State of California
The Natural Resources Agency
DEPARTMENT OF WATER RESOURCES
Bay-Delta Office

Skinner Evaluation and Improvement Study
2017 Annual Report

February 2019

Gavin Newsom	**Wade Crowfoot**	**Karla Nemeth**
Governor	Secretary for Resources	Director
State of California	The Natural Resources Agency	Department of Water Resources

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Acknowledgements

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Executive Summary

The California Department of Water Resources (DWR) evaluated the performance of the John E. Skinner Delta Fish Protective Facility (SDFPF) and quantified losses within Clifton Court Forebay (CCF) with a mark-recapture study of juvenile Chinook Salmon tracked with passive integrated transponder (PIT) tags and predation-detection acoustic tags (PDAT). The Skinner Evaluation and Improvement Study (SEIS) had three objectives. The first objective was to estimate juvenile Chinook Salmon total survival from the CCF Radial Gates to the salvage release sites. The second objective was to estimate survival in various segments of the entrainment and salvage process, including loss across CCF (pre-screen loss; PSL) and whole facility efficiency (WFE) at the SDFPF. The third and final objective was to assess the importance of operational and environmental covariates on survival including the effectiveness of predator reduction activities that took place over the study period as part of another concurrent project.

To assess juvenile salmon survival from the Radial Gates through salvage, from January to March, late-fall run Chinook Salmon (161 ± 24.9 mm FL (mean ± SD)) were PIT-tagged and released in groups of 108-111 fish over eight discrete releases. From late April to June, eight groups of smaller fall run Chinook Salmon (120 ± 14.5 mm FL) were similarly tagged and released in groups ranging from 168-169 fish. Four groups of 25-27 of the late-fall run Chinook Salmon received both a PIT and PDAT tag. Only late-fall run juveniles were large enough (172± 19.5 mm FL) to carry PDAT tags (1.11g). Three of these PDAT releases occurred in February and one occurred in March. Approximately half of the fish were released at night (0100 hrs) and the other half during daytime (0700 hrs), only when the Radial Gates were open. Releases occurred on Mondays and again on Fridays to assess whether predator removals during the week resulted in changes in juvenile salmon survival. In addition, six groups of 30 fish each were released directly into the primary louver bays at the SDFPF trashrack as a control to directly estimate SDFPF WFE, and to indirectly estimate PSL.

PSL was estimated as 77.16% for all races combined using tag detections and modeled results from the 16 releases of PIT tagged Chinook Salmon. PSL was estimated as 56.07% (range=26.1% to 88.5%) and 92.1% (range=92.1% to 98.5%) for late-fall and fall run Chinook Salmon, respectively. WFE was modeled as 81.7% (77.9% to 86.2%) and 55.0% (54.3% to 55.7%) using tag detections from 6 releases of PIT tagged Chinook Salmon at the SDFPF trashrack during “Salmon” and “Striped Bass” operating criteria, respectively.

Survival of PIT-tagged juvenile Chinook Salmon was also modeled in a multi-state Bayesian mark-recapture framework as a function of environmental covariates (downstream and upstream head level at the Radial Gates, flow at the Radial Gates, pumping rate, temperature, turbidity, wind speed, fork length, predator biomass removed and predator CPUE). Total survival from the Radial Gates to the salvage release sites of PIT-tagged fall run juveniles (0.03) was an order of magnitude lower than for late-fall juveniles (0.36). Because of this, race was an extremely strong predictor of survival for release-only models, in which only release group was included as a covariate and it also tended to overpower other predictors (temperature, turbidity, flow, and travel time) when they were included in release-level covariate models. By omitting race from the survival model, increased turbidity had the strongest effect on survival, while temperature had the weakest effect. However, when each run was examined separately, increased turbidity corresponded with increased survival in late-fall run fish and temperature had a much larger effect than it did in the global model. These contrasting patterns are often an artifact of large uncertainty associated with sparse data. Future multi-level modeling work would benefit from some overlap between races to strengthen a more robust conclusion of the significance of various covariates in a global model. Overall, the greater number of observations of late-fall run fish detected by the PIT tag antennae at the release pipes provide more reason to be confident in late-fall-specific model results than the fall run-specific model.

PDAT tags deployed in 2017 represented the first direct estimates of pre-screen survival of juvenile salmon in CCF and provided new insights into spatial variation in mortality within CCF. Importantly, the predation-detection element of these data resolved considerable uncertainty in survival estimates due to predators with ingested tags, and zero detections at receivers placed outside the Radial Gates suggested that tagged fish were not leaving the forebay of their own volition or in the guts of emigrating predators. Of the five tags that triggered in response to predation, only two were suspected of having triggered within CCF based on their overall detection history. The others triggered at the salvage release site. Low predation mortality in CCF was also reflected in estimates of pre-screen survival of PDAT-tagged fish, with point estimates greater than 90% for all releases. These high-prescreen survival estimates were much higher than indirect estimates of pre-screen survival produced by PIT-tagged fish releases at the Radial Gates and in front of the primary louvers. Total survival estimates from the Radial Gates to the release pipes were similar for fish that received PIT tags or PDAT tags. This indicates significant loss occurred between the debris boom (last acoustic receiver before the SDFPF) and the primary louvers and suggests re-evaluation of the prevailing conceptual models of predation in CCF. Predator removal catch per unit effort (CPUE) for a concurrent study in CCF was comparable to CPUE for predator removal projects in the San Joaquin and Mokelumne rivers where survival per km was similarly high for juvenile salmon. Considered with results that indicate that neither predator biomass removed nor CPUE were significant predictors of release-specific survival, these data suggest that pre-screen loss reduction efforts in the CCF may need to be re-focused on the area between the debris boom and the primary louvers.

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Acronyms and Abbreviations

AIC	Akaike's Information Criterion
Banks	Harvey O. Banks Pumping Plant
BDO	DWR Bay-Delta Office
BiOp	Biological and Conference Opinion
CCF	Clifton Court Forebay
CESA	California Endangered Species Act
CDEC	California Data Exchange Center
cfs	Cubic Feet per Second
CLC	Clifton Court Gates CDEC station code
CCFPS	Clifton Court Forebay Predation Study
CI	Confidence Interval
CJS	Cormack- Jolly-Seber
CPUE	Catch per Unit Effort
CVP	Central Valley Project (federal)
˚C	Degrees Celsius
Delta	Sacramento-San Joaquin River Delta
DWR	California Department of Water Resources
ESA	Endangered Species Act
FESA	Federal Endangered Species Act
FSB	Fish Science Building
hrs	Hours
HTI	HTI-VEMCO USA, Inc.
km	Kilometer
L	Liter
m	Meters
min	Minutes
mm	Millimeter
NMFS	National Marine Fisheries Service
NTU	Nephelometric turbidity units
O&M	Operations and Maintenance
PDAT	Predation Detection Acoustic tag
PIT	Passive Integrated Transponder
PRES	Predation Reduction Electrofishing Study
PSL	Pre-Screen Loss
QA/QC	Quality Assurance/Quality Control
RPA	Reasonable and Prudent Alternative
SCHISM	Semi-Implicit Cross-scale Hydroscience Integrated System Model
SD	Standard Deviation
SDFPF	John E. Skinner Delta Fish Protective Facility
SEIS	Skinner Evaluation and Improvement Study
SWP	State Water Project (California State)
SWRCB	State Water Resources Control Board
WFE	Whole Facility Efficiency
WY	Water Year

1. Introduction

In 2009 the National Marine Fisheries Service (NMFS) issued a Biological and Conference Opinion (BiOp) on the Long-term Operations of the Central Valley Project (CVP) and State Water Project (SWP) requiring the Department of Water Resources (DWR) to implement Reasonable and Prudent Alternative (RPA) action (IV.4.2) to reduce pre-screen losses of Endangered Species Act (ESA) protected salmon and steelhead within Clifton Court Forebay (CCF) to no more than 40 percent, and to operate the John E. Skinner Delta Fish Protective Facility to achieve a minimum 75 percent salvage efficiency for these species (NMFS 2009). Previous studies have shown pre-screen losses (PSL) of federal and State ESA listed salmonids ranging from 63% to 99% (Gingras 1997; Clark et al. 2009).

This report describes the results from a Water Year (WY) 2017 mark-recapture study, termed the Skinner Evaluation and Improvement Study (SEIS), which featured similar but augmented mark-recapture methods as WY 2016, and refined statistical analysis. The results from WY 2017 provide an additional year of baseline survival, salvage efficiency, and PSL information, as well as more detailed study of environmental factors affecting survival and the information was used to refine methods for a mark-recapture study planned and completed for WY 2018.

1.1 Background

In response to BiOp requirements, DWR has undertaken or has planned a number of proposed actions to comply with the pre-screen loss reduction target. DWR petitioned the Fish and Game Commission to remove size restrictions and increase or eliminate bag limits on Striped Bass recreational fishing in CCF. Additionally, DWR proposed and planned to construct a public access fishing facility within CCF near the Radial Gates to increase recreational fishing pressure on legally sized predatory fishes in an effort to reduce predation of protected fish species. However, during the consultation process for the pier, it became apparent that CCF design changes associated with the California WaterFix project would limit public access to the fishing pier and therefore reduce fishing pressure. As one of the interim measures while DWR and NMFS agreed and implemented an acceptable alternative to the fishing pier proposal, predatory fish relocation from CCF to nearby Bethany Reservoir was initiated with the Predation Reduction Electrofishing Study (PRES), consisting of a short-term pilot effort in 2016 and a broader scale, longer duration program in 2017 in order to optimize collection locations for a full-scale effort completed in 2018.

In tandem with PSL reduction actions and to evaluate their effectiveness and the performance of the John E. Skinner Delta Fish Protective Facility (SDFPF), DWR initiated a mark-recapture study to evaluate losses of juvenile salmonids from the SWP intake at the CCF Radial Gates to the terminus of the fish salvage process at the SDFPF. Results from a WY 2016 mark-recapture study indicated that PSL in CCF was within the range observed in previous studies.

1.2 Study Objectives

The SEIS has three main objectives:

1. Estimate juvenile Chinook Salmon total survival from the CCF Radial Gates to the salvage release sites;
2. Estimate survival in the various segments of the CCF entrainment and salvage process, including survival across CCF (pre-screen loss) and Whole-SWP survival and Efficiency at the SDFPF;
3. Assess the importance of operational and environmental covariates on survival including the effectiveness of predator reduction activities.

1.3 Concurrent Predator Studies in Clifton Court Forebay

Predation Reduction Electrofishing Study (PRES)

The PRES evaluates feasibility of electro-shocking and relocation of predatory fish in CCF to comply with the interim measure for reducing PSL in CCF. Each year of the three-year study has a specific focus. The 2016 field season was primarily a pilot effort, focusing on field logistics, equipment and personnel needs, developing effective electrofishing methods, and collecting initial data on predator density patterns. The 2017 field effort focused on refining methods based on lessons learned and recommendations from the 2016 effort, determining spatial and temporal patterns in predator catch rates using a standardized electrofishing regime, and assessing environmental variables that may affect catch rates. The 2018 field season used information on factors that affect predator catch rates and recommendations from 2016 and 2017 efforts to maximize predator removal rates.

Additional information on the predatory fish relocation for the PRES effort in 2017, which was implemented concurrently with the 2017 SEIS project, can be found in the "Clifton Court Forebay Predator Reduction Electrofishing Study Annual Report 2017." The results of the PRES effort in 2018 can be found in the "Clifton Court Forebay Predator Reduction Electrofishing Study Annual Report 2018." The corresponding results of the 2018 SEIS effort will be presented in a planned future report.

Clifton Court Forebay Predation Study (CCFPS)

The Clifton Court Forebay Predation Study (CCFPS) was initiated in 2013 in response to RPA Action IV.4.2 from the 2009 NMFS BiOp to gain a better understanding of predation as a factor in survival of listed salmonids in CCF. One element of CCFPS is to tag predatory fish with PIT and Floy tags and follow their recaptures through time to estimate movement, population size, and prey consumption. Field sampling during PRES regularly captures predatory fish that were tagged for CCFPS and reports all recaptured fish to the CCFPS project manager.

Additional information on the CCFPS can be found in the "Clifton Court Forebay Predation Study: 2016 Annual Report."

2. Methods

2.1 Overview

The WY 2017 SEIS involved obtaining hatchery-raised Chinook Salmon and fitting them with Passive Integrated Transponder (PIT) and Predation Detection Acoustic (PDAT) tags. Tagged fish were released near the CCF Radial Gates or at the SDFPF (for Whole Facility Efficiency releases) and detected with hydrophones and PIT tag antennae in CCF, adjacent waterbodies, and the salvage release locations in the western Delta. The pattern of these detections was analyzed statistically in order to estimate total survival from the Radial Gates to the salvage release locations, as well as survival within portions of the overall pathway and the operational and environmental covariates influencing survival.

2.2 Study Site

Located near Byron in Contra Costa County, California, CCF was constructed in 1969 by inundating a 2,200-acre tract of land approximately 2.6 miles long and 2.1 miles across (Kano 1990). CCF is operated as a regulating reservoir within the tidally influenced region of the Sacramento-San Joaquin River Delta (Delta) to improve operations of the SWP, Harvey O. Banks Pumping Plant, and water diversions to the California Aqueduct (Figure 1). During high tide cycles, when the elevation of water in Old River exceeds the elevation of water in CCF, up to five radial gates located in the southeast corner of CCF are opened to allow water to be diverted from the Delta into CCF. Daily operation of the gates depends on scheduled water exports, tides, and storage availability within CCF (Le 2004). Diversion of water from Old River into CCF results in entrainment of numerous fish species.

Fish entering CCF travel a minimum of 2.1 miles across CCF to reach the SDFPF. The SDFPF was designed to protect fish from entrainment into the California Aqueduct by diverting them into holding tanks where they can be salvaged and safely returned to the Delta. Water is drawn to the SDFPF from CCF via an intake canal past a floating trash boom. The trash boom is designed to intercept floating debris and guide it to an onshore trash conveyor. Water and fish then flow through a trash rack, equipped with a trash rake, to a series of louvers arranged in a V pattern. Fish are behaviorally guided by turbulence generated by the louvers to salvage holding tanks where they await transport via truck to two release locations in the western Delta.

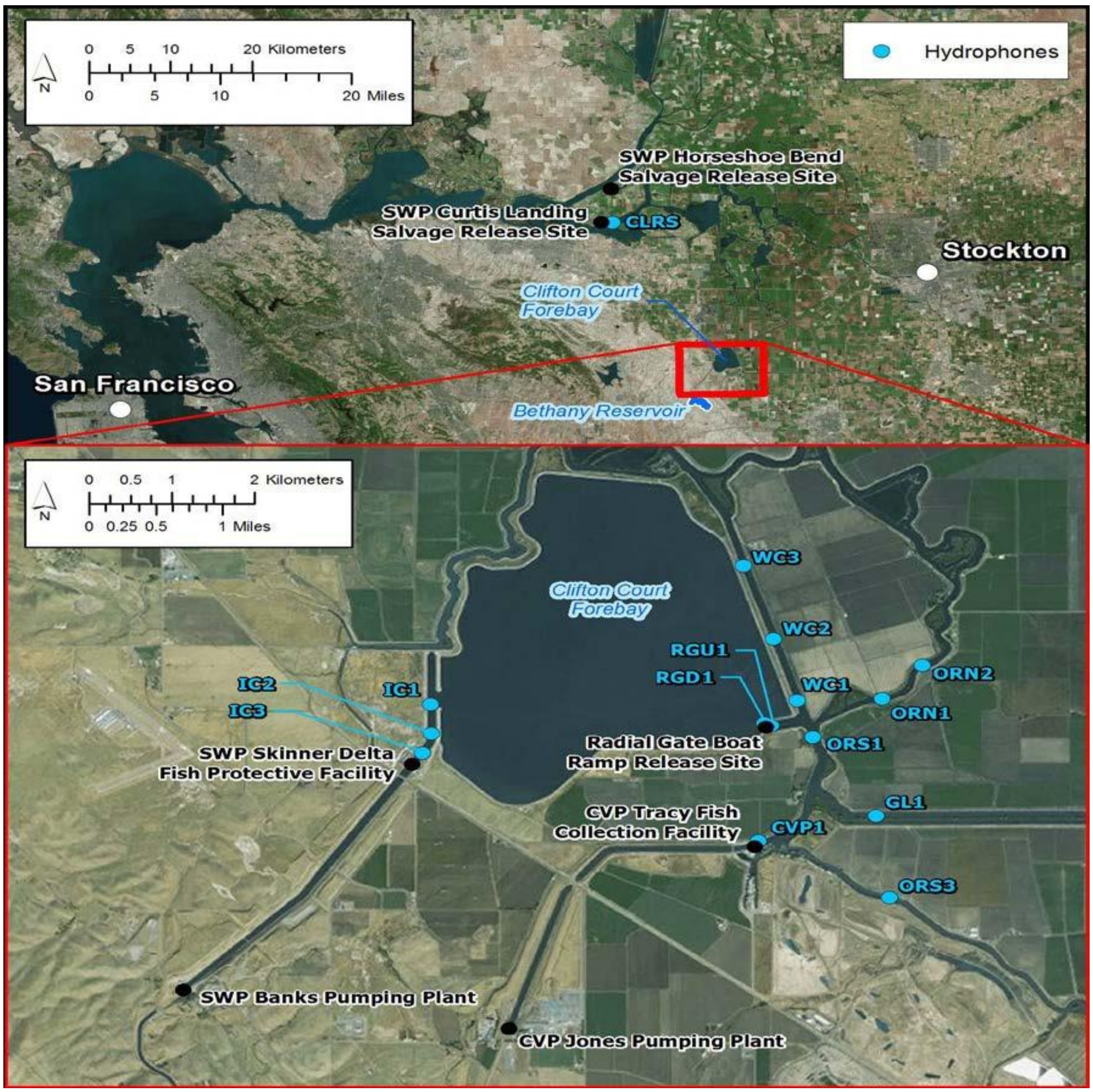

Figure 1. Clifton Court Forebay Location Map.

2.3 Chinook Salmon Stock and Husbandry

Juvenile late-fall run Chinook Salmon and fall run Chinook Salmon for this study were obtained from the Coleman National Fish Hatchery and Mokelumne River Fish Hatchery, respectively. Late-fall run Chinook Salmon were utilized in releases from January through early March, while fall run Chinook Salmon were released from late April through early June. The selection of these runs and their respective size classes was intended to be representative of the general seasonal size distribution of Chinook Salmon salvaged at the SDFPF.

Juvenile salmon provided by the hatcheries were transported in two separate events using a 1,700-L insulated fish hauling tank and transferred to the Fish Science Building (FSB) at the SDFPF. Upon arrival at the FSB facility, fish were transferred to 1,362-L and 3,558-L circular, aerated fish holding tanks. These tanks were supplied with "recirculated" water (filtered, recirculated, and temperature-controlled. California Aqueduct water) held at or near mean CCF water temperature. Use of the recirculated water system was to prevent fish health problems as a result of temperature fluctuations in the California Aqueduct water source. The salmon were fed a sinking, pelleted feed daily except when fasted for 24 hours before tagging and the 48-72-hour period between tagging and release.

2.4 Tagging

PIT Tags

Juvenile late-fall run Chinook Salmon selected for PIT tag implantation ranged in fork length from 100 to 230 mm, with a mean of 161 ± 24.9 mm (mean ± SD). Juvenile fall run Chinook Salmon selected for PIT tag implantation ranged in fork length from 75 to 158 mm, with a mean of 120 ± 14.5 mm (mean ± SD). Between 84 and 141 late-fall run Chinook Salmon were PIT-tagged during each of eight tagging sessions from January 13 to February 28 (Table 1). Between 32 and 207 fall run Chinook Salmon were tagged during each of nine tagging sessions from April 21 to June 6 (Table 1). Salmon were tagged following the general guidelines of the PIT tagging procedure manual prepared by the Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee (1999). Each juvenile salmon was netted from the holding tank and placed into an 18.9-L anesthesia bath that contained 35 mg/L of AQUI-S 20E. The salmon was left in the bath for 1-3 minutes until anesthetized. Each salmon was measured for length and weight, evaluated for abnormalities or external signs of disease/injury, and the presence of an adipose fin. If the adipose fin was still present, the tagger clipped the fin using dissection scissors to ensure that the salmon was appropriately identified as a study fish if subsequently captured at the SDFPF. A PIT tag implant gun (Biomark, model MK 25) utilizing pre-loaded needles was used to inject the PIT tag (Biomark HPT 12; 12.5 mm long) into the abdominal cavity. The time to PIT tag each fish was less than one minute. Tagged fish were placed into an 18.9-L aerated container and held for observation to ensure recovery. Once recovered, fish were transferred to a 1,362-L tank supplied with recirculated water and aeration and held for a 48-72-hour recovery period prior to release.

Table 1. Summary of PIT and PDAT Tagging for SEIS, WY 2017.

Tag Session ID	Date	Number Tagged	Mean Weight (g)	SD Weight	Mean Fork Length (mm)	SD Fork Length	Chinook Salmon Run
PIT1	1/13/2017	141	40.7	17.5	150.8	21.1	Late-fall
PIT2	1/17/2017	112	41.9	19.4	149.6	23.1	Late-fall
PIT3	1/27/2017	112	51.6	22.1	159.6	23.2	Late-fall
PIT4	1/31/2017	116	56.4	25.5	168.9	23.3	Late-fall
PIT5	2/10/2017	114	57.8	24.8	166.0	24.2	Late-fall
PIT6	2/14/2017	84	53.6	25.2	161.6	24.6	Late-fall
PIT7	2/24/2017	85	59.0	26.0	166.0	24.6	Late-fall
PIT8	2/28/2017	85	67.0	30.7	170.8	26.8	Late-fall
PIT10	4/21/2017	202	13.6	3.5	103.2	8.5	Fall
PIT11	4/25/2017	170	15.3	3.9	107.6	9.1	Fall
PIT13	5/5/2017	207	19.3	5.0	113.5	9.7	Fall
PIT14	5/9/2017	172	19.4	4.8	116.1	9.8	Fall
PIT15	5/19/2017	206	25.9	7.2	125.3	11.3	Fall
PIT16	5/23/2017	171	26.8	6.2	127.9	9.0	Fall
PIT17	6/2/2017	171	33.2	8.2	133.2	9.8	Fall
PIT18	6/2/2017	32	31.8	6.9	131.9	9.6	Fall
PIT19	6/6/2017	172	30.0	7.5	133.0	9.6	Fall
PDAT1	2/9/2017	31	65.0	24.5	170.8	19.2	Late-fall
PDAT2	2/13/2017	30	71.5	20.9	177.4	16.5	Late-fall
PDAT3	2/23/2017	30	60.0	18.7	167.7	16.6	Late-fall
PDAT4	2/27/2017	30	62.0	32.8	167.9	23.9	Late-fall

Predation Detection Acoustic Tags (PDAT)

Juvenile late-fall run Chinook Salmon selected for PDAT tag implantation ranged in fork length from 134 to 235 mm, with a mean of 172 ± 19.5 mm (mean ± SD). All fish receiving a PDAT tag also received a PIT tag or had a combination PIT/PDAT tag. Around 30 late-fall run Chinook Salmon were tagged during each of four tagging sessions from February 9 to February 27 (Table 1). Salmon were tagged following the general guidelines developed by Liedtke et al. (2012) and Liedtke and Wargo-Rub (2012). Prior to surgery, PDAT tags (HTI 900-PD, 25 mm long × 10 mm wide, weight 1.11 g) were washed in distilled water and sterilized with ultraviolet light. All surgical instruments were sterilized in an autoclave prior to the start of each tagging session. Anesthesia with AQUI-S 20E to sedation, fish measurement, evaluation for abnormalities, and adipose fin assessment were the same as the previously described procedures for PIT-tagged fish. Anesthetized fish for surgery were placed ventral side up on the surgery table, with continuous flowing anesthesia (AQUI-S 20E solution) immediately provided through tubing placed in the mouth. PDAT tags were inserted into an incision made with a scalpel approximately 3 mm from, and parallel to, the mid-ventral line (Figure 2). The incision was closed with two uninterrupted sutures. The time to tag each fish was generally three to five minutes. Tagged fish were placed into an 18.9-L aerated container and held for observation to ensure recovery. Once recovered, fish were transferred to a 1,362-L tank supplied with recirculated water and aeration and held for a 72 hour recovery period prior to release.

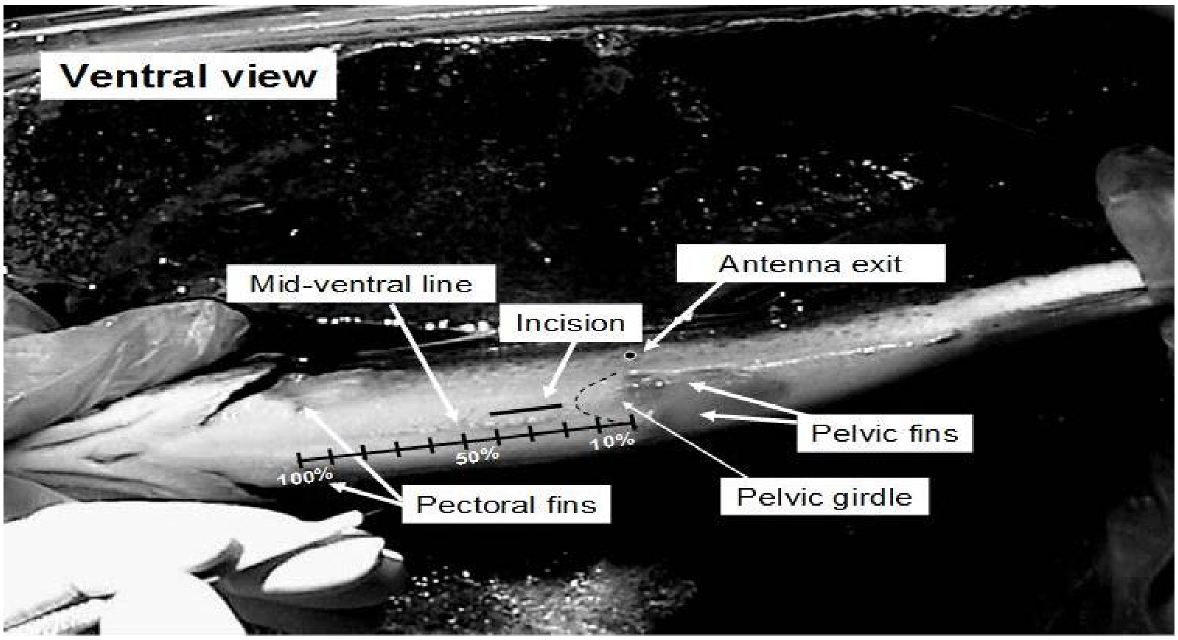

Figure 2. Ventral view of a juvenile salmonid, showing the proper placement of incision for acoustic tag insertion. This view corresponds to a left-handed surgeon's view; for right-handed surgeons, the fish would be facing the right and the incision would be on the opposite side of the midline. Antenna exit hole is not required for the PDAT used for SEIS.

2.5 Tagged Fish Releases

Tagged fish were released in groups of around 110 to 170 fish on 16 occasions from January 16 to June 9 (Table 2). Late-fall run Chinook Salmon released prior to April generally were around 150 mm or larger, whereas fall run Chinook released after April generally were between 100 and 130 mm (Figure 3). Releases generally occurred around 01:00 or 07:00, to coincide with Radial Gate operations—all releases occurred with the Radial Gates at least partially open, in order to simulate entrainment into CCF. Releases generally occurred on Mondays and Fridays, in order to assess survival before and after weekly PRES electrofishing sessions. Prior to transportation of tagged salmon to the CCF Radial Gate release site, all salmon were checked individually for presence of operational PIT and acoustic tags and their tag identification number recorded. Fish with non-operational or shed PIT or PDAT tags were not released, and the total release group size reduced accordingly. Fish were transported to the Radial Gates in a 1,314-l insulated fish transport livewell supplied with oxygen, which was on a flatbed trailer hauled by a ¾-ton pickup truck. Temperature and oxygen content in the livewell was monitored to assess water quality conditions for transported fish. Fish were released directly into CCF from the transportation livewell by backing the trailer down the boat ramp to the south of the Radial Gates until the livewell drain was at water level, at which point the drain was opened and the fish swept into CCF.

Six releases directly into the primary louver bays at the trashrack to assess whole facility efficiency were made during the study, two with late-fall run Chinook Salmon and the remainder with fall run (Table 3).

Fish were transported and released into the primary louver bays using 18.9-l aerated, buckets lowered by ropes and inverted immediately above the water surface several feet downstream of the trashrack.

Table 2. Summary of tagged juvenile Chinook Salmon releases at Clifton Court Forebay Radial Gates for SEIS, WY 2017.

Release Date	Release Time	Number of PIT Released	PIT Tag Session ID	Number of PDAT Released	PDAT Session ID	Chinook Salmon Run
1/16/2017	06:54	111	PIT1	0		Late-fall
1/20/2017	01:02	111	PIT2	0		Late-fall
1/30/2017	06:57	111	PIT3	0		Late-fall
2/3/2017	12:17	109	PIT4	0		Late-fall
2/13/2017	08:53	84	PIT5	27	PDAT1	Late-fall
2/17/2017	12:30	83	PIT6	25	PDAT2	Late-fall
2/27/2017	05:05	84	PIT7	27	PDAT3	Late-fall
3/3/2017	00:51	84	PIT8	26	PDAT4	Late-fall
4/24/2017	07:05	169	PIT10	0		Fall
4/27/2017	01:05	169	PIT11	0		Fall
5/8/2017	07:30	169	PIT13	0		Fall
5/12/2017	01:35	169	PIT14	0		Fall
5/23/2017	07:17	169	PIT15	0		Fall
5/26/2017	01:14	168	PIT16	0		Fall
6/5/2017	07:10	168	PIT17	0		Fall
6/9/2017	00:45	168	PIT19	0		Fall

Table 3. Summary of tagged juvenile Chinook Salmon primary louver (trashrack) releases for SEIS, WY 2017.

Release Date	Release Time	Number of PIT Released	PIT Tag Session ID	Chinook Salmon Run	Primary Louver Bay Release Locations
1/25/2017	9:14	30	PIT2	Late-fall	P1, P2, P3A
2/15/2017	10:25	30	PIT5	Late-fall	P5, P4B, P4A
4/26/2017	8:48	29	PIT10	Fall	P4A, P4B
5/10/2017	9:00	30	PIT14	Fall	P3B, P4A, P3A
5/24/2017	9:18	30	PIT15	Fall	P4B, P4A, P3B
6/9/2017	8:30	30	PIT18	Fall	P3A, P2, P1

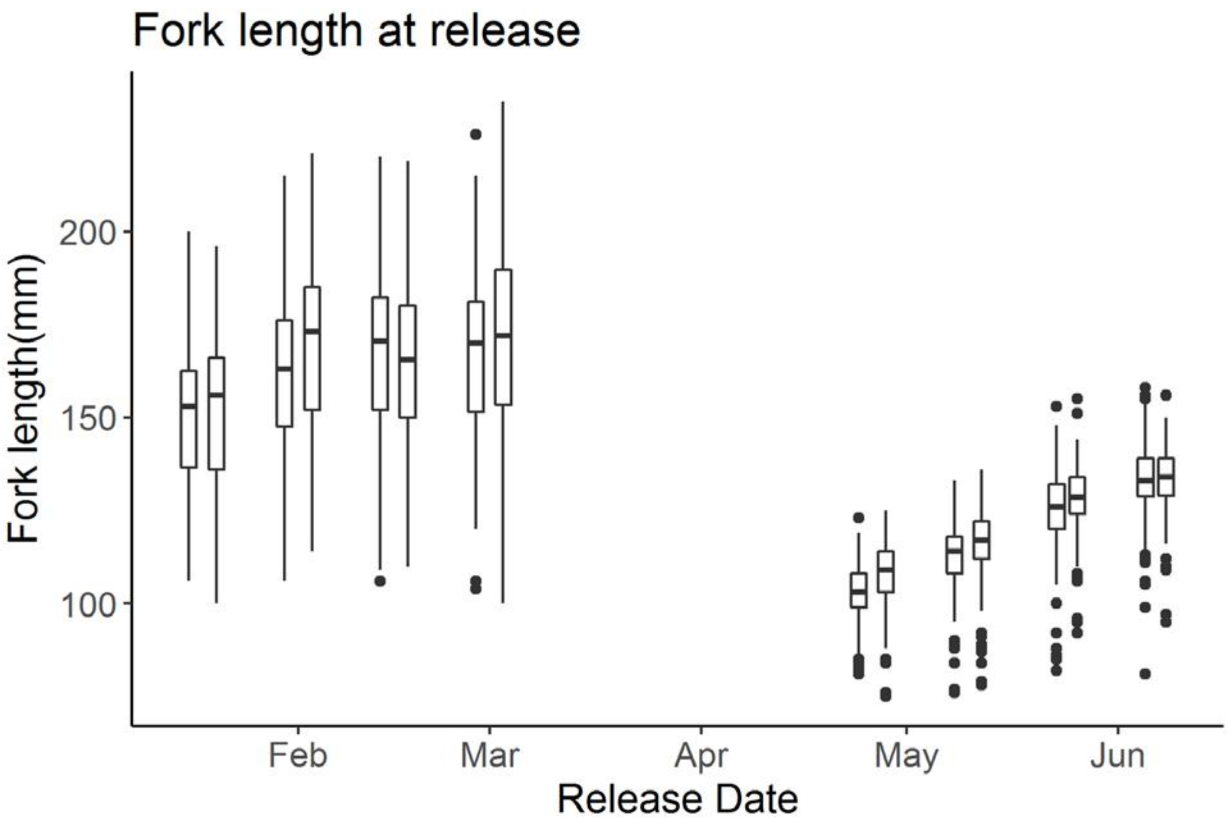

Figure 3. Juvenile Chinook Salmon Fork Length at Release (Pre-April: Late-Fall Run; Post-April: Fall Run). Line = median; box = interquartile range; whiskers = minimum/maximum; dots = outliers (>1.5 times upper quartile or <1.5 times lower quartile).

2.6 Tag Detection Systems

PIT Tags

To detect salvaged, PIT-tagged salmon released as part of this study, PIT tag detection systems installed at the two SWP salvage release sites on Sherman Island in the Central Delta were used. The detection systems consisted of three custom-made, circular antennae with aluminum shields at the Horseshoe Bend release site (Figure 4) and two custom-made, circular antennae at the Curtis Landing release site. Any study fish that were salvaged were trucked to the release sites and released through these pipes outfitted with the PIT antennae according to the SDFPF standard operating procedures. All detections of PIT tagged salmon were made post-salvage. All PIT-tagged salmon detected during the salvage release process were assumed to have been successfully salvaged and alive[1]. Any PIT-tagged salmon encountered during routine counts at the SDFPF were immediately released to a holding tank for subsequent detection on the detection system installed at the salvage release sites. This ensured that all fish were subjected to the entire salvage process through release.

[1] Striped Bass and other predatory fishes of the size required to consume the PIT-tagged salmon are occasionally encountered within the SDFPF holding tanks and fish hauling truck. However, no PIT tags were found during examination of predatory fishes encountered during counts at the SDFPF during experimental salmon releases in WY 2015 and 2016. This suggests that the predation rate on study fish is likely very low, and so was assumed to be zero for the WY 2017 releases.

Attached to each antenna was a transceiver/datalogger capable of storing tag detections. The Curtis Landing site was equipped with two types of transceivers/dataloggers: a Destron Fearing FS2001F-ISO and a Biomark HPR+. The antennae at the Horseshoe Bend release site were connected to a series of three Biomark IS1001 transceivers/dataloggers equipped with a battery backup system and remote telemetry. Direct measurements of detection efficiency conducted in 2016 indicated that the systems have a combined nominal detection efficiency in excess of 90.5% (DWR 2016).

Figure 4. PIT tag detection array installed at the Horseshoe Bend Release Site. Shown are the three Biomark IS1001 transceivers/dataloggers (left) and three custom antennae with their aluminum shields mounted on the salvage release pipe (right).

Predation Detection Acoustic Tags (PDAT)

PDAT-tagged fish were detected with stationary hydrophones and data loggers (HTI 395-Series Data Logger) installed throughout CCF and nearby waterbodies (Figure 1), of which a subset was used in the statistical analysis. Fish were also detected by a mobile, boat-based survey which covered CCF weekly as part of CCFPS, but these detections are not considered further in this analysis.

2.7 Operations and Environmental Covariates

Operational data for Banks pumping and Radial Gate flow (cfs) were provided by the DWR Division of Operations and Maintenance (O&M). As part of the QA/QC process, Banks pumping rates from O&M were compared to pumping rates reported as part of the salvage process (ftp://ftp.dfg.ca.gov/salvage/). If pumping rates differed by more than 5% between datasets, pumping rates from salvage data were used.

Water temperature (°C) and turbidity (Nephelometric turbidity units, NTU) 15-minute data for Clifton Court (CLC: 37.8298°N, 121.5574°W) were downloaded from the California Data Exchange Center (CDEC: cdec.water.ca.gov) website maintained by DWR.

A YSI® Model EX02 multiparameter sonde was placed in CCF to collect 15-minute data on several water quality parameters, including water temperature, conductivity, turbidity, and dissolved oxygen. The dataset for the 2017 field season was incomplete because of sonde malfunctioning for a large portion of the middle of the study period, so these data were not used for this annual report.

In addition to measured covariates, simulations were undertaken to estimate water transit time across CCF during each release. The simulations consisted of particle tracking using a 3D SCHISM model (Shu and Ateljevich 2017). Particle tracking simulations were made for the environmental conditions that occurred during each release of juvenile Chinook Salmon for SEIS in 2017 (Table 4). Model inputs included Banks pumping, Byron Bethany Irrigation District diversions, CCF Radial Gate operations, bathymetry, and wind, as described by Shu and Ateljevich (2017). For each simulation, 2,000 neutrally buoyant particles were released near the tagged salmon release point adjacent to the Radial Gates, and particles were tracked until the end of the study. The covariate used in the statistical analysis described in the following section was the time taken for 10% of particles to reach the debris boom in the Intake Canal (i.e., just south of hydrophone IC3 in Figure 1).

Table 4. The number of hours estimated on a given date for a percentage of seeded particles to transit from their insertion point near the Radial Gates to the SDFPF debris boom.

(%)	1/16/2017	1/20/2017	1/30/2017	2/3/2017	2/13/2017	2/17/2017	2/27/2017	3/3/2017
1	13.1	3.5	3.4	7.4	2.5	6	19.2	48.1
5	21	3.8	3.5	8.2	2.6	15.6	20.5	49.3
10	22.7	4.5	3.7	9.1	3.1	15.6	21.3	56.4
20	31.6	9.3	4.6	9.3	3.7	23.8	42.8	59.8
25	42.1	23.4	5	9.6	17.7	41.9	68.2	60.9
50	52.1	48.1	7.4	10.1	45.6	131.8	77.3	62.2
75	55.5	49.1	11.4	10.9	46	233.8	132.4	74.5

(%)	4/24/2017	4/28/2017	5/8/2017	5/12/2017	5/23/2017	5/26/2017	6/5/2017	6/8/2017
1	26.1	11.3	17.2	16	35.7	71.8	18.6	24.8
5	38.3	12.5	17.5	16.1	45.6	75.3	20.9	25.2
10	53.1	12.7	17.5	16.2	45.6	77.8	23.1	25.8
20	79.1	23.5	17.7	16.6	45.7	92	24.3	30.8
25	85	27	17.7	16.7	45.7	112.8	25	39.6
50	119.4	86.3	17.9	17	45.7	147	39	60.5
75	141.8	116.1	18	17.7	45.7	173.9	59.2	100.5

2.8 *Statistical Analysis*

PIT Tag Analysis

Analysis of Covariates

Figure 5 shows the observed proportion of fish detected at the final detection station for each release group. Mean observed survival (calculated as the number of fish detected at the final antennae divided by the number of fish released in the group) across releases was 0.03 for the fall run fish, and 0.36 for late-fall fish.

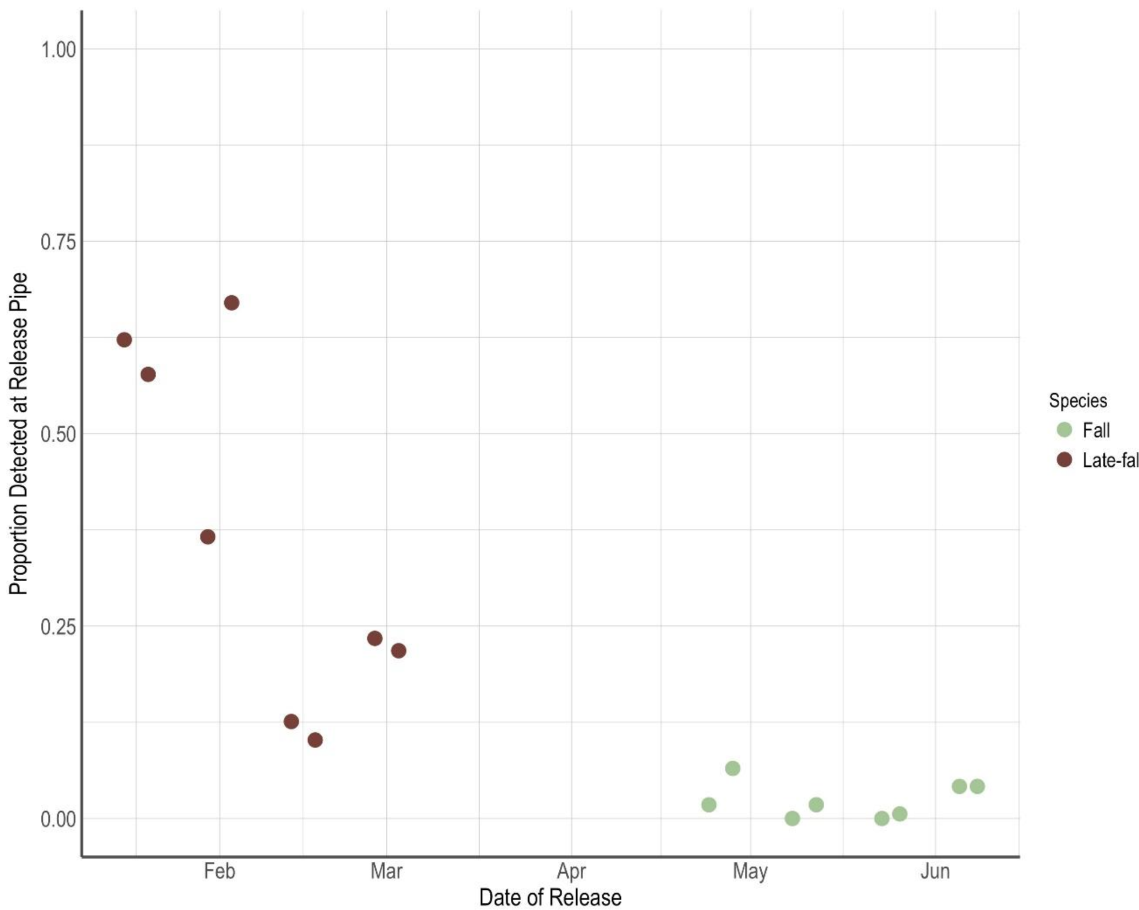

Figure 5. Observed proportion of fish detected at the final detection station for each release group.

Preliminary modeling was conducted on all twenty covariates included in the original set. Of these 20 covariates, nine of them were included for further modeling efforts. These nine variables were selected based on their nonzero effect sizes in preliminary models, as well as for their documented potential for affecting the survival of juvenile salmonids. Excluding the biomass removed and CPUE covariates (whose values were specific to individual releases), the remaining seven covariates modeled in the mark-recapture models are plotted across the experimental timescale of releases in Figure 6, below.

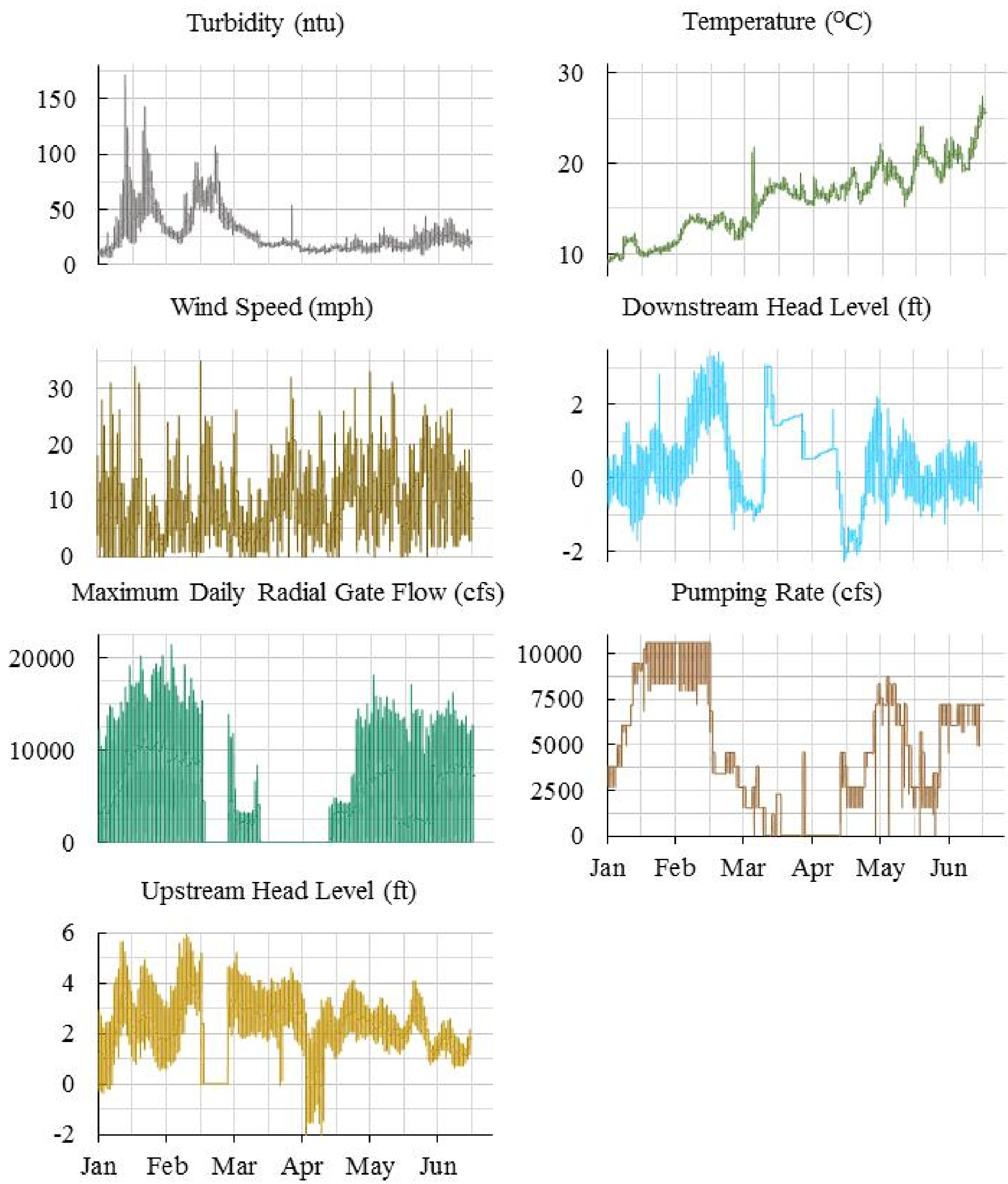

Figure 6. Values of abiotic covariates across experimental release period.

To determine which of these covariates were correlated or collinear with each other across the release period, we conducted a basic correlation analysis of the seven covariates referenced above. Figure 7 summarizes the results of the correlation analysis (pairwise, Pearson method). Correlation values greater than 0.5 or less than -0.5 are highlighted in blue or red, respectively. When all covariates were aggregated across time, the only correlations that stood out were between temperature and month of the year (month was not a modeling covariate but was included in the correlation analysis as an aggregator). Pumping rate and flow at the radial gates showed a correlation.

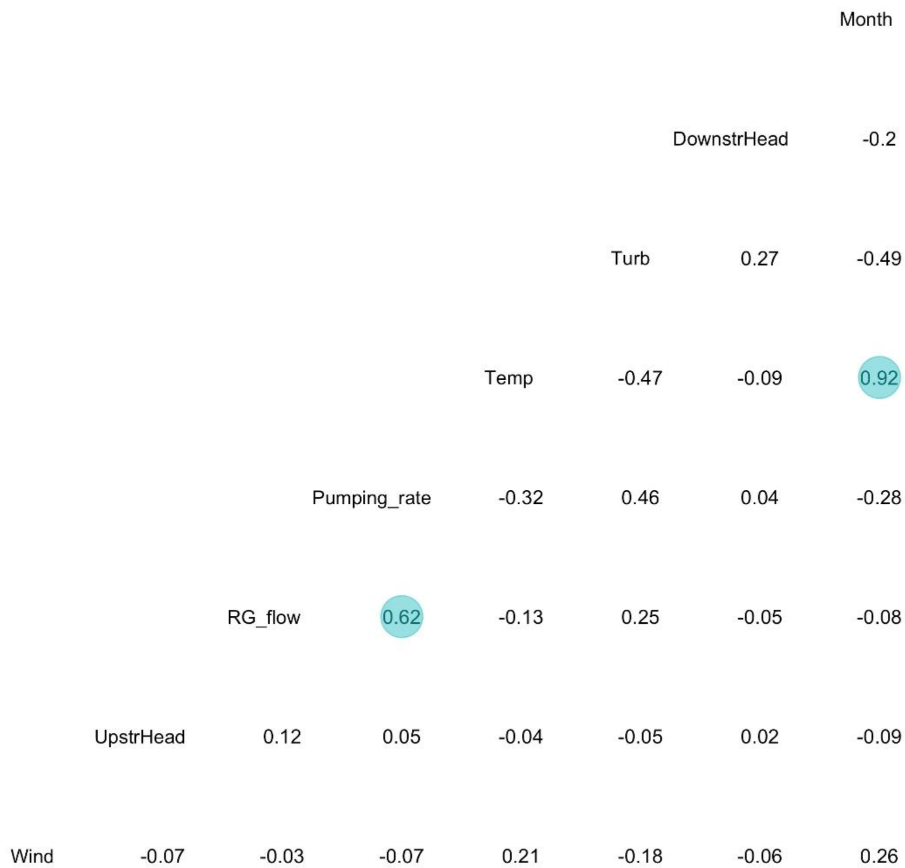

Figure 7. Correlation values for covariates across experimental release time period (January – June).

We also investigated correlation of covariates by individual month (January-June). Many of the covariates that were not correlated overall showed correlation within some months (Figure 8). Upstream head level, in particular, is strongly positively correlated with pumping rate in March; March showed the highest number of correlated covariates.

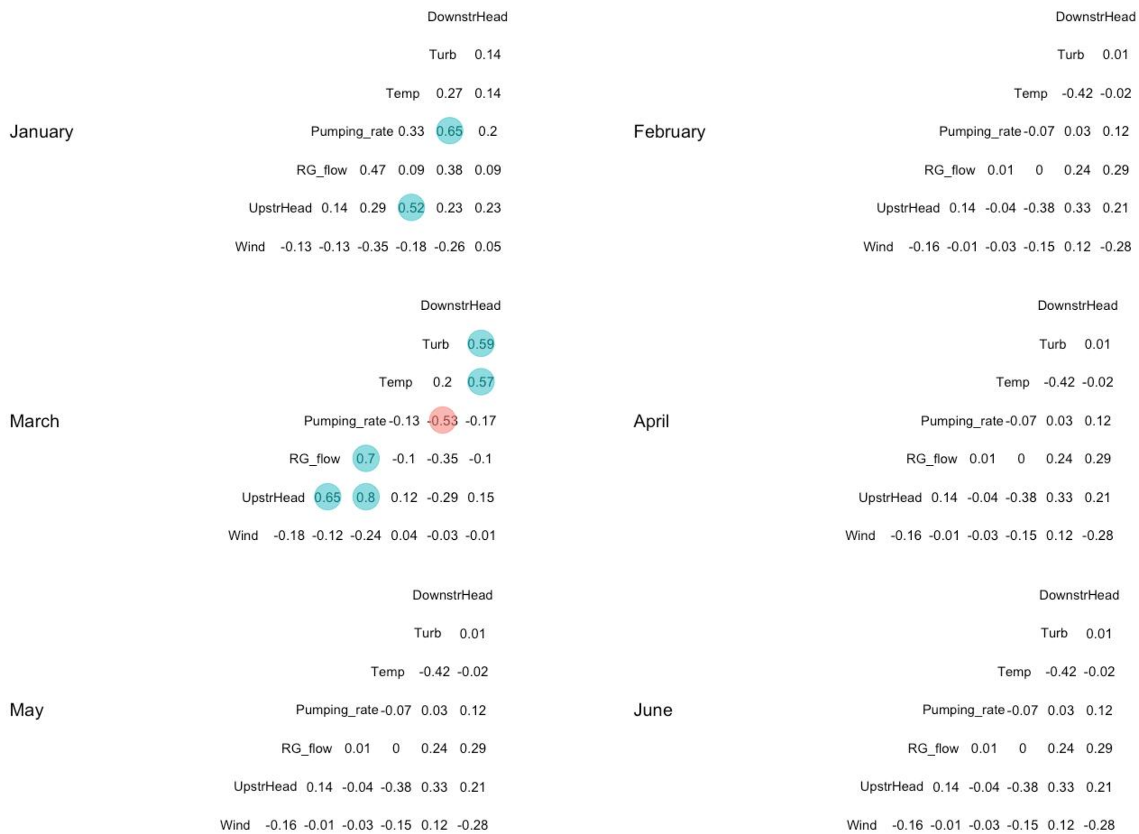

Figure 8. Correlation values for covariates by month.

Based on their correlation with pumping rates and flow at the Radial Gates, as well as their relatively weaker documented relationship with survival in juvenile salmonids, we omitted upstream and downstream head levels from this initial modeling effort. For those covariates that were correlated in some months (i.e. temperature and turbidity, or pumping rate and turbidity), their interactions were included in candidate models.

Individual Covariates: Fork Length

The only individual-level covariate included in mark-recapture modeling was fork length; however, fork length is highly correlated with run, as shown in Figure 9.

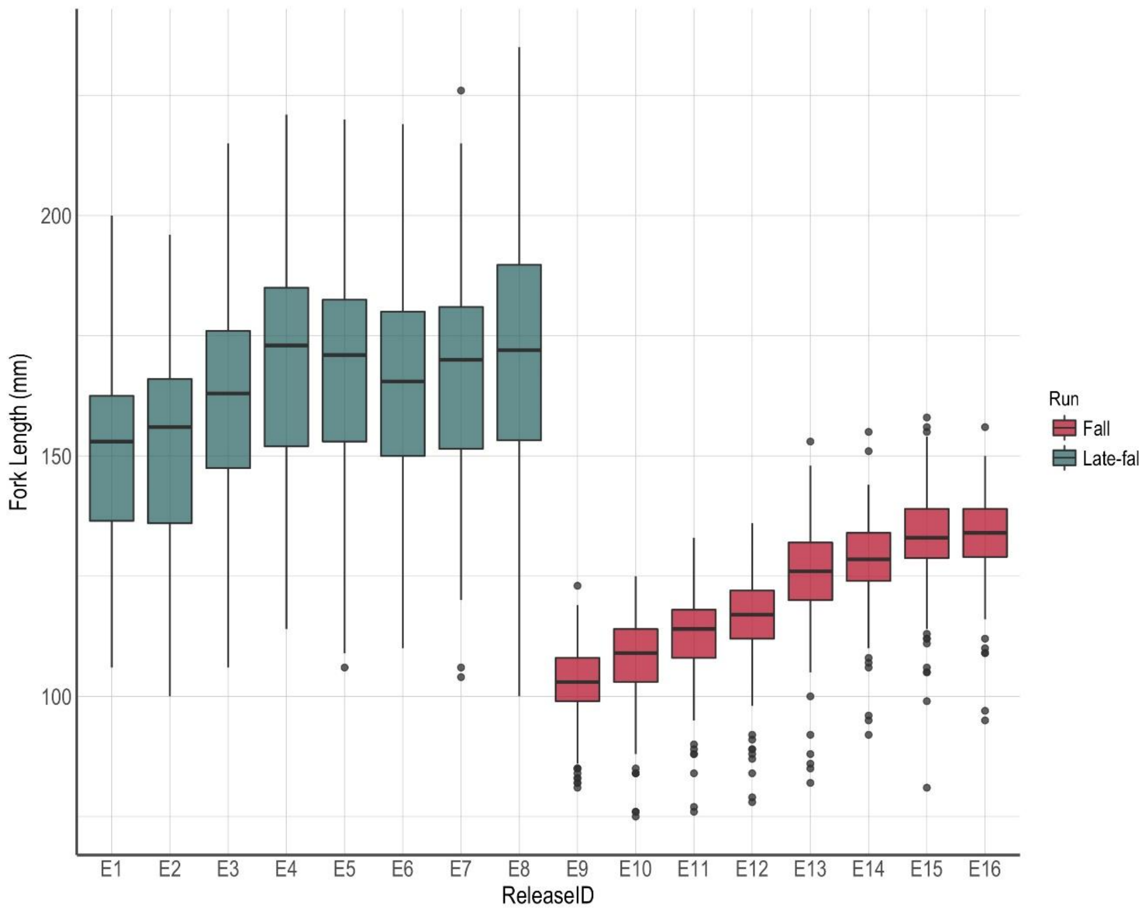

Figure 9. Individual fork length by release and run.

To avoid quasi-separation of the linear regression model within the mark-recapture models, fork length was only included in the run-specific candidate models. The effect of fork length was not significant in any of the models that included it. After building release-specific models with both predator biomass removed and predator CPUE covariates included and determining that their effect was not significant, these predictors were excluded from subsequent models described in the following sections.

Release-specific covariates

The final covariates for release-level modeling were averaged within the 48-hour period following each release of fish. This mean value was then used as a release-specific predictor value for each release-level covariate. These values are plotted in Figure 10, where the x-axis is the individual release identification index associated with each covariate value. E01-E08 are the late-fall run releases; E09-E16 are the fall run releases.

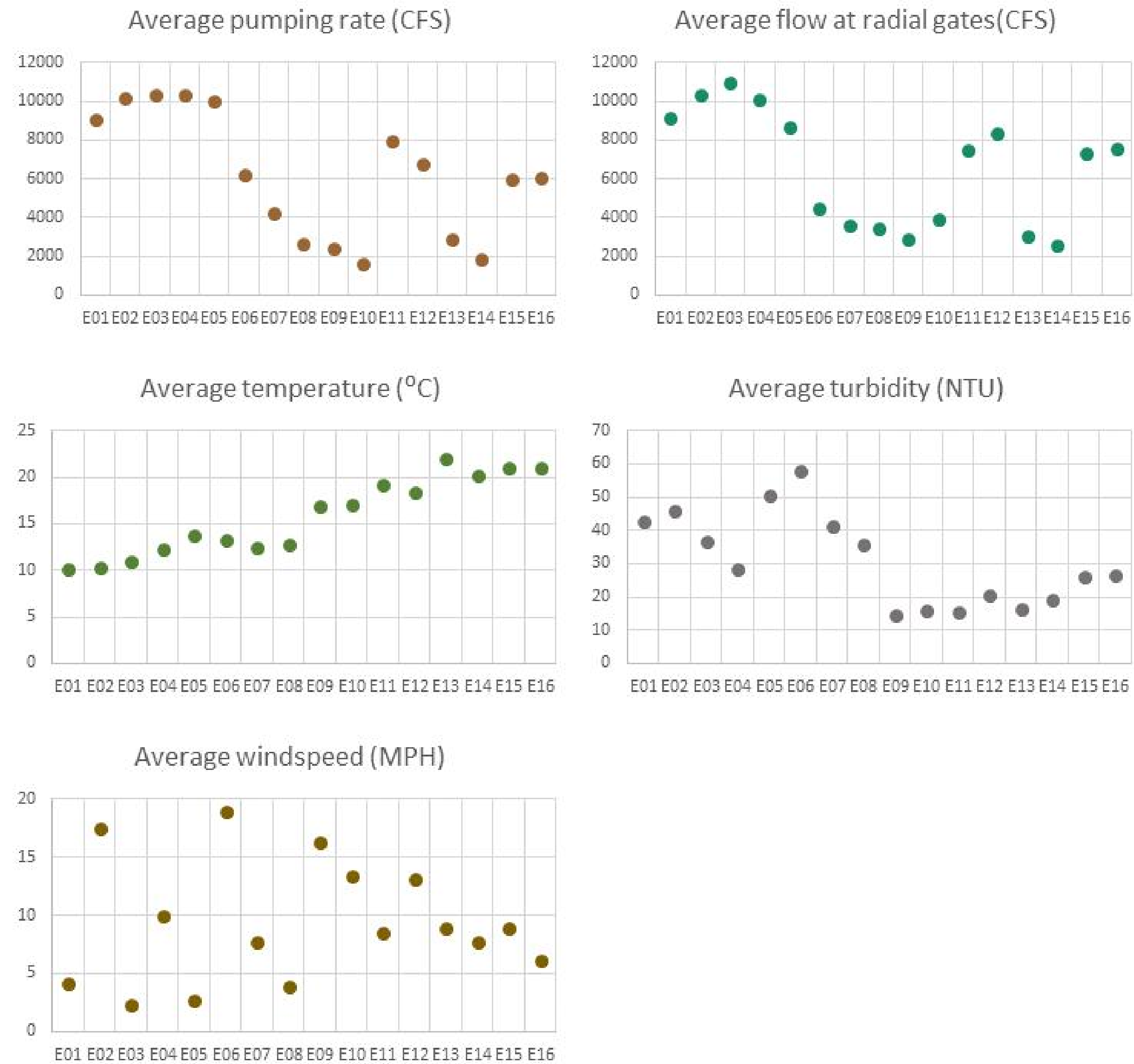

Figure 10. Release-specific covariate values.

Modeling

To estimate the probability of survival, a Bayesian multistate mark-recapture model (after Kery & Schaub, 2011) was fit to the PIT-tag data. The model estimates the probability of a fish existing in a certain state at each route interval (antenna location), given the previous and subsequent encounter history. Since it is possible for a fish to be alive but undetected, the observable states for the model are: 1) alive and detected in a known route, 2) alive in a known route but undetected at a certain antenna point within that route, 3) dead (or undetected). The observed data are either $y_t = 1$ when a fish is observed alive at antenna *t*, or $y_t = 0$ if the fish is unobserved at antenna *t*. Since the probability of survival in the current reach and the probability of having died in the previous reach depend on the fish's state in the previous reach, this quantity is calculated recursively for each fish and location. For each scenario, the probability of surviving the previous reach is a mixture of individual-level effects (fork length) and release-level effects (the covariates described above).

PDAT Analysis

All detections and trigger status of PDAT tags were processed by HTI and a final data file was provided for analysis. Analysis with a multi-state mark-recapture model was considered. However, few PDAT tags were triggered and no fish were detected leaving CCF through the Radial Gates. Thus, a Cormack-Jolly-Seber (CJS) model was employed to model reach-specific survival from the site of fish release near the Radial Gates to the Delta release sites at Curtis Landing and Horseshoe Bend. Five PDAT tags were triggered during the study, indicating predation had likely occurred. Determination if the event occurred in CCF or after release in the Delta was necessary to inform the construction of encounter histories. To accomplish this, the pattern of detections by hydrophones was examined. Tags that had been triggered moved frequently between hydrophones in both directions and remained in CCF for long periods of time, whereas tags that had not been triggered moved quickly through CCF and did not move back and forth between hydrophones. Based on this pattern, two of the five tags were triggered in CCF. Since the time of mortality cannot be reliably determined, these fish were considered dead after release and received a zero in their encounter history for each station after release. The other three triggered tags had similar movement to untriggered tags through CCF, suggesting they were still in live salmon in CCF. However, once detected at Curtis Landing, they returned to the Curtis Landing hydrophone several times over days to weeks suggesting that predation happened after release in the Delta. A fourth untriggered tag had similar movement patterns as the triggered tags at the Curtis Landing hydrophone and was assumed to be a predation event that failed to trigger the tag. Tags that triggered after release in the Delta were retained in the survival model as they were likely still in juvenile Chinook Salmon when they were salvaged. A large proportion of Chinook Salmon predators are physically excluded from entering the salvage facilities because of their large body size.

Encounter histories were constructed that included all hydrophones in the array where tags were detected, including: Radial Gates Down-Stream (RGD1), Intake Canal 1 (IC1), Intake Canal 2 (IC2), Intake Canal 3 (IC3) and Curtis Landing (CL) (Figure 1). To increase detection probabilities at the Delta release sites, detections at PIT tag antennae were also used in the model. The PDAT tags used in this study contained integrated PIT tags that allowed advantage to be taken of these additional detections. The Horseshoe Bend release pipe contains three independent PIT tag antennae (Figure 4) and the Curtis Landing release pipe contains two antennae. The encounter histories were coded so that survival was estimated to the first PIT tag antenna at each site and detections at the subsequent antennae and the Curtis Landing hydrophone were used to estimate detection probabilities.

After reviewing the results of the survival model, it was apparent that a large fraction of mortality was occurring between the final CCF hydrophone (IC3) located near the debris boom, and release in the Delta. To further examine this pattern, a second CJS model was constructed to estimate the effects of covariates on the survival of salmon from near the debris boom (IC3 hydrophone), through the facility, to release in the Delta. This model only used fish that were detected at the IC3 hydrophone, with triggered PDAT tags removed as described above. With the exception of fish fork length, all covariate values were assigned to individuals based on the time they were last detected at IC3. It was assumed that conditions at that time best represent what each fish experienced as it approached the facility. Individual covariates included: diel period (data obtained using the maptools package [Bivand et al. 2017] in R [R Development Core Team 2010] for the location 37.825765, -121.596698), Banks pumping rate (cfs), turbidity (NTU), water temperature (°C) and fish fork length at time of tagging (mm). With the exception of diel period, which was entered in the model as a dummy variable (day/night), covariates were standardized as z-scores (subtract mean, divide by standard deviation) so that results could be interpreted in units of standard deviation.

A series of candidate CJS models were constructed using the covariates described above, including a global model that contained all covariates, models with each individual covariate, and a model with no covariates. To select the best model from the candidate set, Akaike's Information Criterion [corrected for sample size (AIC_c)] was calculated for each model. The AIC_c value of each model was subtracted from the lowest AIC_c value in the candidate set to obtain the ΔAIC_c value. The model with the lowest AIC_c was considered the best model and any model with a ΔAIC_c value less than 2.0 was considered to be a competing explanation of the data (Burnham and Anderson 2002).

Transit time between hydrophones was calculated for individual fish as the time between the last detection at an upstream hydrophone and the first detection at the next downstream hydrophone. Reaches for which transit times were estimated included: Radial Gate (RGD1 in Figure 1) to IC1, IC1 to IC2, IC2 to IC3, and IC3 to the Delta release pipes.

The simultaneous release of PIT-tagged and PDAT juvenile Chinook Salmon during four releases provided an opportunity to evaluate assumptions about how pre-screen survival is estimated and where in CCF mortality is greatest. Fish that receive PIT tags can only be detected in the release pipes at Horseshoe Bend and Curtis landing. To estimate pre-screen survival, PIT tagged fish are released at the Radial Gates and downstream of the trash rack in the primary louver bays. Pre-screen survival is then calculated as:

$$Sps = \frac{Srg}{Str}$$

Where S_{ps} is pre-screen survival, S_{rg} is survival of fish released at the Radial Gates and S_{tr} is the survival of fish released in the primary louver bays downstream of the trash rack (Figure 11).

For fish receiving PDATs, pre-screen survival can be estimated directly between the Radial Gates and the hydrophone at IC3 that is located ≈128 m upstream of the trash rack. Additionally, survival from IC3 to the Delta release pipe can be directly estimated (Figure 11).

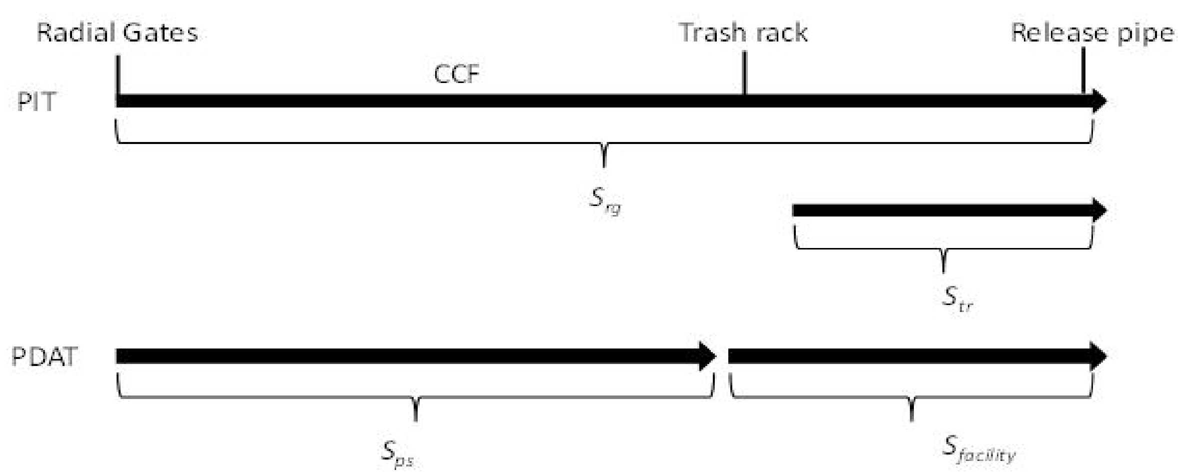

Figure 11. Diagram Depicting the Estimates of Survival Obtained from Releases of PIT-Tagged and PDAT-Tagged Juvenile Chinook Salmon During Four Releases in 2017.

3. Results

3.1 SWP Pumping, CCF Radial Gate Operations, and Environmental Covariates

Banks pumping was greatest at the start of the study period (mid-January to mid-February), with mean daily pumping close to 10,000 cfs (Figure 12). Pumping subsequently decreased in February/March to around 1,500-4,000 cfs, prior to pumping largely ceasing for a month because of CCF Radial Gate damage and repair. Following Radial Gate repair, pumping was variable in late April/May, ranging from 0 to around 8,000 cfs.

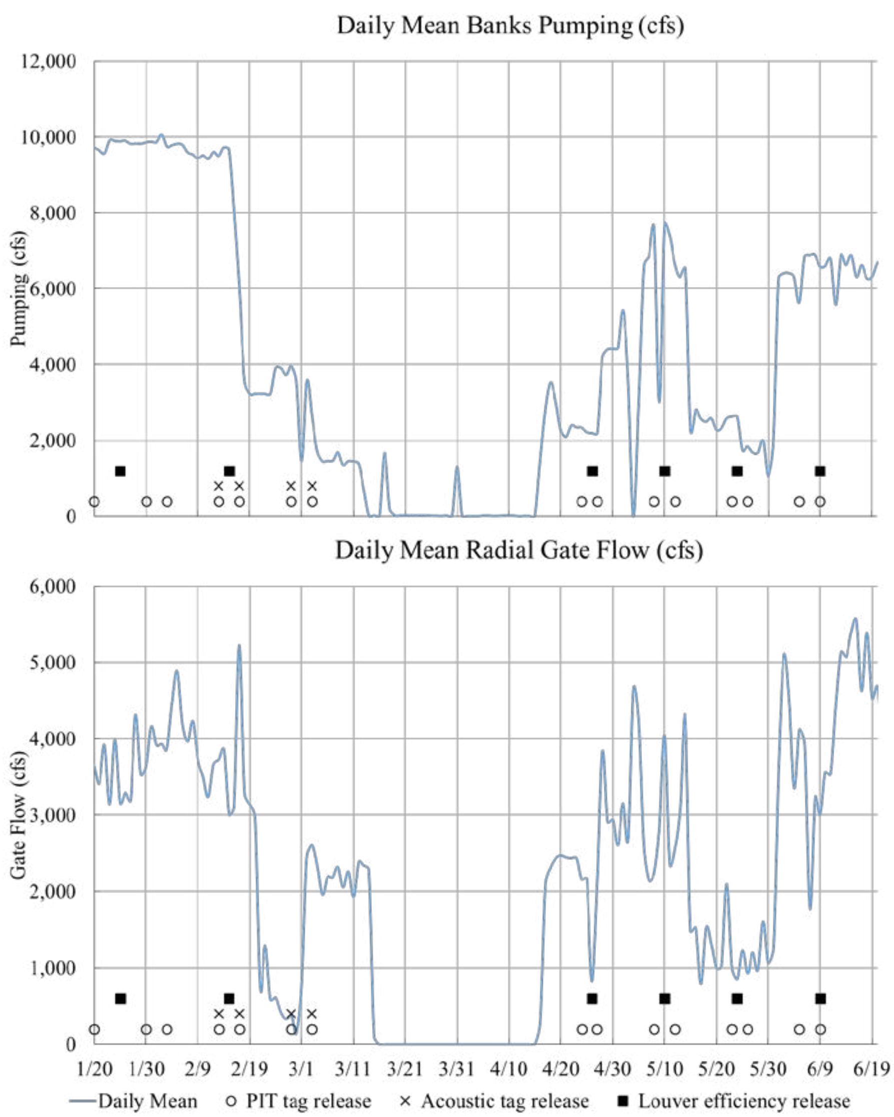

Figure 12. Daily mean Banks pumping rate and Radial Gate flow, with juvenile Chinook Salmon release dates.

Flow through the CCF Radial Gates varied considerably both daily and seasonally (Figure 12; Table 5). The study began during a period of very high gate flow, e.g., daily mean of around 7,000-8,000 cfs in January/February, whereas gate flow in March was lower, generally from a few hundred cfs to around 3,800 cfs. This was in part due to damage, resulting in a prolonged outage, discovered at the CCF Radial Gate inlet structure. Following CCF Radial Gate damage and repair, releases tended to coincide with relatively high gate flow, from around 4,000 cfs to 6,000 cfs.

Table 5. Summary statistics for Clifton Court Forebay Radial Gate daily mean water flow (cfs) from January 1 through June 30, 2017.

	January	February	March	April	May	June	Overall
Min.	3,090	3,251	0	0	1,697	6,509	0
Max.	10,300	10,299	3,796	4,496	6,679	6,679	10,300
Mean	7,788	7,271	927	1,373	4,122	6,665	4,656

Water temperature gradually increased over the course of the study period, from just over 10°C in January to over 21°C in early June (Figure 13). The study was stopped when the water temperature had exceeded 21°C, a threshold above which reduced physiological performance of juvenile Chinook Salmon has been found (Marine and Cech 2004).

Turbidity was variable over the study period, with two storm-driven events in January and February that resulted in high daily mean turbidity of around 50-90 NTU (Figure 14). At other times in the winter, turbidity was generally 30-40 NTU, whereas spring turbidity following the damage and repair to the CCF Radial Gates was typically 15-30 NTU.

Wind speed varied considerably over the study period, but trended upward as the season progressed through May (Figure 15).

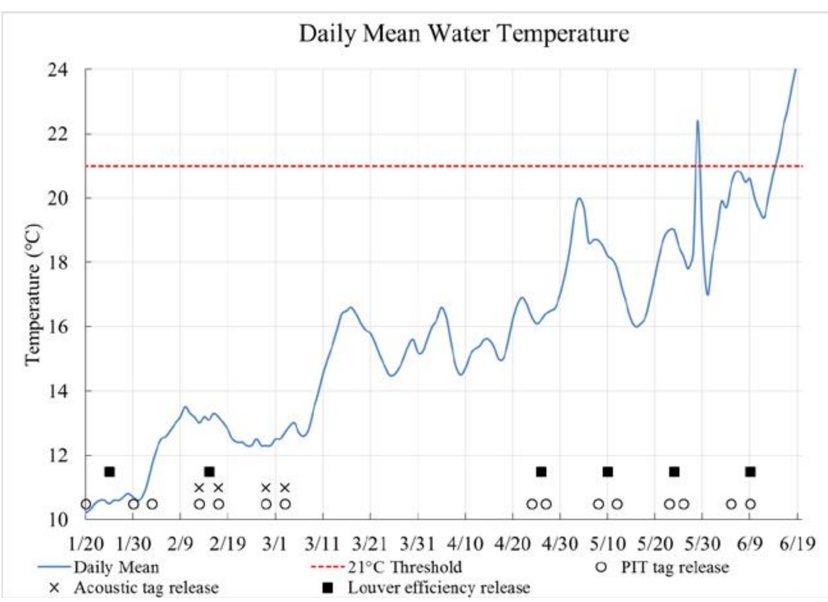

Figure 13. Daily mean Clifton Court Forebay water temperature, with Juvenile Chinook Salmon release dates.

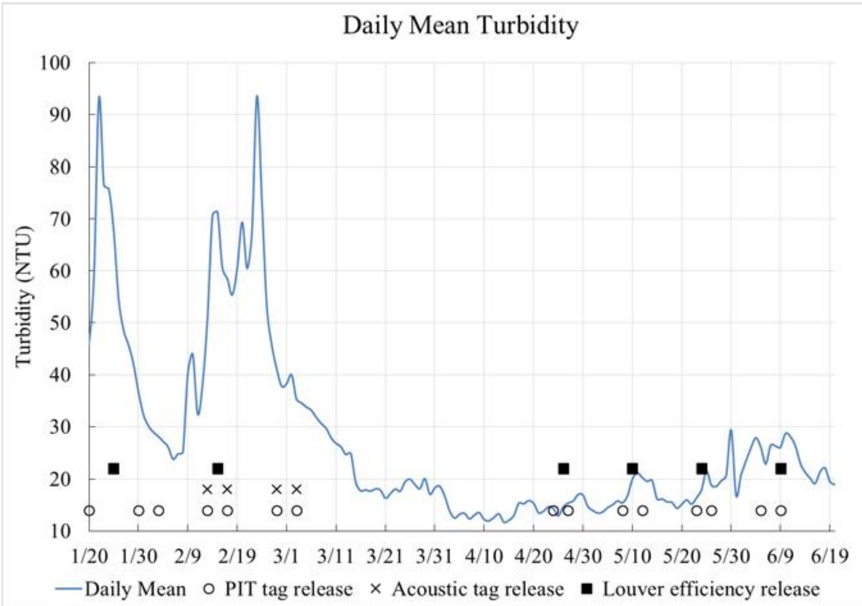

Figure 14. Daily Mean Clifton Court Forebay turbidity, with juvenile Chinook Salmon release dates.

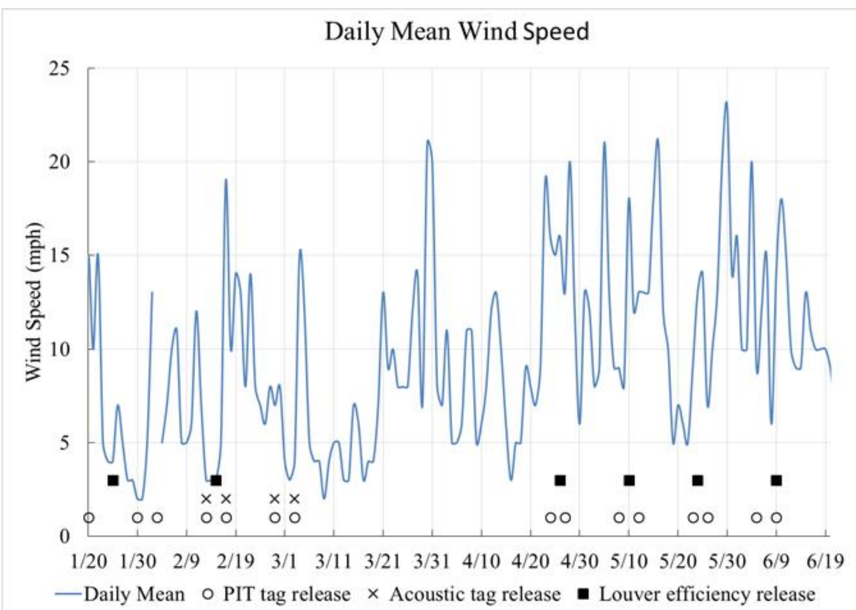

Figure 15. Daily mean wind speed with juvenile Chinook Salmon release dates.

3.2 *Chinook Salmon Survival*

Summary of Radial Gate Releases

A total of 16 releases at the CCF Radial Gates occurred for SEIS in WY 2017, eight each for late-fall run and fall run Chinook Salmon (Table 6). The percentage of fish detected ranged from 6% to 70% for late-fall run and 0% to 5% for fall run. Mean time to detection ranged from 0.87 days (d) to 3.75 d for late-fall run and 1.17 d to 1.94 d for fall run (Table 6).

Table 6. Summary of release and detection of tagged Chinook Salmon released at the Clifton Court Forebay Radial Gates during SEIS, WY 2017.

Release ID	Release Date	Day/ Night	Number Released	Percent Detected	Chinook Salmon Run	Mean Detection Time (d)	Radial Gate Flow (daily mean, cfs)	Banks Pumping (daily mean, cfs)
E1	1/16/2017	Night	111	70	Late-fall	0.88	9,093	8,950
E2	1/20/2017	Night	111	64	Late-fall	1.21	10,290	10,028
E3	1/30/2017	Night	111	41	Late-fall	1.03	10,289	10,233
E4	2/3/2017	Day	109	73	Late-fall	0.87	10,290	10,190
E5	2/13/2017	Day	111	13	Late-fall	2.52	10,055	9,825
E6	2/17/2017	Day	108	10	Late-fall	3.75	6,487	6,148
E7	2/27/2017	Night	111	26	Late-fall	1.03	3,593	4,145
E8	3/3/2017	Night	110	6	Late-fall	2.48	2,689	2,697
E9	4/24/2017	Day	169	3	Fall	1.94	2,244	2,396
E10	4/28/2017	Night	169	5	Fall	1.29	4,489	4,233
E11	5/8/2017	Day	169	0	Fall	NA	6,673	7,694
E12	5/12/2017	Night	168	1	Fall	1.72	6,668	6,629
E13	5/23/2017	Day	169	0	Fall	NA	2,595	2,670
E14	5/26/2017	Night	168	0	Fall	NA	1,998	1,825
E15	6/5/2017	Day	168	2	Fall	1.17	6,673	5,765
E16	6/9/2017	Night	168	3	Fall	1.25	6,677	6,634

Summary Primary Louver (Trashrack) Releases

The percentage of PIT-tagged juvenile Chinook Salmon detected from releases in the primary louver bays was greatest for late-fall run Chinook Salmon in January/February (83-86%), whereas relatively high detection for fall run Chinook Salmon was found only in late April/early May (77-79%) (Table 7). Detection was relatively low for fall run Chinook in late May/June (33-53%) when the SDFPF switched from "Salmon" to "Striped Bass" operating criteria in accordance with State Water Resources Control Board D-1485 requirements. The size of released fish and detected fish was similar (Table 8).

Table 7. Summary of tagged Juvenile Chinook Salmon primary louver (trashrack) releases during SEIS, WY 2017.

Release Date	Release Time	Tag Session ID	Number Released	Primary Channel Velocity (ft/s)	Number Detected	Chinook salmon run
1/25/2017	09:41	PIT1	30	3.5-4.03	25 (83.3%)	Late-fall
2/15/2017	10:25	PIT5	29	3.30	25 (86.2%)	Late-fall
4/26/2017	09:48	PIT10	29	3.39	23 (79.3%)	Fall
5/10/2017	10:00	PIT13	30	3.05-3.40	23 (76.7%)	Fall
5/24/2017	10:10	PIT15	30	0.99-1.07	10 (33.3%)	Fall
6/9/2017	09:30	PIT17	30	2.3-2.31	16 (53.3%)	Fall

Table 8. Length and weight of tagged Juvenile Chinook Salmon released in the primary louver bays at the trashrack and those subsequently detected at salvage release during SEIS, WY 2017.

	Released Fish				Detected Fish			
Release Date	Mean Weight	SD Weight	Mean Length	SD Length	Mean Weight	SD Weight	Mean Length	SD Length
1/25/2017	41.9	21.3	151.2	23.8	43.8	22.18	153.0	24.5
2/15/2017	63.6	28.9	171.1	25.7	66.1	23.83	175.2	19.6
4/26/2017	14.6	3.8	104.8	8.7	14.8	3.85	105.1	9.2
5/10/2017	20.6	5.5	115.7	8.9	21.2	5.82	116.5	9.1
5/24/2017	26	5.9	125.2	8.4	26.3	6.11	125.4	8.4
6/9/2017	31.1	7.6	130.9	10.8	33.1	7.00	132.9	10.2

Statistical Analysis

PIT Tag Analysis

Release-only models

We first modeled the data using the release ID itself as a covariate, in order to determine whether survival of the release groups was fundamentally different from each other. Not only did survival vary widely from release to release, but survival varied both within and across races between releases (fall run vs. late-fall run fish). Figure 16 shows the posterior probability distribution of estimated survival for each of the individual 16 releases. ReleaseID is consistent across figures; releases E01-E08 were late-fall run fish; releases E09-E16 were fall run fish; T01-T06 were the Primary Louver (trashrack) releases but are included in Figure 16 for comparison. For the experimental releases, almost none of the posterior probability distributions overlap between runs; this indicates that race is an extremely strong predictor of pre-screen survival in this dataset. Estimates of whole-SWP survival, pre-screen survival and survival of primary louver (trashrack) releases (WFE) with 95% confidence intervals are listed in Appendices 1-3.

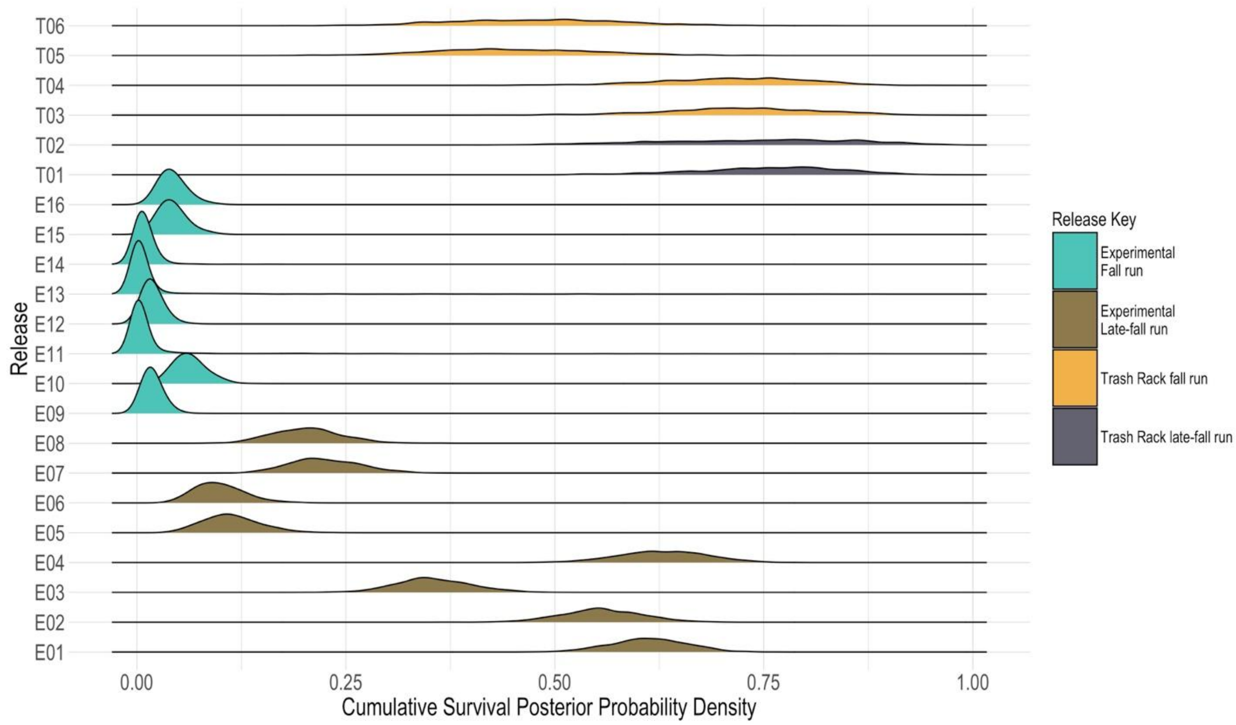

Figure 16. Posterior probability distributions for estimated survival across releases.

Release-level covariate models

This set of models estimated a base-level survival probability range for each run, and beta coefficients for each release-level covariate. The most complex covariates model included predictors for race, temperature, turbidity, flow at the Radial Gates, pumping rate, and travel time (the 10th percentile values in hours from the Particle Tracking Model results). In this model, and in all the candidate models composed of simpler combinations of the covariates, the effect size of race (fall vs. late-fall) overpowered other predictors (Table 9).

Table 9. Parameter estimates from run-specific covariates model.

Model parameter	Estimate	SE	Lower 95% CI	Upper 95% CI
intercept	-1.21	0.200	-1.511	0.724
standardized pumping rate	-0.269	0.309	-0.338	0.883
temperature (centered)	-0.167	0.038	-0.240	-0.095
standardized turbidity	-0.346	0.138	-0.629	-0.075
standardized flow at radial gates	-0.544	0.234	-0.999	-0.094
10th Percentile PTM	-0.001	0.005	-0.010	-0.008
Run indicator (1 = late-fall run)	-1.282	0.409	-2.106	-0.490

The estimates above are presented on the scale of log-odds. In this model, fall run fish become the intercept, and all other coefficient values are offsets from that intercept. All the beta coefficient estimates except for pumping rate affected survival in the negative direction, but the run indicator variable (Table 8, bottom row) had by far the largest effect size in the model. The 95% credible intervals of turbidity, temperature, flow at the Radial Gates, and 10^{th} Percentile PTM are all on one side of zero, but with small effect sizes relative to the run indicator coefficient.

Baseline survival for fall run fish, holding all other covariates at their mean, was 0.23 (0.18 – 0.67, 95% CI) on the probability scale. For late-fall run fish, baseline probability of survival was 0.71 (0.52 – 0.90, 95% CI). By holding all covariates at their mean values, the model is estimating survival at a gradient of environmental conditions that may never have occurred in reality. The relevant take-away from this model is that even holding all environmental covariates constant, race alone captured much of the variance in survival.

Omitting run as a predictor variable

When the race indicator variable is omitted, we can examine the effect sizes of the abiotic covariates on survival of an average Chinook salmon (either late-fall run or fall run) across these releases. Table 10 contains the parameter estimates for the model omitting race as a predictor, presented on the probability scale except for the last column, which presents the original estimate for each coefficient on the log-odds scale so that effect sizes can be compared.

Table 10. Parameter estimates from covariates model omitting the run-indicator predictor variable.

Model parameter	Survival probability	SE	Lower 95% CI	Higher 95% CI	Coefficient estimate
intercept	0.1628	0.1218	-1.8737	-1.3897	-1.6374
standardized pumping rate	0.4740	0.2729	-0.6209	0.4492	-0.1041
temperature (centered)	0.4814	0.0228	-0.1173	-0.0259	-0.0743
standardized turbidity	0.3593	0.1136	-0.7956	-0.3522	-0.5785
standardized flow at Radial Gates	0.4335	0.2121	-0.6981	0.1363	-0.2675
10th Percentile PTM	0.4986	0.0042	-0.0136	0.0023	-0.0055

The intercept value represents the baseline survival for the average fish (irrespective of run) for the entire season. The estimate is slightly higher than the observed survival average across fish of ~15%, but as with the previous model, this estimate assumes all covariates are at their mean value, which may not have actually occurred for any of the releases in reality. It is important to *ignore* the Survival probability estimate (2^{nd} column) for all parameters except for the intercept, as they are not interpretable on their own. Instead, looking at the final column (Coefficient estimate), we see that all predictors had a negative effect on survival, with temperature having the smallest effect and turbidity having the largest (as turbidity increases by each standard deviation, survival decreases). Both temperature and turbidity were significant (credible intervals on one side of zero), although temperature was only marginally significant.

Run-specific models

Finally, we modeled each group of releases separately (either all fall run or all late-fall run) in order to examine whether the effects of covariates estimated in Table 10 were consistent across runs.

Late-fall run fish

For the late-fall run fish, both the effects of turbidity and flow at the Radial Gates switched direction relative to the global model (Table 11). That is, for late-fall run fish, increased turbidity corresponded to increased survival; increased RG flow corresponded to increased survival as well, but not significantly so (90% credible interval spanning zero). Additionally, temperature had a much larger effect size relative to the global model, corresponding to decreased survival as temperature increased.

Table 11. Parameter estimates from covariates model of the late-fall run releases.

Model parameter	Survival probability	SE	Lower 95% CI	Upper 95% CI	Coefficient estimate
intercept	0.2711	0.4891	-1.9847	-0.0560	-0.9889
standardized pumping rate	0.3719	0.5137	-1.4849	0.5503	-0.5242
temperature (centered)	0.4326	0.0616	-0.3883	-0.1594	-0.2713
standardized turbidity	0.5507	0.0928	0.0340	0.3889	0.2036
standardized flow at Radial Gates	0.5255	0.3344	-0.5986	0.7360	0.1021
10th Percentile PTM	0.4930	0.0142	0.4863	0.4999	-0.0280

Fall run fish

Estimated survival probability is much lower for fall run fish than it was for the late-fall fish (although still much higher than observed survival; see discussion section below; Table 12). The confidence interval is broad, indicating large uncertainty associated with the sparse data. Turbidity again changed sign relative to the global model, but remains the largest coefficient, and was the only covariate whose credible interval was reliably on one side of zero on the outcome scale (log-odds). No other covariates were significant predictors of survival in fall run fish.

Table 12. Parameter estimates from covariates model of the fall run fish releases.

Model parameter	Survival probability	SE	Lower 95% CI	Upper 95% CI	Coefficient estimate
intercept	0.1013	0.3825	-2.9546	-1.4183	-2.1824
standardized pumping rate	0.4790	1.4278	-2.9081	2.7514	-0.0842
temperature (centered)	0.5398	0.1015	-0.0389	0.3627	-0.1594
standardized turbidity	0.8250	0.6964	0.1439	2.9125	1.5506
standardized flow at Radial Gates	0.3061	1.1866	-3.2011	1.5086	-0.8186
10th Percentile PTM	0.4928	0.0150	-0.0583	0.0004	-0.0288

PDAT Analysis

Across the four releases of PDAT tags, five tags were triggered to indicate predation likely occurred. Based on the movement patterns of these tags, it is likely that two were consumed in CCF and three were consumed at the Curtis Landing release site. A hydrophone was not deployed at the Horseshoe Bend release site and it is possible that additional predation occurred there but could not be detected. One tag that had not been triggered displayed movement patterns similar to the triggered tags at the Curtis Landing release site and this may have been a tagged juvenile Chinook Salmon that had been consumed but the tag failed to trigger. No tags were detected exiting CCF through the Radial Gates.

Reach-Specific Survival

The CJS model produced reach-specific estimates of survival for each release and the model fit the data well (c-hat = 1.9). Detection probabilities were good at all sites within CCF and were fair at the Delta release sites (Figure 17). Among all releases, survival across CCF was high, with values > 91% for all reaches between the Radial Gate and IC3, which is located near the debris boom (Figure 18). Between release and the Radial Gates, survival was 100% for the first three releases and 93.5% (CI: 76.8 – 98.4%) for the fourth release on March 3rd. The reach between the Radial Gates and IC1 was the longest reach (≈3.2 km) and extended across CCF to the entrance of the intake canal. Survival in this reach ranged from a low of 91.7% (CI 72.1 – 97.9%) during the release on February 17th to a high of 96.3% (CI: 77.9 – 99.5%) during the release on March 3rd. For all releases, survival in the two reaches between IC1 and IC3 was 100%. Both of these reaches were relatively short with lengths of ≈350 m (ICF1 to IC2) and 240 m (IC2 to IC3) (Figure 18). The lowest survival in all four releases occurred between IC3 and the release sites in the Delta, which included the salvage facility (Figure 18). Survival through this reach was lowest in this reach during the March 3rd release [14.8% (CI: 5.7 – 33.5%)], and highest during the release on February 17th [45.5% (CI: 26.5 – 65.9)].

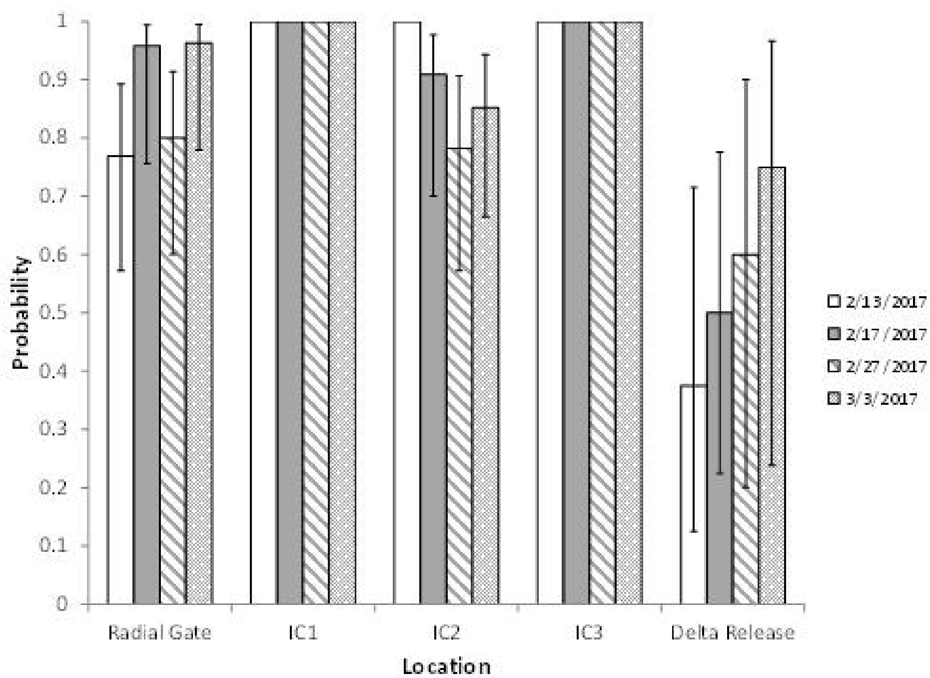

Figure 17. Detection probability estimates (with 95% Confidence Intervals) at each hydrophone location from the CJS mark-recapture model for four releases of PDAT late-fall run Chinook Salmon into Clifton Court Forebay during 2017. The Delta release site includes acoustic and PIT tag detections.

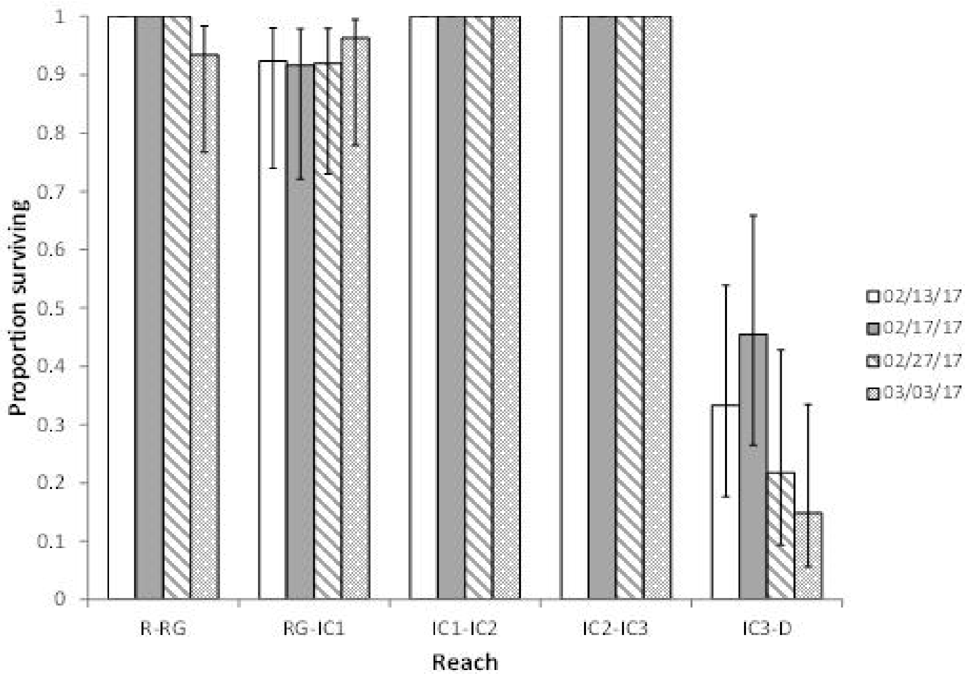

Figure 18. Reach-specific survival estimates (with 95% Confidence Intervals) from the CJS mark-recapture model for four releases of PDAT Late-Fall Run Chinook Salmon into Clifton Court Forebay during 2017. R = release, RG = Radial Gates, and D = Delta salvage release sites.

IC3 to Delta Release Pipe Survival Model

The model selection exercise identified turbidity as the best predictor of juvenile Chinook Salmon survival between the last hydrophone at IC3 near the debris boom and the Delta release pipe (Table 13). A second model that included day/night as the predictor had a ΔAIC_c value of less than 2.0 (0.714), indicating it had sufficient support to be considered a competing explanation of survival. No other model had a ΔAIC_c value < 4.13 points. Turbidity ranged from 31 to 106 NTU. Over that range of values, predicted survival increased from 21.5 % to 76.9% (Figure 19). The model that included day/night as the predictor revealed that survival for fish leaving IC3 during the night (47.4%) was almost double that for fish leaving IC3 during daylight hours (24.1%) (Figure 20).

Table 13. Results of the CJS model selection process evaluating the strength of covariates to predict juvenile Chinook Salmon survival from IC3 to the salvage release pipe.

Model	AICc	ΔAIC_c	AIC_cW
Turbidity	166.5	0.000	0.475
Day/Night	167.3	0.714	0.332
None	170.7	4.130	0.060
Full Model	170.9	4.380	0.053
Temperature	171.8	5.199	0.035
Banks Pumping	172.6	6.062	0.023
Fork Length	172.8	6.238	0.021

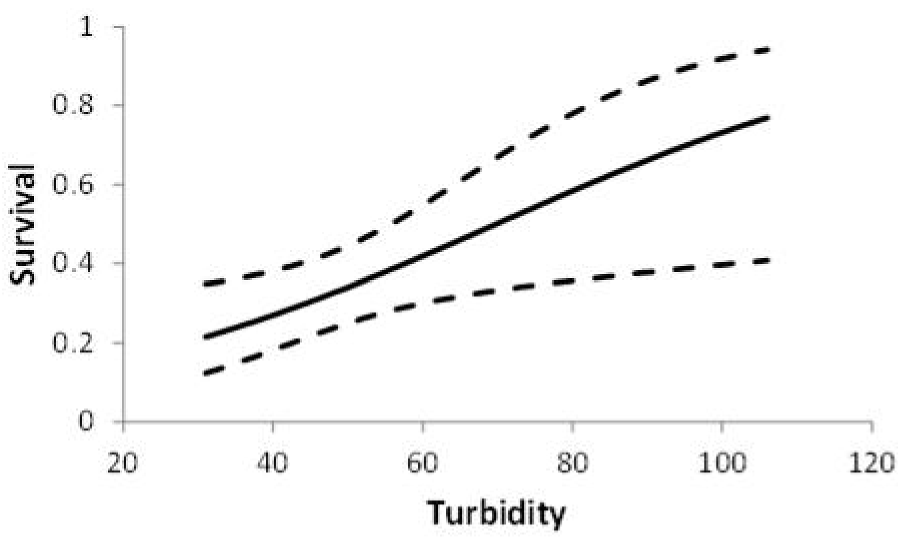

Figure 19. Predicted juvenile Chinook Salmon survival from IC3 to the salvage release pipe as a function of turbidity, from the best-fit CJS model.

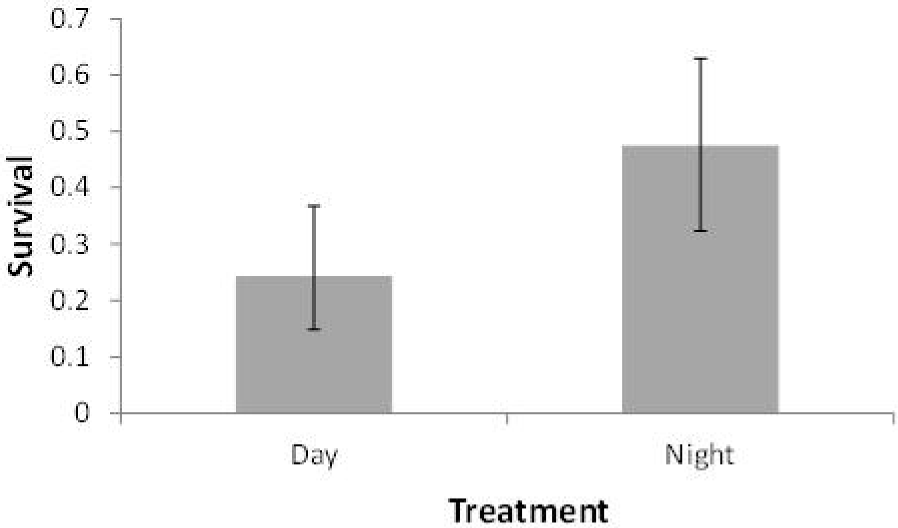

Figure 20. Predicted juvenile Chinook Salmon survival from IC3 to the salvage release pipe as a function of day and night, from the competing CJS Model.

Transit Time

Acoustically tagged juvenile Chinook Salmon, on average, took approximately 16 hours to travel between the Radial Gates and the first hydrophone in the Intake Canal (IC1), with a minimum transit time of ≈3 hours and a maximum of >5 days (Table 14). This was the longest reach in the study at ≈ 3.2 km. Fish transited rapidly between the hydrophones in the intake canal, suggesting that they moved quickly through this area. Between IC1 and IC2, transit times averaged just over nine minutes and between IC2 and IC3 transit times averaged ≈8.5 min. Transit times between IC3 and the Delta release pipe varied between 3.5 hours and >24 hours, with an average of 9.5 hours (Table 14). This reach included the salvage facilities and fish could remain in the holding tanks for various periods of time prior to trucking to the salvage release locations.

Table 14. Summary statistics of reach-specific transit time (Hours:Minutes:Seconds) for acoustically tagged late-fall run Chinook Salmon from the Clifton Court Forebay Radial Gates (RG) to the Delta salvage release pipes (D).

	RG-IC1	IC1-IC2	IC2-IC3	IC3-D
Mean	16:03:45	0:09:02	0:08:27	9:35:15
Standard Deviation	17:48:00	0:08:05	0:04:41	5:56:48
Minimum	2:54:24	0:00:03	0:00:17	3:29:58
Maximum	127:37:38	0:33:20	0:35:54	27:05:45

Comparison of Four Simultaneous PIT and PDAT Releases

Comparison of survival estimates from the two tag types yielded very different estimates. Estimates of whole-SWP and pre-screen survival (and 95% confidence intervals) from PDAT and PIT releases are provided in Appendices 1 and 2. The pre-screen survival estimates from PDAT Chinook salmon had 95% confidence intervals that ranged between 60 and 98% whereas estimates from PIT-tagged fish ranged between 16 and 40% (Figure 21). Despite the difference in pre-screen survival estimates, 95% confidence intervals for whole-SWP survival overlapped, suggesting similar survival rates between the two methodologies (Figure 21). The major difference in the two estimation methods is how facility survival is estimated. PIT tag fish are released just downstream of the trash rack in the primary louver bays and are not required to pass through the rack to enter the primary channel whereas PDAT fish migrate an additional 128 meters from the IC3 hydrophone and pass through the trash rack before entering the primary channel. This indicates the region between IC3 and the primary channel may be a high mortality area that requires further study, and it should be noted that previous studies including Clark et al 2009 and Gingras 1997 documented similar high or variable loss rates in this area.

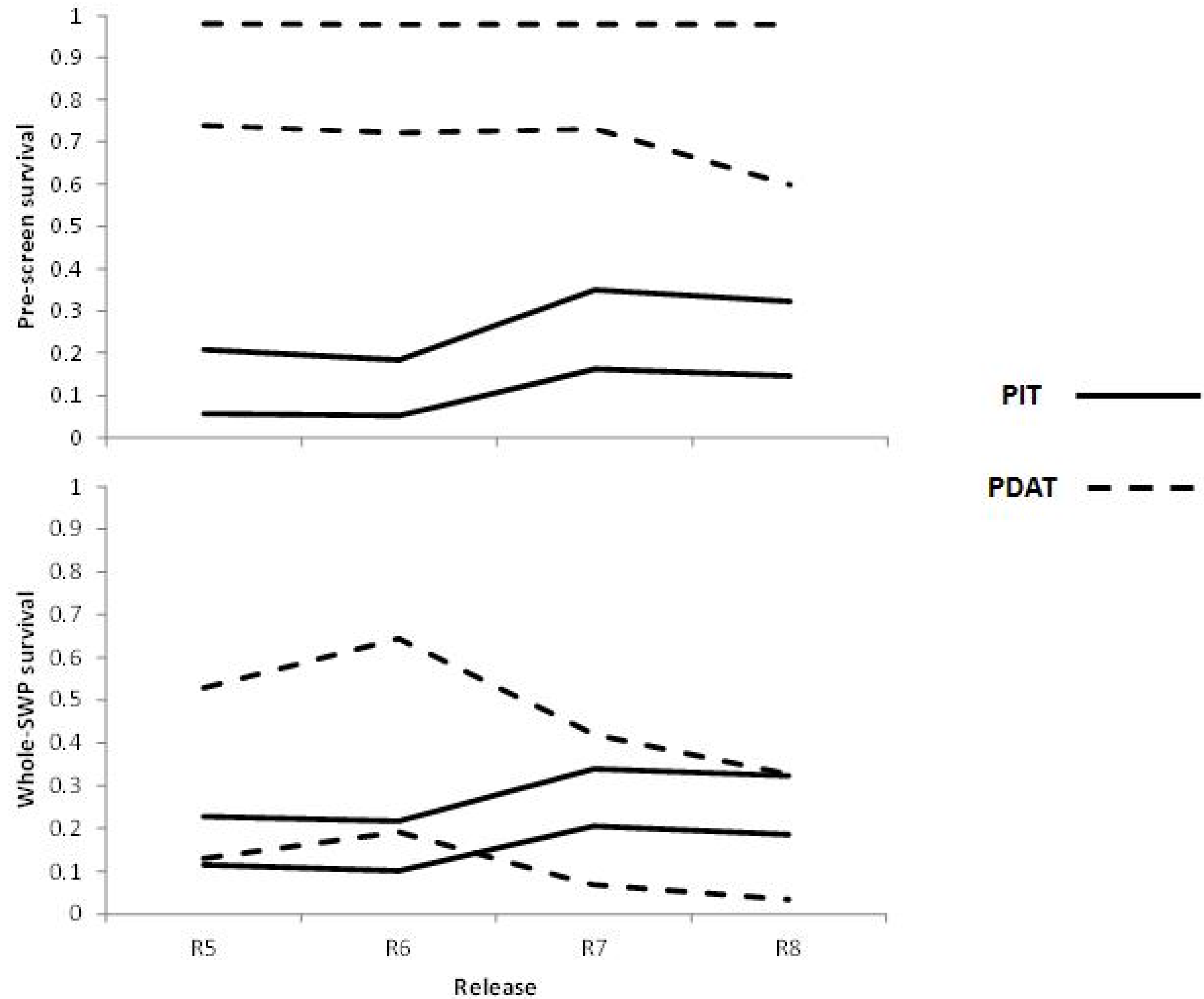

Figure 21. Ninety-five percent confidence intervals for estimates of pre-screen survival (upper panel) and Total SWP Survival (lower panel) for four simultaneous releases of PIT and PDAT late-fall run Chinook Salmon into Clifton Court Forebay during 2017.

4. Discussion

4.1 PIT Tag Analysis

From the models built so far, the only consistent predictors of survival probability were run and turbidity level. Interestingly, when both fall run and late-fall run fish were modeled together, increasing turbidity had a negative effect on survival, but when modeled separately, increasing turbidity had a significantly positive effect on survival for both runs. One likely explanation for this is that in a fixed effects model, the overwhelmingly low survival of the fall run fish pulls the estimate of the only predictor with a significant effect in a strongly negative direction. Often when the sign of a significant predictor changes depending on which covariates are included, it indicates a paucity of data related to that predictor in one group or another. This would certainly apply to the fall run fish, of which there were only 32 detected at the final Delta release pipes.

Temperature did not strongly affect the survival of either group, but flow at the Radial Gates had a slightly positive effect on the survival of fall run fish. This is in contrast to the late-fall releases, when flow at the Radial Gates had a slight negative effect on survival. Transit time across the forebay did not have a significant effect on survival, nor did predator removal efforts.

One of the main challenges with modeling these data with covariates was that there was a lack of overlap in outcome observations with respect to covariates between release groups. Because the observed outcome variable (survival) was in stark contrast between releases of the two runs, and because no mixed-run releases could occur, the ability of release-level covariate models to estimate the effect of abiotic variables on survival across releases became limited. For some covariates (fork length, for example), a complete or quasi-separation in the regression model of covariates took place, and a maximum likelihood estimate of survival simply didn't exist. To account for this, separate models of each salmon run were built. This approach comes with its own drawbacks, primarily a limited ability to compare groups of models directly. For example, we know from the global model that detection probability at the release pipes is fairly high (95% CI = 0.92 - 0.97). Thus, it's likely that survival for fall run fish is closer to raw observed survival (32/1348) than to the survival probability that the fall run specific model estimates above. With so few fish surviving to the release pipe, and with only two locations with which to improve the estimate of detection probability, the model is (in all likelihood) overestimating survival and underestimating detection probability. This is one reason to include detections from late-fall run fish within the same model. Future modeling efforts will employ multilevel techniques in order to allow intercepts and slopes to vary according to different species across covariates, so that global estimates of detection probability can be improved without affecting differential survival estimates for individual groups.

Overall, there is more reason to be confident in the results from the late-fall run-specific model than the fall run specific model, simply because the former is based on more observations of both surviving and non-surviving (or surviving but non-detected) fish at the release pipes. The global model is useful for identifying general significance of different covariates, but multilevel modeling must be conducted (ideally, on data that includes overlapping releases of fish) before the direction of environmental effects on survival can be reliably confirmed for different runs of fish and time periods.

4.2 PDAT Analysis

The use of PDAT tags during 2017 provided the first direct estimates of pre-screen survival in CCF for Chinook Salmon and provided substantial insight into spatial variation in mortality. Consumption of acoustic tags by predators, and subsequent detections of those consumed fish, can introduce considerable uncertainty in survival estimates in high mortality environments such as CCF (Clark et al. 2009). However, the PDAT tags were able to compensate for this issue, lending additional credibility to the estimates produced. Although PDATs can take multiple days to trigger, no tags were detected leaving CCF and mobile surveys covered areas of CCF that were not covered by stationary receivers. Thus, it is unlikely that tags left the study area without being detected. Out of the 5 tags that were triggered, only two were suspected to have triggered within CCF, with the other three triggering at the Curtis Landing release site.

The lack of predation mortality indicated by the low number of triggered PDAT tags was reflected in the estimates of pre-screen survival from PDAT-tagged fish. Point estimates of pre-screen survival were > 90% for all four releases, which was much higher than indirect estimates of pre-screen survival produced from PIT tagged fish. Additionally, these high pre-screen survival estimates are contrary to the prevailing conceptual model of high mortality as fish transit across CCF. The lack of concordance with the conceptual model of high predation as fish transit CCF may arouse suspicion of the estimates. However, several lines of evidence suggest the estimates are reasonable. Electrofishing of predatory fish for the PRES that occurred concurrently with tagged salmon releases provided an opportunity to compare pre-screen survival in CCF with other regions of the Delta. Predator catch per unit effort (CPUE) was comparable to the San Joaquin River and lower than the Mokelumne River, and juvenile Chinook Salmon pre-screen survival during the SEIS PDAT releases was comparable to survival per km in these two locations (Table 15). In contrast, standardized pre-screen survival estimates from PIT tags are consistently lower than observations in the San Joaquin River or Mokelumne River at similar or lower predator CPUE. Results from the analysis of experimental PIT tag releases in this study report that neither biomass removed nor CPUE were significant predictors of release-specific survival (see PIT Tag analysis section). Additionally, previous genetic investigations of Striped Bass stomach contents in CCF revealed that Chinook Salmon only occurred in 1.1- to 1.6% of stomachs examined (Stroud and Simonis 2016). In total, these data suggest pre-screen loss within CCF may be lower than previously estimated.

Table 15. Predator density and acoustically-tagged juvenile Chinook Salmon survival estimates from elsewhere in the Delta relative to Clifton Court Forebay.

System	Predator Catch Per Electrofishing Boat Hour	% Survival km^{-1}	Source
Mokelumne River	56-130	80-100	Cavallo et al. (2013); Cramer Fish Sciences (unpublished data)
CCF (PDAT)	6-46	95-98	This study; DWR (2017)
CCF (PIT)	6-46	59-73	This study; DWR (2017)
San Joaquin River	15-64	73-100	Michel et al. (2017); Michel (personal communication)

Despite the large difference in pre-screen survival between PIT-tagged and PDAT-tagged fish, estimates of whole SWP survival were comparable. This suggests that how pre-screen survival is estimated has a large influence on the partitioning of survival with the reaches of the SWP. The major difference between the two methods is that PDATs allow direct estimation of survival between receivers whereas PIT tags rely on a separate release in the primary channel to estimate facility survival. PIT tag facility efficiency releases occur in the primary channel downstream of the trash rack and are detected at the release pipe. Salmon with PDATs are last detected at IC3 near the debris boom and are then detected at the release pipe. Thus, the difference between what these two groups experience is that PDAT fish must travel ≈120 m between IC3 and the trash rack and they must move through the trash rack to enter the primary channel. If these differences were insignificant, the survival estimates should be similar. However, point estimates of survival in this reach from PDATs ranged from 14.8 to 45.5% and the PIT tag estimate of facility efficiency during this period was 86.2%. A summary of previous CCF studies with coded wire tags by Gingras (1997) included fish releases at the debris boom and survival of those releases fluctuated between 25 and 90% with an average of ≈50.0%. This suggests the pattern of survival in this area is not restricted to the current study. Future investigations of fish loss in this relatively small region may provide considerable insight into where mortality is occurring.

Modeling of survival between IC3 and the release pipe revealed that turbidity and diel period were both strong predictors of survival. Gregory and Levings (1998) reported that higher levels of turbidity reduced predation on migrating salmonids and the relationship found in this study suggests that the increase in survival observed during periods of higher turbidity was caused by reduced predation. This agrees with observations from the junction of the Sacramento River and Georgiana Slough, for which turbidity was the only statistically significant predictor of predation (DWR 2016).

In the present study, survival at night was almost double that during the day. This is consistent with the patterns observed at the Head of Old River, for which day/night was the strongest predictor of juvenile fall run Chinook Salmon survival (DWR 2015). The abundance of predators in shallow estuarine habitats has been shown to decrease during night hours with subsequent increases in prey survival (Clark et al. 2003). However, trials with Northern Pikeminnow (Ptychocheilus oregonenis), a visually oriented piscivore, yielded lower juvenile salmon capture success during daylight hours (Petersen and Gadomski 1994). The region between IC3 and the Delta release pipe is difficult to compare with other studies because there are numerous engineered structures and artificial lighting within the reach, yet clearly survival was greater in low light conditions. It is possible that as juvenile salmon approach the trashrack during the day, they are more likely to volitionally avoid passage as they may perceive the structure as a passage impediment or threat. Conversely, during the night, they may have greater difficulty in detecting the structure, and would thus be more likely to pass through. Any delay in passage at this location could lead to greater exposure to predators.

Several predictors had little support in the model selection exercise. Fish size (fork length) had the least predictive power, despite previous research that links size to survival probability (Hartman 2000, Zabel and Achord 2004). The Chinook salmon in this study were hatchery-origin from the same cohort and represented a relatively narrow size range (95% between 140 and 213 mm). This may not have been enough variation in size for differences in survival to be captured in the model. There was also a narrow range of temperatures during the four PDAT releases (12.0 to 13.2°C) and this variable was also a poor predictor of survival. Pumping rate varied between 1,505 and 10,545 cfs during the times fish left the IC3 receiver. Despite the large range in pumping, it was not a strong predictor of survival. The design of the facility allows velocities near the louvers to be maintained at specific criteria at a range of pumping rates, so it is unlikely that differences in louver efficiency would be affected by pumping rate. The inclusion of pumping was based on the hypothesis that more water moving through the forebay would move experimental fish more quickly through the forebay and reduce the time they were exposed to predators. Survival of PDAT tagged Chinook salmon was high through the forebay to IC3; thus, any reduction of transit times from increased pumping may have had only minor, and undetectable effects on survival.

Inclusion of PDAT tags into the 2017 study provided important insights into survival of Chinook salmon through CCF and the SDFPF. Several improvements could be made to future studies to gain additional information. First, detection probabilities of the integrated PIT tags was not as high as for fish receiving only PIT tags. It is unknown what the source of the discrepancy is. Reduced detection probabilities did not bias the estimates of survival to the release pipe but did increase the size of confidence intervals. Additional hydrophone placements would be useful to both increase detection probability at release and more clearly define the locations of fish loss. High water conditions at the Horseshoe Bend release site prevented deployment of a hydrophone at that location. Addition of a hydrophone there in the future should increase detection probability. Receivers placed in the primary channels, the canal behind the louvers, and the holding tanks will allow determination of how and where fish are being lost as they move through the trash rack and the rest of the facility.

4.3 Summary

Whole Facility Efficiency (WFE) for the SDFPF was greatest for late-fall run Chinook Salmon in January/February (83-86%; Appendix 3), whereas relatively high WFE for fall run Chinook Salmon was found only in late April/early May (78-80%; Appendix 3). WFE was comparatively low for fall run Chinook Salmon in late May/June (54-56%; Appendix 3). The findings were similar to those measured by Skinner (1974) shortly after construction of the facility. The findings also indicate that while the SDFPF is able to comply and often exceed its 75% WFE objective from the NMFS 2009 BiOp during the majority of the November through June salmon outmigration season, there is a window from mid-May through June where compliance may not be possible because of State Water Resources Control Board D-1485 requirements which change from "salmon" to "striped bass" optimized water velocities annually on May 15th.

Survival across CCF was higher than expected for acoustically tagged fish, averaging 90% across four releases. Prior estimates of pre-screen survival using differences in survival between fish released at the Radial Gates where fish enter CCF and fish released at the trash racks at the terminus of the intake canal in front of the salvage facilities (with adjustments made for detection efficiency at the salvage release pipes) were acknowledged to be slight overestimates due to unaccounted loss due to emigration into Old River (Clark et al. 2009). In the present study, no acoustically tagged fish were detected by hydrophones in Old River. Furthermore, only five predation detection tags triggered, suggesting that predation in CCF may not be as significant as previously thought.

Improvements in survival might have been attributed to this being a high flow water-year, however, survival estimates of PIT-tagged smolts, using aforementioned assumptions for survival based on the two release locations at either end of the forebay, were not dissimilar to survival estimates from previous years. Indeed, pre-screen survival estimates in CCF were similar to survival estimates observed in other studies in the Delta in habitats with similar or greater predator density (Table 15). Use of the differential method, in which pre-screen survival is estimated by differential survival of fish that had to traverse CCF to reach the salvage facility compared to those that were released directly in front of it, produces survival estimates lower than any other in the Delta despite similar, if not lower, predation pressure.

One possible explanation for low survival estimates for the whole SWP is that loss increases as fish leave the intake canal and enter the salvage facility. Detections of coded wire tagged fish released by the trash boom in front of the trash rack can be highly variable, ranging from 25% to 90% (Gingras, 1997). There are at least three possible ways that fish can be lost from the facility. The first is by way of the canal leading to the pumps downstream of the louvers. The second way that fish can be lost is by avian predation. Avian predators are afforded subsidized foraging habitat along the trash boom and trash racks from which they can hunt. Last, elevated predation rates have been documented in the area between the debris boom and trash rack. Predation in this area may have been undetected if predatory fish did not swim within range of IC3, or if consumed tags were defecated out of range of IC3. Furthermore, 2017 may not be representative of prior conditions, particularly because it was one of the wettest years on record.

Finally, results of the SEIS indicated that predator relocation efforts as part of the PRES did not have a detectable effect on salmon survival. The effects of predatory fish CPUE and Biomass Removed were assessed but were not significant and were dropped from the model of salmon survival.

5. Recommendations

5.1 PIT Tags

The following recommendations will improve interpretation of multilevel modeling before the direction of environmental effects on survival can be reliably confirmed for different runs of fish and time periods:

1. Overlap releases of late-fall and fall run Chinook Salmon.
2. Increase the size and frequency of releases, particularly for fall run, which had a low number of detections at the release pipe.

5.2 Acoustic Tags

The following investigations are recommended to improve understanding of predation dynamics in CCF:

1. **Predation downstream of IC3.** Evaluation of predation and predators downstream of the last hydrophone (IC3) in the intake canal will likely provide critical insights to the drop in survival as fish leave CCF and enter the fish salvage facility. Specifically, placement of hydrophones in the California Aqueduct downstream of the louvers, in the primary channels, and in the holding tanks should provide increased resolution to factors that affect survival between the debris boom and trash racks and post-screen mortality.

2. **Predation downstream of IC3.** Factors, such as lighting at night are known to aggregate predators, and migrating salmon may behave differently near the trashrack structure during the day as opposed to at night. For example, salmon may volitionally avoid passing through the trashracks during the day when they can more easily see them. An evaluation of predator activity using echosounders deployed near the debris boom could provide an indication of the extent of diel patterns of predation that may be occurring in front of the trash racks, and improved acoustic receiver instrumentation in this area could be used to further evaluate salmon behavior at this location.

3. **Expand Chinook Salmon acoustic data set.** In 2017, only late-fall run Chinook Salmon were large enough to carry the PDAT tags used in the study. It was not possible to evaluate race-specific differences in survival between late-fall and fall run salmon because collinearity issues with body size and season. Future work to rear fall run large enough to carry acoustic tags will resolve the body size collinearity. Increasing the frequency and size of releases will provide greater resolution to temporal changes in conditions that affect survival.

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7. Appendices

Appendix 1. Estimates of whole-SWP survival (with 95% confidence intervals) for PIT tag and PDAT releases.

	PIT tag estimates Whole SWP survival (S_{rg})			PDAT tag estimates Whole SWP survival (S_{rg})		
ReleaseID	Survival	Lower 95% CI	Upper 95% CI	Survival	Lower 95% CI	Upper 95% CI
E01	0.613	0.528	0.699	NA	NA	NA
E02	0.556	0.464	0.652	NA	NA	NA
E03	0.355	0.272	0.445	NA	NA	NA
E04	0.629	0.529	0.731	NA	NA	NA
E05	0.113	0.049	0.179	0.308	0.130	0.528
E06	0.099	0.045	0.158	0.417	0.191	0.645
E07	0.225	0.140	0.302	0.200	0.068	0.419
E08	0.204	0.126	0.278	0.133	0.034	0.328
E09	0.018	0.003	0.039	NA	NA	NA
E10	0.063	0.029	0.100	NA	NA	NA
E11	0.016	0	0.054	NA	NA	NA
E12	0.018	0.002	0.040	NA	NA	NA
E13	0.016	0	0.064	NA	NA	NA
E14	0.008	0	0.024	NA	NA	NA
E15	0.042	0.012	0.075	NA	NA	NA
E16	0.043	0.013	0.073	NA	NA	NA

Appendix 2. Estimates of pre-screen survival (with 95% confidence intervals) for PIT tag and PDAT releases.

	PIT tag estimates Pre-Screen survival (S_{ps})			PDAT tag estimates Pre-Screen survival (S_{ps})		
ReleaseID	Survival	Lower 95% CI	Upper 95% CI	Survival	Lower 95% CI	Upper 95% CI
1/16/2017	0.739	0.637	0.843	NA	NA	NA
1/20/2017	0.671	0.560	0.786	NA	NA	NA
1/30/2017	0.428	0.328	0.537	NA	NA	NA
2/3/2017	0.730	0.614	0.848	NA	NA	NA
2/13/2017	0.131	0.057	0.208	0.923	0.739	0.981
2/17/2017	0.115	0.052	0.183	0.917	0.721	0.979
2/27/2017	0.261	0.162	0.350	0.920	0.731	0.980
3/3/2017	0.237	0.146	0.323	0.900	0.732	0.967
4/24/2017	0.023	0.004	0.049	NA	NA	NA
4/28/2017	0.079	0.036	0.125	NA	NA	NA
5/8/2017	0.021	0	0.069	NA	NA	NA
5/12/2017	0.023	0.003	0.051	NA	NA	NA
5/23/2017	0.029	0	0.118	NA	NA	NA
5/26/2017	0.015	0	0.044	NA	NA	NA
6/5/2017	0.075	0.022	0.135	NA	NA	NA
6/9/2017	0.077	0.023	0.131	NA	NA	NA

Appendix 3. Estimates of survival (WFE) with 95% confidence intervals for experimental fish released at the trash rack.

	Whole facility survival (S_{tr})		
Release	Survival	Lower 95% CI	Upper 95% CI
1/25/2017	0.829	0.702	0.957
2/15/2017	0.862	0.718	0.974
4/26/2017	0.798	0.663	0.945
5/10/2017	0.779	0.615	0.902
5/24/2017	0.543	0.363	0.709
6/9/2017	0.557	0.395	0.742