as possible, we combined capture records from Cougar’s RO by week, and calculated the number of trapping hours per week according to the combined operational hours of the RO and PH RSTs over that time. Because the 6-blade RO trap was only used post-injunction, we filtered out captures at this RST and only included records from the 5-foot RO trap.

At Lookout Point, RSTs have been operated in each of the spillway and PH channels over multiple years but for only one trap, PH1, were there corresponding HOR records in both the pre- and post-injunction periods. Before implementation of injunction measures, the Lookout Point HOR RST was only in operation from 2010-2014. From 2009-2010 two RSTs were operated in the PH channel, reduced to one from 2011 to 2016 (in 2011, the RST was also moved within the channel to catch maximum flow; T. Pierce pers. comm). Following 2017 and into the post-injunction period, two RSTs were placed in the PH channel and one in the spillway channel. However, because the spillway RST and second powerhouse RST only operated in years without corresponding HOR trap records in the pre-injunction period, we could not include capture records for these RSTs. Only records from PH1 met the criteria of having corresponding HOR records during both pre- and post-injunction years. RST captures were available from the HOR and PH1 traps from 2010-2014 during the pre-injunction period and from 2022-2023 during the post-injunction period.

Statistical analysis

The following equation represents a general form of the statistical model used to estimate PPE:

$$C_{f,T,y,i} = \bar{c}_{f,H,y} * exp\left(P_{f,I} + \beta H_{T,y,i} + a_{week}(w_i - h_{week})^2 + e_i\right)$$

where $C_{f,T,y,i}$ is the trap-efficiency adjusted catch rate of fry per hour from a tailrace trapping event *i* in year *y*, $\bar{c}_{f,H,y}$ is the average catch rate of fry at the head of reservoir in year *y*, $P_{f,I}$ is a factor indicating whether the trapping occurred during the pre- or post injunction period, β is a coefficient for hydrological covariate H over the same time period (including, e.g., pool elevation, outflow through the dam outlet in which the RST is placed). Weekly run timing is described with parameters w_i, the week of the year (adjusted so that the midpoint of the run timing is centered); h_{week} the coefficient for the deviation from the run timing maximum, and a_{week}, the scaling coefficient for precision in run timing around the central tendency term for run timing. e_i is a normally distributed residual error term.

To account for variable run timing, we estimated a normally-distributed run timing curve from observed tailrace captures, assuming that observed run timing by week is approximately normally distributed and symmetrical (see Figure A 25).

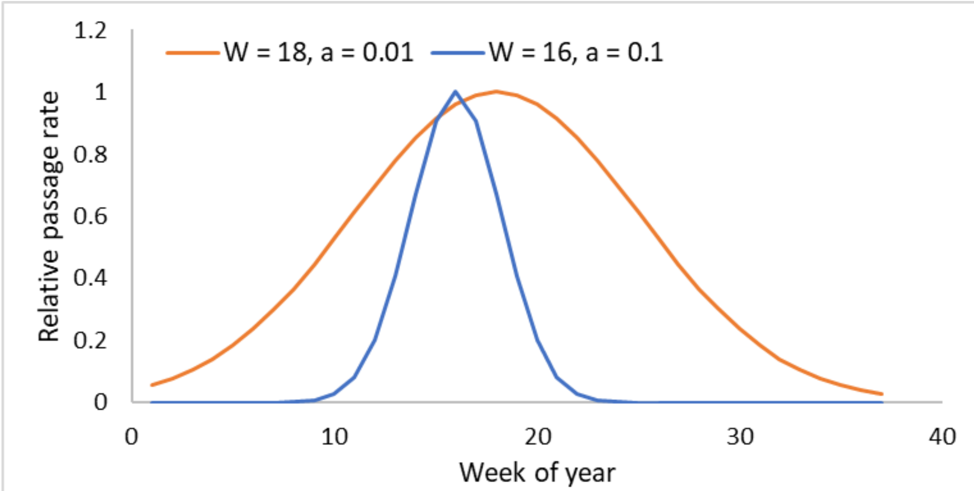

Figure A 25. Example of the functional form of non-linear components of the PPE statistical model. In this example, two run timing relationships are shown by week: in orange, a model form where the median week of passage occurs in week 18 with a spread parameter = 0.01. In blue, a contrasting model is shown with a median week of passage in week 16 and a spread parameter = 0.1. The run timing values shown above are limited to be between 0 and 1; in the full statistical model, it is multiplied by the average catch rate in a given year.

We linearized the above statistical model by log-transforming both sides of the equation after dividing the mean catch rate in the tailrace during a given trap event, $C_{f,T,y,d,i}$, by the average catch rate at the head-of-reservoir:

$$ln\left(\frac{C_{f,T,y,i}}{\bar{C}_{f,H,y}}\right) = P_{f,I} + \beta H_{T,y,i} + a_{week}(w_i - h_{week})^2 + e_i$$