Technical Report 2017-3

EVALUATION OF ADULT CHINOOK SALMON BEHAVIOR AT THE FOSTER DAM ADULT FISH FACILITY ON THE SOUTH SANTIAM RIVER – 2016

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For

U.S. Army Corps of Engineers
Portland District

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Acknowledgements

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Executive Summary

In 2015 and 2016, we investigated factors that may have contributed to apparent low trap collection efficiency of adult Chinook salmon at the Foster Dam Adult Fish Facility (AFF). The AFF was rebuilt in the winter of 2013-2014. In both study years, we monitored water temperatures in the Middle Fork and South Fork Santiam rivers and in the Foster AFF fishway and Foster tailrace. We conducted a randomized block study of altered hydraulic head (i.e., water velocity) at the Foster AFF main entrance where the weir gate was partially lowered ('Auto') or completely lowered ('Open'). Differences in the numbers of adult Chinook salmon trapped were compared under the two velocity treatments. In 2016, the main entrance velocity test was repeated, and fish behavior was evaluated using Dual Frequency Identification Sonar (DIDSON) and optical video cameras. We examined associations between environmental variables and fish behaviors quantified from the video.

Although 2015 was warmer than 2016, the general temperature patterns observed in the Foster fishway and tailrace were similar and much cooler than found in upstream tributaries such as the South Santiam River because both are strongly influenced by hypolimnetic water from the Foster Dam Reservoir. The pre-sort pool and upper fishway remained cool throughout the season with a strong Middle Fork Santiam River temperature signature. We observed complex lateral and longitudinal temperature gradients in the tailrace relative to the fishway before spill was stopped.

Based on review of DIDSON data, the majority of fish moved in and out of the AFF main entrance during the day. Little or no movement was observed at night based on a subsample of DIDSON data from nighttime (5-10% of total nighttime video reviewed). In the optical video data, rates of fish movement were similar throughout the day except at the upstream channel camera where more upstream and downstream events were observed in the early evening. Large movement events (upstream and downstream) occurred in the early evening when spill was terminated on 14 July 2016.

In both study years there was evidence that the low-head, lower-velocity treatment ('Open') was associated with higher rates of fish entry (and exit) into the AFF than during the 'Auto' treatment. In 2015, more adult Chinook salmon were collected (in the trap) during the low-velocity 'Open' entrance treatment compared to during the 'Auto' treatment. Nonetheless, significant numbers of adult fish were observed holding in the tailrace throughout the experimental period, indicating low effective passage rates at the entrance and/or other areas of the fishway. In 2016, lower entrance velocities ('Open' weir setting) were associated with higher fish entrance rates (day and night) and fewer fish were observed holding just downstream of the entrance (assessed using DIDSON). However, higher fish exit rates from the AFF during the day and night were also observed at the entrance during the low velocity treatment, revealing turnaround within the fishway. Optical video monitoring at two sites in the fishway channel could not fully quantify up- and downstream movement rates due to visibility limitations; treatment effects were consistent with DIDSON results, but had less statistical support. Results from both methods indicated substantial holding and milling near the entrance of the ladder and higher movement rates in portions of the ladder closest to the trap.

Overall, the results from fishway monitoring indicated adults frequently held near the fishway entrance and that the ‘Open’ treatment increased entrance rates, but that substantial holding, milling, and turnaround in the fishway as far upstream as the base of the upper ladder limited collection rate at the trap.

Examination of environmental data revealed temperature gradients within the tailrace during periods of spill and cooler water in the fishway ladder and tailrace. Temperatures encountered in the tailrace by adult salmon were cooler than in unregulated systems (no dams) and reductions in temperatures at the fishway entrance may have further affected adult salmon behavior by reducing swimming rate and or motivation for upstream movement. We found some statistically significant correlations between environmental variables and adult fish behaviors. However, the observed statistical relationships were likely spurious because the range of observed environmental variation was narrow (temperature range: 11-12 °C).

Continuing research in 2017 may shed more light on factors that are contributing to the low trap collection efficiency at the Foster AFF. We plan to radio/PIT tag adult Chinook salmon at Lebanon Dam in the South Santiam River and monitor their behavior in the Foster Dam tailrace and AFF. Individual fish monitoring will provide detailed information of fish behaviors, overall facility collection rates and residence times and enable us to more directly associate fish movements with potential explanatory covariates.

Introduction

The Foster adult fish facility (AFF) was reconfigured in the winter of 2013-2014 with significant structural modifications. The rebuild addressed several objectives, including more efficient collection and sorting of adult migrants, reduced fish handling, and improved ability to transport fish to outplant sites upstream from Foster Dam. In spring and summer of 2014, Oregon Department of Fish and Wildlife (ODFW) hatchery personnel observed that many adult Chinook salmon (*Oncorhynchus tshawytscha*) were congregating in the Foster tailrace, but that few were being collected in the trap facility. Similar holding behavior was observed in some years prior to the new AFF configuration (USACE 1995) and was a concern for managers because: 1) extended holding in the tailrace may delay broodstock collection; 2) delayed collection may compromise trap-and-haul of natural origin fish to upstream release sites; and 3) failure to collect hatchery fish may result in increased straying and inter-breeding with natural origin fish at downstream sites.

In addition to the observations of adult fish holding in the Foster tailrace, data from a basin-wide radiotelemetry study conducted in 2011-2014 indicated that many adults held downstream from Foster Dam for extended periods (Jepson et al. 2015). Adult Chinook salmon were radio-tagged at Willamette Falls and then their behavior was monitored downstream from Foster Dam, with increased monitoring effort in 2014 after the Foster AFF construction was completed. Fish spent 25-52 days, on median, near the dam before they were either recaptured at the Foster AFF, reported harvested, or permanently moved downstream from the dam (Figure 1). Behaviors were generally similar for natural origin (unclipped) and hatchery (fin-clipped) salmon.

Several hypotheses for the apparently low trap collection rates have been suggested. Possible hydraulic explanations include poor attraction to fishway openings or false attraction to non-collection sites such as the spillway or turbine outlets. Operational modifications that included modifying flow from the auxiliary water supply (AWS) and closing the spillway entrance weir produced generally inconclusive results. It is also possible that differences in water temperature or water chemistry contribute to the observed Chinook salmon behaviors in the Foster Dam tailrace. Because water for the adult fish facility and water entering the tailrace is sourced from several locations (i.e., spillway, reservoir hypolimnion, hatchery effluent, etc.), large water temperature gradients have been observed in the study area. Notably, water temperatures in the AFF ladder and pre-sort pool are sourced from a deep-water inlet and thus have been cooler than at many tailrace sites and much colder during summer than in unregulated reaches of the South Santiam River above Foster Dam, suggesting temperature differences between the ladder and tailrace may impede fishway entry. Temperatures gradients within fishways have been shown to slow passage and affect body temperature in Chinook salmon at Lower Granite Dam where the fishway was warmer than the tailrace (Caudill et al. 2013), the converse of the conditions observed at Foster Dam.

Reservoir surface water and the combination of source, depth, and temperature also produce quite different chemical signatures at the AFF, spillbay, and turbine outflow. Salmon use chemosensory olfaction to differentiate among water sources (Keefer and Caudill 2014) and it is possible that differences in water chemistry among sites contributed to the observed salmon behaviors. Alternatively, biogeochemical processes within the reservoir may decrease differences or homogenize dissolved free amino acids (DFAAs), which are among the most important compounds used by salmon for imprinting and homing (Ueda et al. 2011); such homogenization would reduce the ability of salmon to differentiate among water sources while in the tailrace.

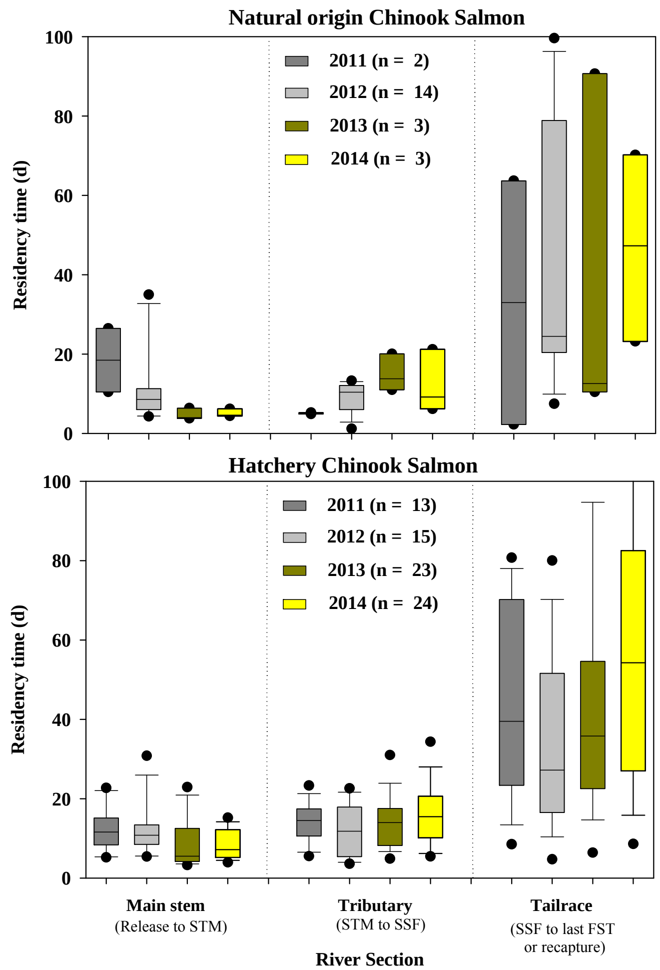

Figure 1. Box plots showing the distributions of radio-tagged adult Chinook salmon residence and transit times (days) in the main stem Willamette River (left panels), in the Santiam and South Santiam rivers (middle panels), and in the Foster Dam tailrace (right panels) in 2011-2014. Top graph is for natural origin salmon and bottom is for hatchery salmon. Release = Willamette Falls Dam; STM = Santiam River mouth; SSF = Foster Dam tailrace; FST = Foster Dam trap. Source: Jepson et al. (2015).

To better understand the low Foster AFF trap collection efficiency, our research objectives in 2015 were to: 1) develop and deploy temperature monitoring at relevant locations below the dam and within the adult passage system; and 2) evaluate experimental effects of the main entrance velocity test (‘Open’ and ‘Auto’) on Foster trap counts.

In 2016, our research objectives were to: 1) review and assess data collected before and after Foster AFF trap construction; 2) deploy temperature monitoring and water chemistry equipment at relevant locations below the dam and within the adult passage system; 3) evaluate adult Chinook salmon behavior at the Foster AFF during experimental fishway operations using acoustic (DIDSON) and optical video; 4) analyze data from Objectives 2 and 3 to test for experimental effects of the velocity test at the main fish entrance (‘Open’ vs. ‘Auto’); and 5) evaluate potential environmental effects and measures that could be tested to increase adult fish collection.

Methods

Trap and redd counts

Oregon Department of Fish and Wildlife (ODFW) personnel provided Foster Dam AFF trap counts of adult salmon and steelhead from 2007-2016. ODFW also provided redd count data from sites downstream from Foster Dam from 2007-2015. We used the trap count data to assess the seasonal timing of adult Chinook salmon collection and to qualitatively evaluate whether there were changes in collection rates after the AFF modifications. For the latter, we compared the time series of counts before and after the modification and the ratio of the number of adult salmon trapped per redd counted as a coarse estimate of trapping efficiency. We assumed that improved collection would decrease percent hatchery origin spawner (pHOS) observed during spawning ground surveys and increase the number trapped relative to the number of redds. This method requires the additional assumptions that the females:redd and female:male ratios remained constant, which we could not verify from the available data.

Water temperature monitoring

In 2015, 13 temperature recorders (HOBO V2 Pro Onset, Inc., Bourne, MA) were deployed at the Foster Dam AFF ladder and tailrace (rkm 418.2 from the Columbia River mouth; Figure 2). All recorded water temperatures at 15 min intervals and most were deployed from ~5 May until 20 October to coincide with the adult Chinook salmon migration.

In 2016, 15 temperature recorders were installed at Foster Dam ladder and tailrace, and 2 each were deployed in the Middle Fork Santiam near Sunnyside (rkm 426.8) and at Green Peter Tailrace (429.2), and in the South Fork Santiam at Menear’s Bend (rkm 425.5) and Gordon Rd (rkm 445.1). All recorders were deployed from ~2 June until 4 October.

Water chemistry monitoring

We monitored water chemistry parameters (pH, dissolved oxygen (DO), conductivity) in the fishway and tailrace of the Foster Dam AFF in 2016. Two Hydrolab (Hach HL4 Sonde, Loveland, CO) units were deployed from ~1 July until 4 October. One hydrolab unit was inside a PVC pipe mounted on a T-post in the tailrace (near tailrace temperature logger #9, Figure 2) and the other mounted to the camera trolley off the I-beam of the turn pool camera (see camera details below). Hydrolab results were corrected for sensor drift.

We evaluated the composition of DFAAs by point sampling of water originating from different sources (i.e., forebay surface water, AFF, reservoir hypolimnion, turbine outflow, etc.) to assess whether the chemical signatures at these locations may be affecting adult salmonid behavior in 2016. However, analyses by an outside lab have been delayed and results from sampling were not available at the time of this report.

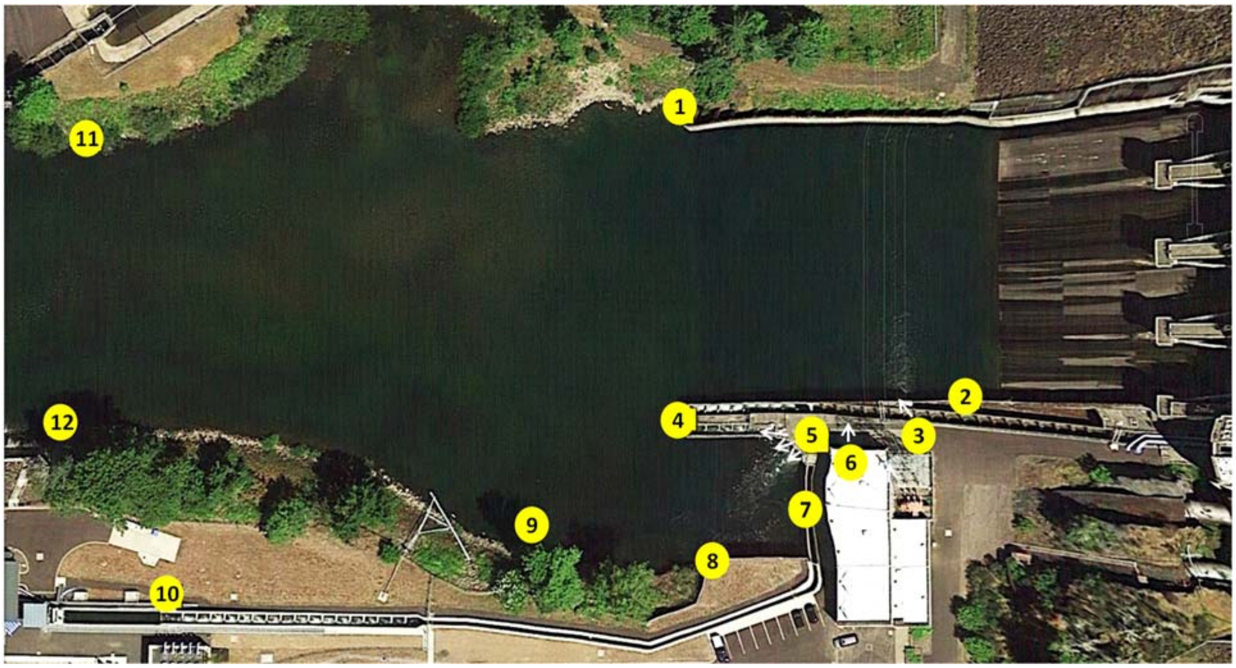

Figure 2. Map of the Foster Dam tailrace study area with water temperature logger locations (numbered circles) in 2015 and 2016. Logger sites: 1) North shore; 2) Spill Bay; 3) spillway fishway entrance (two loggers: outside entrance attached to rail and inside attached to ladder entrance grate); 4) outside ladder wall; 5) main entrance (three loggers: outside, inside, and ~2nd weir (lower ladder)); 6) auxiliary water supply; 7) powerhouse wall; 8) turbine wall; 9) tailrace; 10) presort pool, 11) downstream north, and 12) downstream south. Sites 11 and 12 were only deployed in 2016.

Main entrance water velocity experiment

Entrance velocities at the Foster Dam AFF are controlled by a complex combination of discharge from the ladder (fixed), auxiliary water supply (AWS) pumped into the collection channel inside the fishway, and by altering the height of fishway entrance weirs. AWS discharge is provided by up to four pumps, and the number of pumps operating increases discharge from the fishway as tailwater elevation decreases. In 2015, the main entrance weir gate was manipulated in either the 'Open' treatment position with the gate completely lowered or in the 'Auto' position with the gate partially raised. Seven randomized treatment blocks were evaluated during the experimental period from 27 May until 28 July (Table 1). In both 2015 and 2016, we deployed two water level loggers (Hobo water level logger U20-001-02) at the main entrance (one inside and one outside the entrance) to assess water level differences during the experimental period. The Auto treatment increased hydraulic head by approximately one foot compared to the Open treatment (see Results). Pump operations data for 2015-2016 were not archived and we assume higher water velocity at the fishway opening was produced in the Auto treatment on average because tailwater elevation did not systematically change with treatment during the experimental period. Main entrance velocities were estimated to be ~4 to 5 ft/sec during the ‘Open’ treatment and ~9 to 10 ft/sec during the ‘Auto’ treatment based on head and estimated cross-sectional area of the fishway entrance (Steve Schlenker, USACE Portland District, 26 Jan., 2017, pers. comm.). We used a two sample t-test to test for differences in trap counts between the ‘Open’ treatment position and the ‘Auto’position.

Table 1. Randomized block experimental design used in 2015 to test for effects of open vs. automatically-controlled entrance gates at the Foster Dam AFF. Treatments were switched the morning of the end date of each block (1030-1230 hrs).

Start date	End date	Block	Treatment
27-May	29-May	1	Auto
29-May	2-Jun	1	Open
2-Jun	5-Jun	2	Open
5-Jun	9-Jun	2	Auto
9-Jun	12-Jun	3	Open
12-Jun	16-Jun	3	Auto
16-Jun	19-Jun	4	Open
19-Jun	23-Jun	4	Auto
23-Jun	26-Jun	5	Open
26-Jun	30-Jun	5	Auto
30-Jun	10-Jul	6	Open
10-Jul	14-Jul	6	Auto
14-Jul	21-Jul	7	Open
21-Jul	28-Jul	7	Auto

In 2016, the main entrance weir gate was again randomly operated in either the ‘Open’ treatment position with the gate completely lowered or in the ‘Auto’ normal position with the gate partially raised. Five treatment blocks were evaluated during the experimental period from 14-24 July (Table 2). In a separate ad hoc trial, the entrance gate was also ‘Open’ during 3-9 August and 15-20 August.

Table 2. Main entrance experimental design used in 2016 to test for effects of open vs. automatically-controlled entrance gates at the Foster Dam AFF.

Start date	End date	Day	Day	Block	Treatment
14-Jul	15-Jul	1	1	1	Open
15-Jul	16-Jul	2	2	1	Auto
16-Jul	17-Jul	3	3	2	Open
17-Jul	18-Jul	4	4	2	Auto
18-Jul	19-Jul	5	5	3	Open
19-Jul	20-Jul	6	6	3	Auto
20-Jul	21-Jul	7	7	4	Open
21-Jul	22-Jul	8	8	4	Auto
22-Jul	23-Jul	9	9	5	Open
23-Jul	24-Jul	10	10	5	Auto

Fish behavior monitoring and evaluation

In 2016, Chinook salmon behavior at the Foster Dam AFF was monitored using acoustic and optical cameras. A Dual Frequency Identification Sonar (DIDSON) (Sound Metrics Corp., Bothel, WA) that was set to a range of ~6.5 m in high frequency (1.8 MHz) mode monitored fish behavior at the main AFF entrance (Figure 3). Three optical, low light, high resolution cameras (Model SS408. Sidus, San Diego CA) monitored fish in the fishway (at the turnpool, downstream channel, and upstream channel; Figure 3). The viewing window for optical video varied in response to ambient light conditions and turbidity.

DIDSON and optical cameras were deployed on custom aluminum I-beams and manually raised and lowered on custom camera trolleys. Data were routed to an enclosure, located near the main ladder entrance, that housed a customized personal computer-based digital video recorder (DVR; Intel dual-core processor, 2 GB RAM, PCI slot, 2 SATA hard drive ports, Windows 7 OS), using 8- or 16-channel Hikvision video capture cards (Model DS-4008HCI and DS-4016HCI; Hikvision USA, City of Industry, CA) and 2 TB of hard drive space dedicated to video recording. Additionally, for power protection an uninterrupted power supply (UPS-Tripplite OMNI900LCD, Chicago IL) was added to the enclosure. The DIDSON and video cameras were set to record 24 h a day, 7 days a week from mid-June to the end of September. All video cameras were set with the following parameters: 704 × 480 resolution; high quality record (30 frames per second); grayscale color scheme, and no audio.

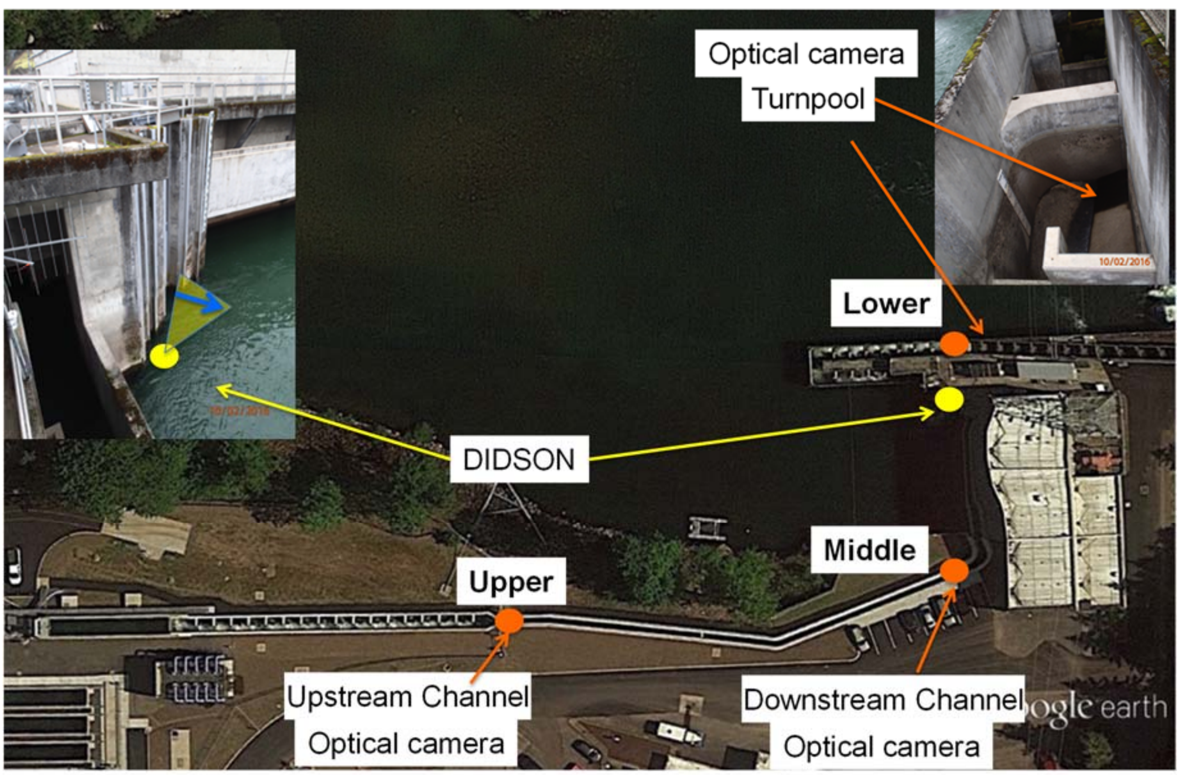

Figure 3. Map of acoustic (DIDSON) and optical camera deployments at the Foster AFF in 2016. The DIDSON (yellow) was at the main fish entrance. The three optical cameras (orange) were located in the lower (turnpool), middle (downstream channel), and upper (upstream channel) parts of the fishway.

Remote connectivity to the two DVR units was achieved using a local wireless internet service provider (Verizon) through a wireless mobile hot spot (Verizon Jetpack). An external antenna was mounted to the Verizon Jetpack, and the wireless internet signal transmitted to routers housed in the enclosure. Remote connectivity allowed staff at University of California-Davis (UCD) to monitor the live status of all cameras, adjust recording parameters, and receive automated notifications in the event of equipment malfunctions. Additionally, recorded video data were backed up to UCD servers daily for analysis and redundant storage using the CBVision video acquisition module via a FTP connection. Video was saved in native MPEG-4 format (.mp4), using standard H.264/MPEG-4 video compression codecs (Thompson et al. 2012). University of Idaho (UI) personnel maintained cameras (e.g., cleaning lenses) and addressed any issues within 24 h.

Video (acoustic and optical) observations were subsampled and reviewed by UCD and UI personnel. Subsamples were randomly selected from daily files and consisted of twelve 15 min files between 0700 and 2000 h each day through most of the season. An additional 36 random subsamples were reviewed from DIDSON observations at night (2100 to 0600 h) during the experimental period (14-24 July) to qualitatively evaluate nighttime behavior. Random subsamples were also reviewed from September 3-8 because many fish entered the fishway during this time; the total effort was 8 subsamples at the turnpool camera and 53 subsamples at the downstream and upstream channel cameras. Reviewers recorded the number of adult fish entries, exits, and rejections per DIDSON file. The number of fish holding in the field of view was recorded near the beginning, middle, and end of each file (frames 3000, 6000, and 8000). Reviewers recorded the number of upstream and downstream fish movements per optical video file. The number of fish holding in the field of view was recorded at the beginning (~ first 30 sec) and end (~last 30 sec) of each 15 min file.

Fish movements (entries, exits, rejections, upstream, and downstream) were converted into observations per hour by multiplying each viewed 15 min file by four (see Table 3 for behavior definitions). All holding observations were averaged per file (e.g. DIDSON observations at frames 3000, 6000, and 8000 were summed and divided by three for average holding per file)

Table 3. Definitions of adult salmon behaviors that were observed at the main entrance and Foster fishway in 2016.

Location	Camera	Behavior	Definition
Main entrance	DIDSON	Entry	Movement upstream into the entrance
		Exit	Movement downstream out of the entrance
		Rejection	Movement upstream towards or slightly into entrance with immediate turn around or downstream movement
		Holding	Stationary or moving in a circular or schooling pattern with no substantial upstream or downstream gain
Fishway	Optical	Upstream	Movement upstream beyond the field of view
		Downstream	Movement downstream beyond the field of view
		Holding	Stationary or moving in a circular or schooling pattern with no substantial upstream or downstream gain

Fish behavior data analysis

We performed two statistical analyses to test for differences in fish behavior between the two treatments ('Auto' and 'Open') using the metrics from the 2016 DIDSON and optical video data. Several of the fish movement metrics were non-normally distributed based on visual assessment and there were unequal variances between treatments. Therefore, Kruskal-Wallis tests, which are robust to non-normality, were used to assess whether behaviors differed between experimental treatments. We also used a Welch's ANOVA as a secondary statistical test because it is more effective for handling unequal variances than the Kruskal-Wallis test (Zar 1999). The following metrics were log-transformed prior to the ANOVAs to improve normality: fishway entry, exit, and rejection rates, and upstream and downstream movement rates inside the fishway. Data for the holding metrics were normally distributed and were not transformed.

We evaluated relationships between environmental variables and fish behaviors at the main entrance during 'Auto' and 'Open' weir gate settings using univariate Pearson's correlations (regardless of experimental period). Evaluations were made for entrance, exit, and holding behaviors during DIDSON collection per day. Data for barometric pressure, solar radiation, and cumulative precipitation were obtained from the Agrimet DTRO site – Cooperative Agricultural Weather Network (https://www.usbr.gov/pn/agrimet/webarcread.html) and flow, tailwater and forebay elevation data were obtained from the U.S. Army Corps of Engineers data query website (http://www.nwd-wc.usace.army.mil/cgi-bin/dataquery.pl?k=id:FOS). All temperature sites at Foster Dam (n=15), and temperature sites in the Middle and South Fork Santiam, along with date, barometric pressure, solar radiation, cumulative precipitation, flow, tailwater elevation and forebay elevation were evaluated for correlations with fish behaviors. Because all temperature variables at Foster were highly correlated only results from a select number of temperature monitoring sites were reported in the results.

Results

Trap and redd counts

In the last 10 years (2007-2016), the earliest adult Chinook salmon arrival at the Foster AFF has ranged from 12 April in 2016 to 20 May in 2009 (Figure 4). Median arrival dates ranged from 23 June (2015) to 6 August (2008). The total number of Chinook salmon collected at the AFF was lowest in 2007 (1,385) and highest in 2010 (8,800; Figure 5). The 2016 count was the fourth lowest among the last ten years.

Collection of hatchery Chinook salmon at the Foster AFF has been approximately in proportion to the number of redds associated with hatchery fish downstream from the dam (Figure 6A). The pattern of collection with natural origin Chinook salmon is far less clear (Figure 6B). Since the installation of the new Foster AFF, the ratio between fish collected and hatchery redds varied from 2-16, approximately within the range of years prior to construction of the new AFF (Figure 7A). The ratio for collected natural origin fish has been consistently low (0.2-2) since the AFF construction, but within the range observed prior to AFF construction

(Brett Boyd, ODFW, unpublished data; Figure 7B), suggesting either a reduction in trap collection efficiency or an increase in natural origin spawners at downstream sites (Cameron Sharpe, ODFW, pers. comm.) or both.

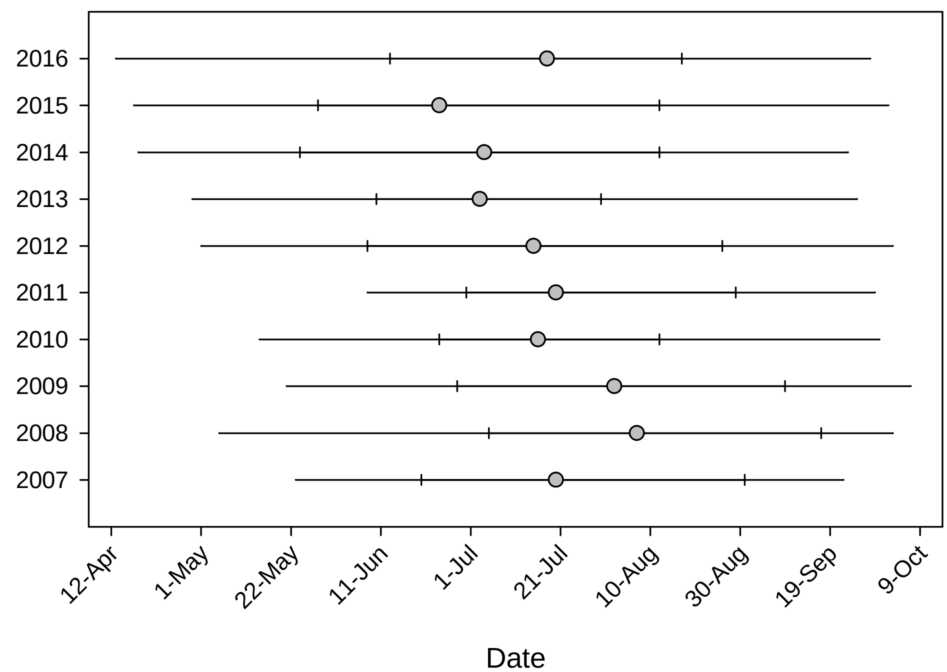

Figure 4. Annual distributions of the dates that adult Chinook salmon were trapped at the Foster AFF, 2007-2016. Circles show median dates, whiskers show 1st and 3rd quartile dates, and ends of lines show first and last dates.

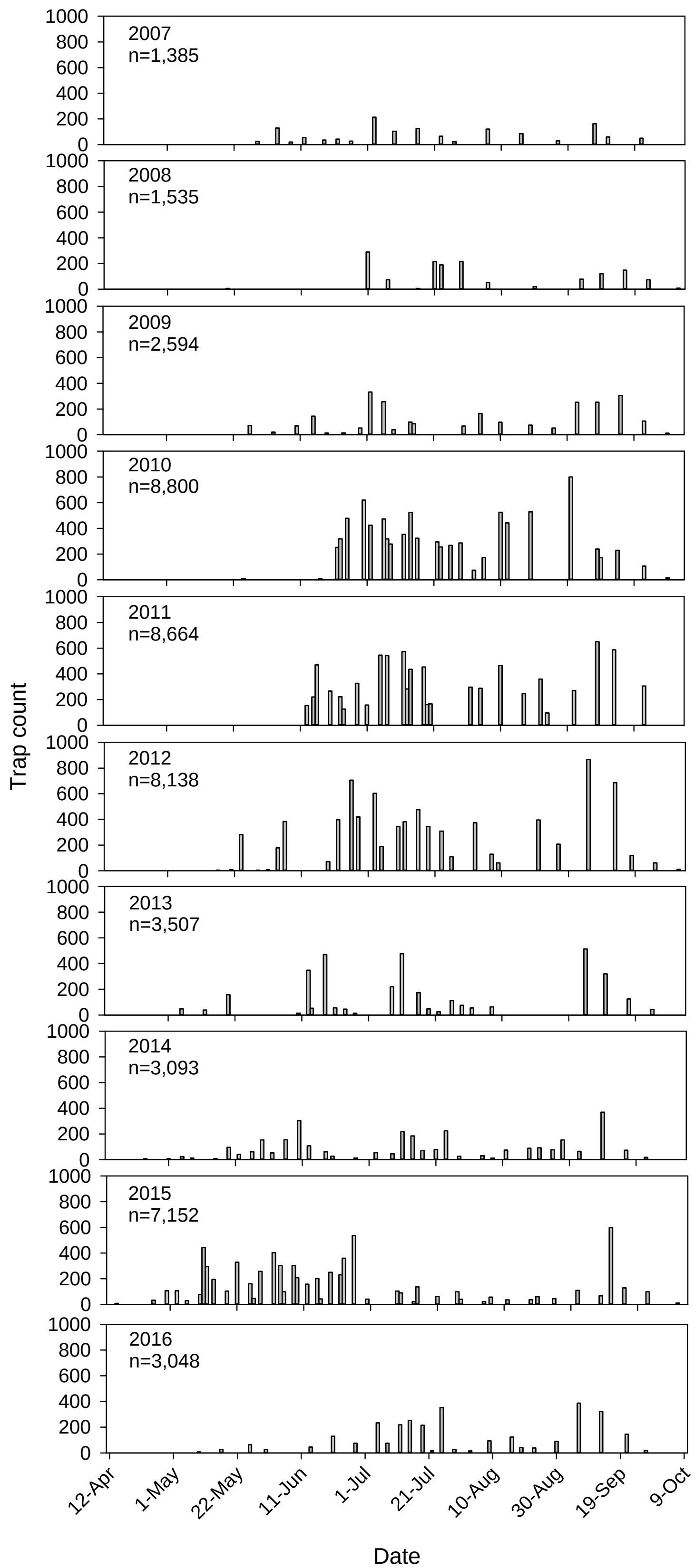

Figure 5. Daily counts of adult Chinook salmon that were trapped at the Foster AFF, 2007-2016.

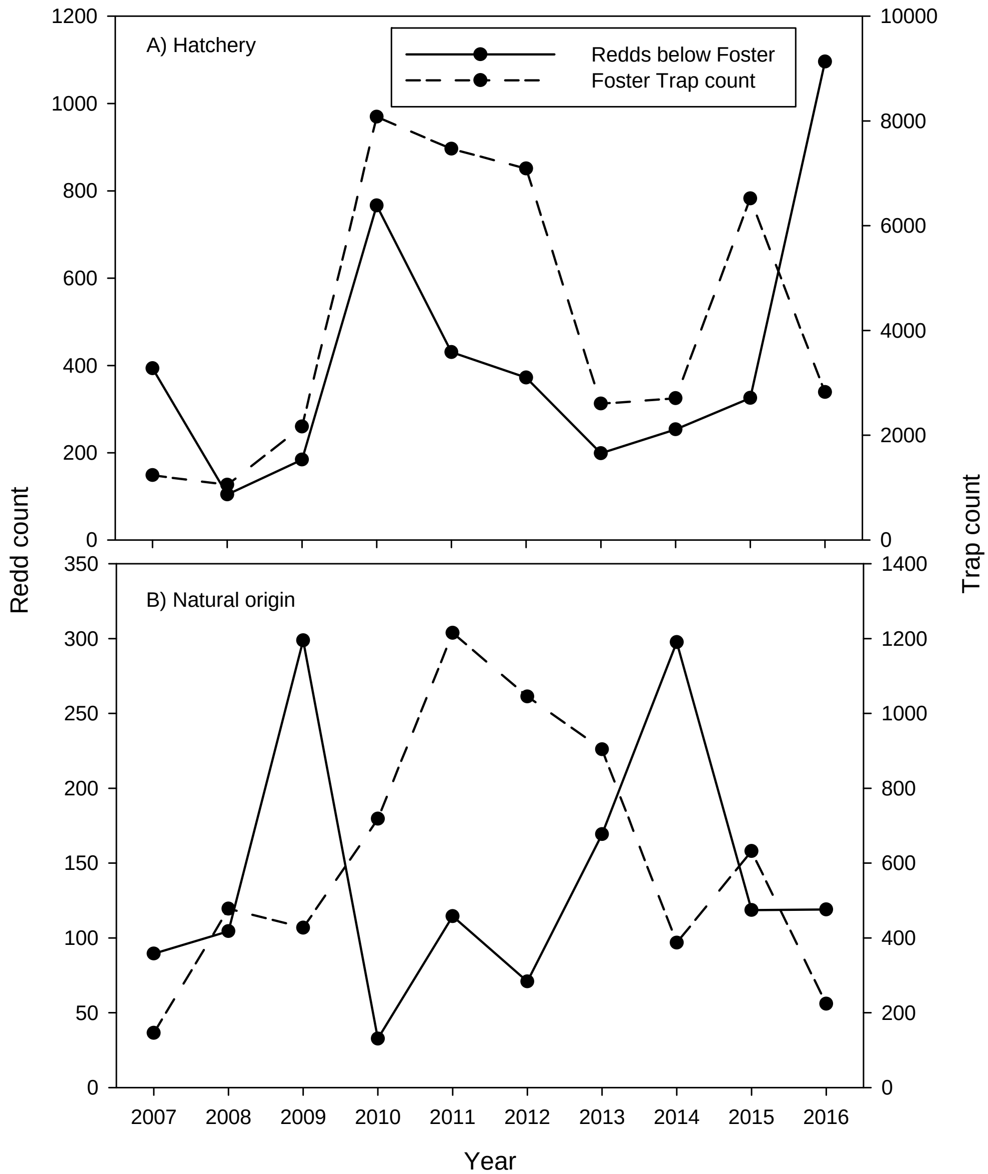

Figure 6. Adult Chinook salmon trap counts at the Foster AFF and redd counts below Foster in 2007-2016 for A) hatchery and B) natural-origin fish. New trap facility was constructed in winter 2013-2014. Redd counts by origin were estimated using total redds observed and estimated proportion of hatchery and natural origin spawners collected during spawning ground surveys; data collected by ODFW.

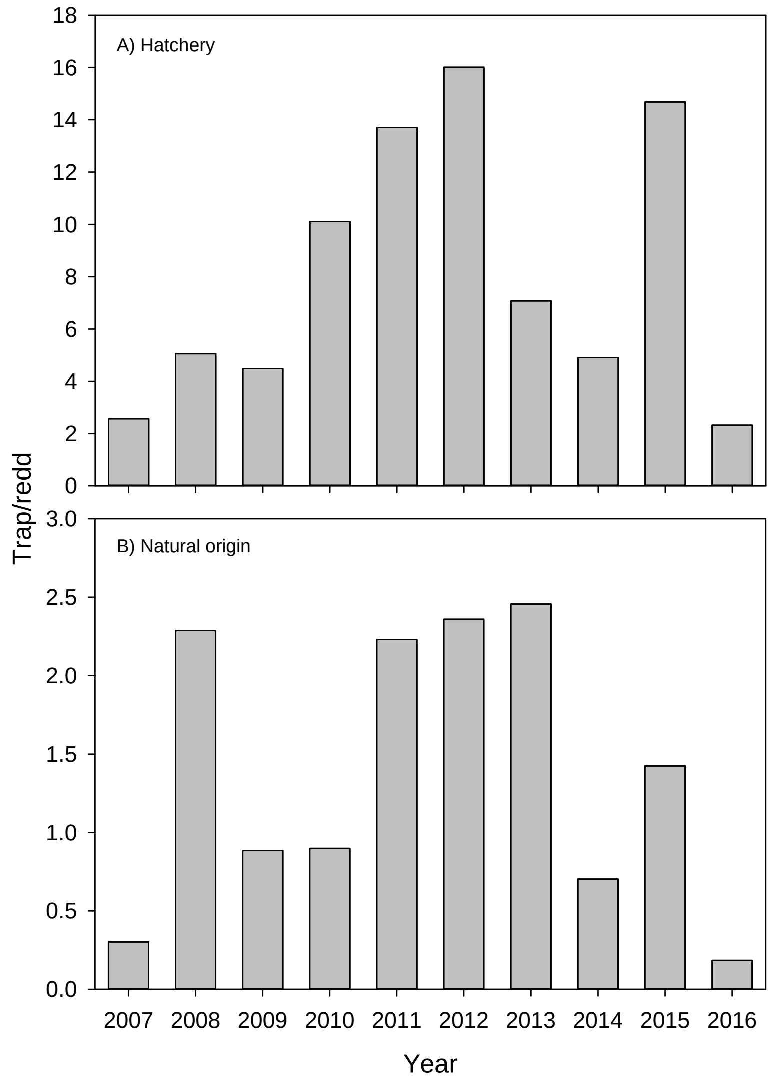

Figure 7. Adult Chinook salmon Foster AFF trap to redd count (below Foster) ratio in 2007-2016 for A) hatchery and B) natural origin fish. New trap facility was constructed in winter 2013-2014. Redd and fish origin data collected by ODFW.

Water temperature

Water temperatures in the Foster Dam tailrace and fishway were affected by conditions in Foster Reservoir and source water (Middle and South Santiam rivers). Mean hourly water temperatures in the Foster fishway and tailrace were warmer, on average, in 2015 than in 2016 (Appendix Figures 1-2). For example, during the 2015 study period, the overall spill bay (e.g., logger site 2 in Figure 2) mean (5 May – 20 October) was 14.0 °C with a peak of 21.6 °C on 27 June. In 2016, the overall spill bay mean for the same time period was 13.6 °C with a peak of 18.6 °C on 6 July. This pattern was similar at other monitoring sites during June and early July until spill stopped.

In 2016, mean hourly water temperatures collected by the U.S. Army Corps of Engineers (USACE) at 10 depths in Foster Reservoir in 2016, ranged from 23.7 °C at 0.5 ft from the surface to approximately 8.2 °C at 80 ft (Figure 8). The thermocline was at approximately 15-20 ft and temperatures below 20 ft generally remained ≤15 °C throughout the summer.

The thermal regime of the Middle Santiam River is affected by Green Peter Dam. Mean hourly water temperature in the Middle Santiam (Sunnyside) during the 2016 study period was 9.2 °C with a peak of 11.8 °C on 26 September (Figure 9). Water temperatures in the South Santiam River (Menear's Bend) were approximately 8.2 degrees warmer (*mean* = 17.5 °C) than in the Middle Santiam with a maximum temperature of 26.1 °C on 19 August.

Water temperatures measured in the Foster Dam tailrace below the spill bay were warmer (~16-18 °C) in June and July during spill than when spill stopped in mid-July (Figure 9). Large temperature differences (4-8 °C) were also observed in the tailrace between the tailrace below the spill bay and all other temperature sites (Figure 10) until spill stopped on 14 July and tailrace water below the powerhouse was primarily cooler water drawn from the lower part of the reservoir through turbines (which was also likely cooler water from the Middle Fork Santiam). Lateral temperature gradients were also observed during spill with the south shore (tailrace site) being much cooler than the north shore (Figure 10). Overall, the Foster tailrace was warmer than the AFF fishway, and both were generally cooler than the unregulated reaches of South Fork Santiam upstream of the reservoir (Figures 9-10).

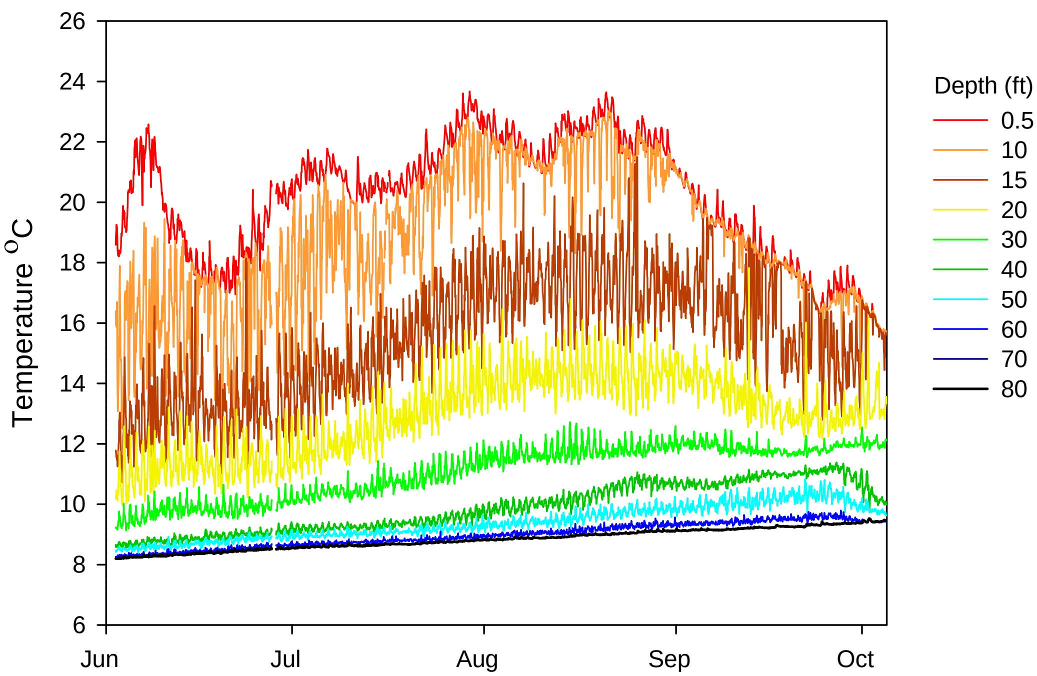

Figure 8. Foster Reservoir mean hourly water temperatures collected at 10 depths between 2 June and 4 October 2016 (Source: U.S. Army Corps of Engineers).

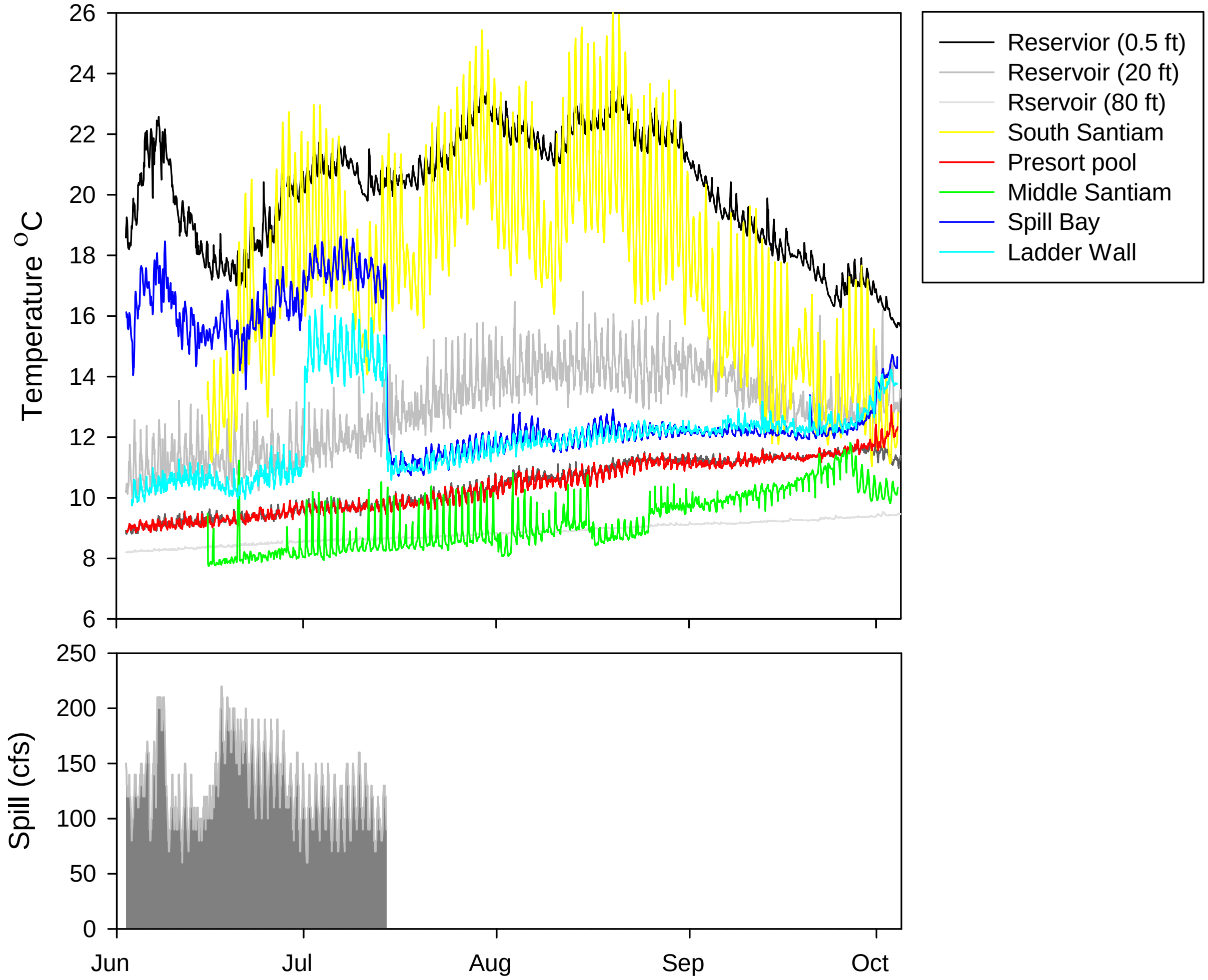

Figure 9. Foster Reservoir, South Fork Santiam (Menear's Bend), Middle Fork Santiam (Sunnyside), and Foster Dam mean hourly water temperatures (top panel) and spill (bottom panel) between 2 June and 4 October 2016. Spill was stopped on 14 July.

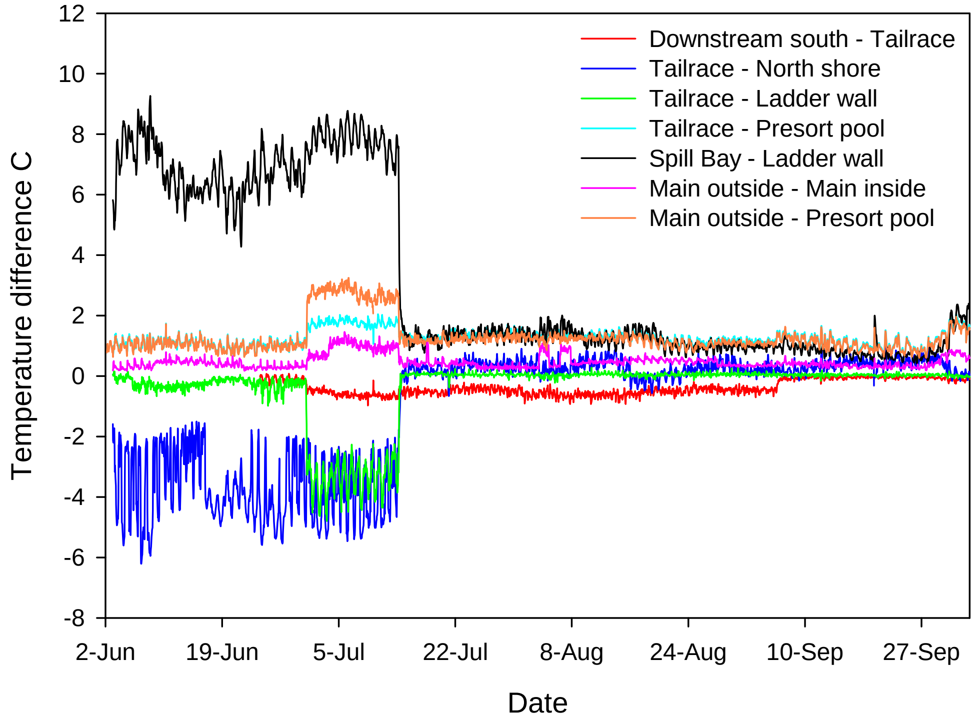

Figure 10. Pairwise differences in mean hourly water temperatures calculated data collected at Foster AFF fishway and tailrace sites between 2 June and 4 October 2016. Site numbers as referenced in Figure 2: Downstream south (12), Tailrace (9), North shore (1), Ladder wall (4), Presort pool (10), Spill Bay (2), Main outside (5) and Main inside (5).

Water chemistry – 2016

The influence of different water sources between the Foster AFF fishway and tailrace was evident in the water chemistry results. Potential of hydrogen (pH), dissolved oxygen percent saturation (DO %), and dissolved oxygen (DO) were all higher in the fishway than in the tailrace during the 2016 collection period (1 July to 4 October; Figure 11). Specific Conductivity (µs/cm) was generally lower in the fishway than in the tailrace.

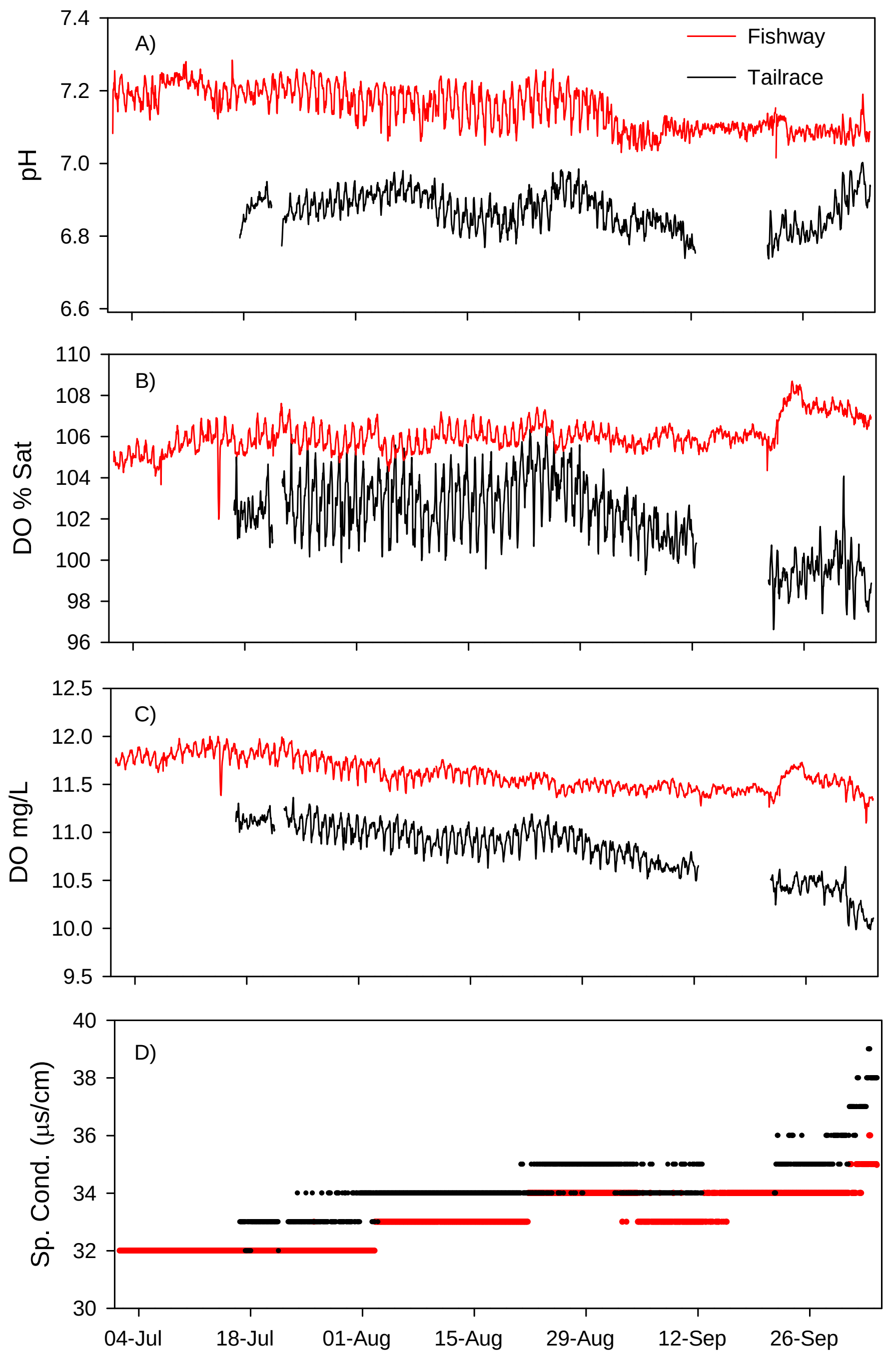

Figure 11. Water chemistry parameters collected in the Foster AFF fishway and tailrace: A) pH, B) dissolved oxygen percent saturation C) dissolved oxygen, and D) specific conductivity in 2016.

Main entrance water velocity experiment

In 2015, the main entrance weir gate was partially raised for ~ 30 days during the 'Auto' treatment and was lowered completely for ~33 days during the 'Open' treatment from 27 May until 28 July during a randomized block experimental period (Figure 12), a period with high trapping rate and extending through the median run date in most years (Figure 5). The hydraulic test provided evidence that adult collection rate was higher when operating the trap with the weir gate completely lowered ('Open' treatment) than when the weir gate was run partially raised to increase hydraulic head ('Auto' treatment) however the trap counts were not significantly different (t-value -1.16, P =0.267) between the two treatments. In total 2,422 salmon were collected during the 'Auto' treatment and 3,275 were collected during the 'Open' treatment (Figure 13). Although the Open treatment may have been an improvement over Auto, systematic observations of adult salmon in the Foster tailrace in 2015 indicated that ~100-500 fish were routinely present in the tailrace each day during the experiment (George Naughton, UI, *unpublished data*).

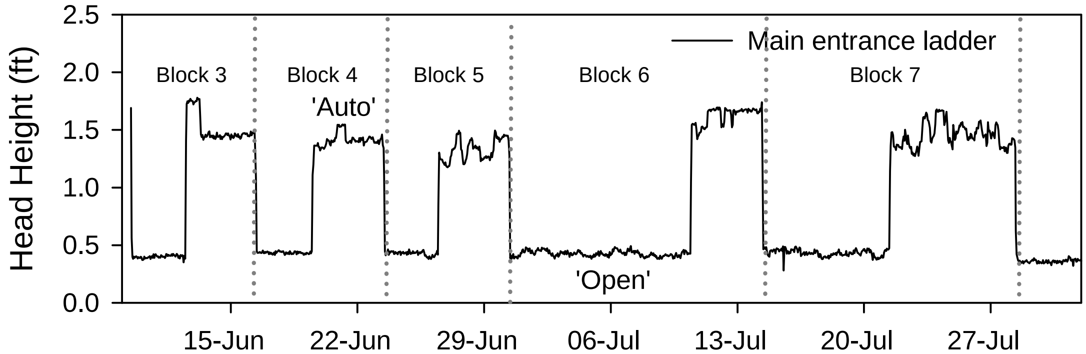

Figure 12. Head height at the main entrance ladder in 2015 indicating 'Auto' when the weir gate was partially raised (head ~1.5 ft) and 'Open' treatments (head ~0.5 ft) when the weir gate was lowered completely during the randomized block treatment period (note blocks 1 and 2 are not shown).

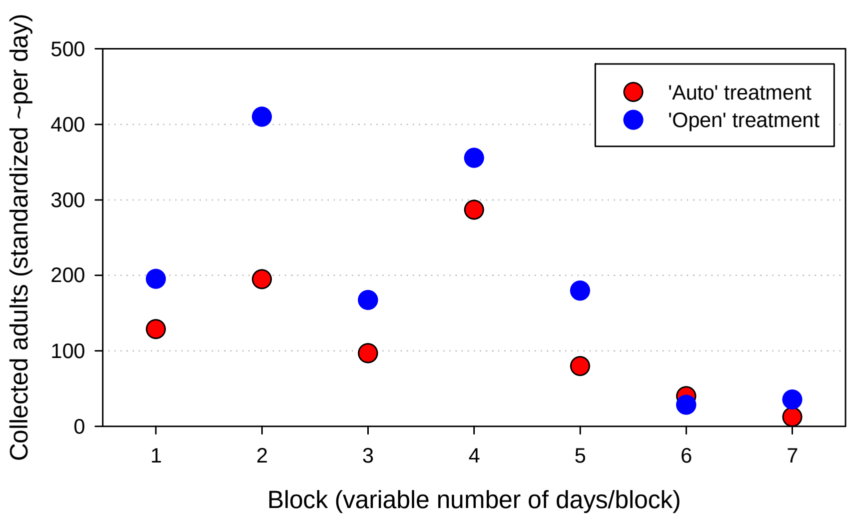

Figure 13. Numbers of adult Chinook salmon collected at the Foster trap (i.e., were enumerated after passing through the fishway and presort pool) during seven experimental treatment blocks in 2015 where the weir gate was either partially raised ('Auto') or lowered completely ('Open').

In 2016, entrance weir gate settings were altered between the 'Auto' and 'Open' treatments approximately every 24 hours during the 14-24 July experimental period (Figure 14). Trap operations were conducted over longer intervals during 2016, preventing meaningful comparisons between trap entry rate between treatments, but the treatment effects on behavior were quantified.

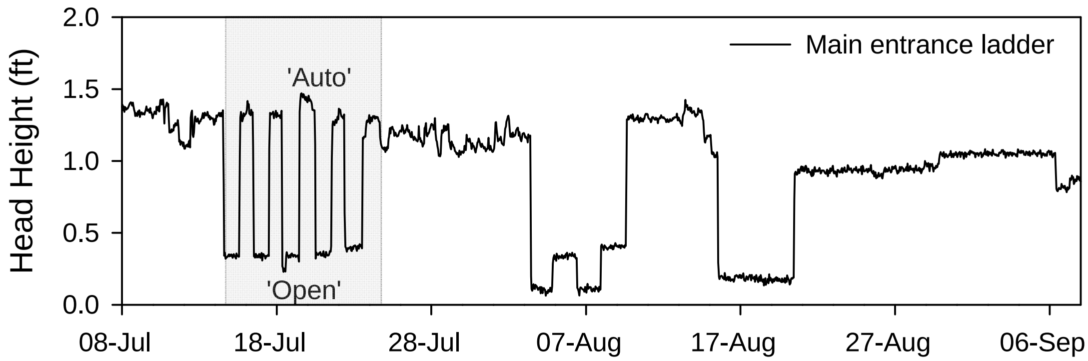

Figure 14. Head height at the main entrance ladder in 2016 indicating 'Auto' when the weir gate was partially raised (head ~1.5 ft) and 'Open' treatments (head ~0.5 ft) when the weir gate was lowered completely during 14-24 July (gray shaded area). Also shown are two 'Open' ad hoc periods on 3-9 August and 15-20 August.

Fish Behavior – 2016 sampling effort

Random subsamples of video were selected for review to: 1) test for differences in rates during the experimental period, and 2) qualitatively evaluate behavior during non-experimental periods until a minimum of 7 hours were watched from each experimental treatment (Table 4). During the experimental period (14-24 July, 2016), a total of 1,295 h of DIDSON and optical video data were collected at the Foster AFF and 9.6% was viewed (Table 4). A small percentage of the nighttime DIDSON data collected was reviewed to determine diel patterns in behavior (5-10% of night video reviewed). Due to lack of lighting, no nighttime optical video data were viewed.

During the non-experimental period (24 July – 1 October, 2016), a total of 6,308 h of data were collected at the Foster AFF and 6.3% was viewed to qualitatively test for seasonal changes in behavior (Table 5). No nighttime data were viewed for either DIDSON or optical video during the non-experimental period.

Table 4. DIDSON and optical camera deployments by site and treatment, with numbers of hours of imagery collected and watched by day and night during the experimental period (14-24 July) in 2016 at the Foster AFF.

			Data Collected (h)			Data watched (h)			Data watched (%)		
Site	Camera	Treatment	Day	Night	Total	Day	Night	Total	Day	Night	Total
Main entrance	DIDSON	Auto	118	97	215	11	5	16	9.3	5.2	7.4
Main entrance	DIDSON	Open	78	50	128	19	5	24	24.4	10.0	18.8
Turnpool	Optical	Auto	118	97	215	15	-	15	12.7	-	7.0
Turnpool	Optical	Open	78	50	128	18	-	18	23.1	-	14.1
DS Channel	Optical	Auto	99	80	179	7	-	7	7.1	-	3.9
DS Channel	Optical	Open	55	32	87	14	-	14	25.5	-	16.1
UPS Channel	Optical	Auto	118	97	215	12	-	12	10.2	-	5.6
UPS Channel	Optical	Open	78	50	128	18	-	18	23.1	-	14.1
		Total	742	553	1295	114	10	124	15.4	1.8	9.6

Table 5. DIDSON and optical camera deployments by site and weir gate setting, with numbers of hours of imagery collected and watched by day and night during the non-experimental period (24 July – 1 October) in 2016 at the Foster AFF.

			Data Collected (h)			Data watched (h)			Data watched (%)		
Site	Camera	Weir gate	Day	Night	Total	Day	Night	Total	Day	Night	Total
Main entrance	DIDSON	Auto	746	556	1,311	59	-	59	7.9	-	4.5
Main entrance	DIDSON	Open trial	156	110	266	34	-	34	21.8	-	12.8
Turnpool	Optical	Auto	746	556	1,311	59	-	59	7.9	-	4.5
Turnpool	Optical	Open trial	156	110	266	33	-	33	21.2	-	12.4
DS Channel	Optical	Auto	746	556	1,311	73	-	73	9.8	-	5.6
DS Channel	Optical	Open trial	156	110	266	33	-	33	21.2	-	12.4
UPS Channel	Optical	Auto	746	556	1,311	73	-	73	9.8	-	5.6
UPS Channel	Optical	Open trial	156	110	266	33	-	33	21.2	-	12.4
		Total	3,608	2,664	6,308	397	-	397	11.0	-	6.3

Fish behavior – 2016 experimental period

Fishway entrance: DIDSON

The fish entry and exit rates at the main fishway entrance as estimated from the DIDSON video were much higher during daytime (0700 to 2000 h; Figures 15-16) compared to night (2100-0600). The highest hourly rate events (>400/h) of any hour occurred when spill stopped on July 14 in the early evening. Mean hourly AFF rejection rates were similar across daytime hours at the main entrance (Figure 17). Mean hourly fishway entrance and exit events increased slightly in the late afternoon and early evening hours.

In the DIDSON data recorded at the main fish entrance, we observed higher hourly fish entrance rates during the 'Open' treatment than during the 'Auto' treatment during the day ($\chi^2 = 36.78$, $P < 0.001$, Kruskal-Wallis test) and night ($\chi^2 = 4.41$, $P = 0.036$) (Figure 18; Table 6). Higher fishway exit rates also occurred during the 'Open' treatment both day ($\chi^2 = 44.12$, $P < 0.001$) and night ($\chi^2 = 8.23$, $P < 0.001$). Hourly rejection rates were similar between treatments during the day. At night, higher rejection rates were observed during the 'Open' treatment ($\chi^2 = 5.05$, $P = 0.025$), though sample size was small ($n = 18$). Consistent with the fishway entry and exit rates, fewer fish were observed holding outside the entrance during the 'Open' treatment during the day ($\chi^2 = 17.72$, $P < 0.001$) and night ($\chi^2 = 21.64$, $P < 0.001$).

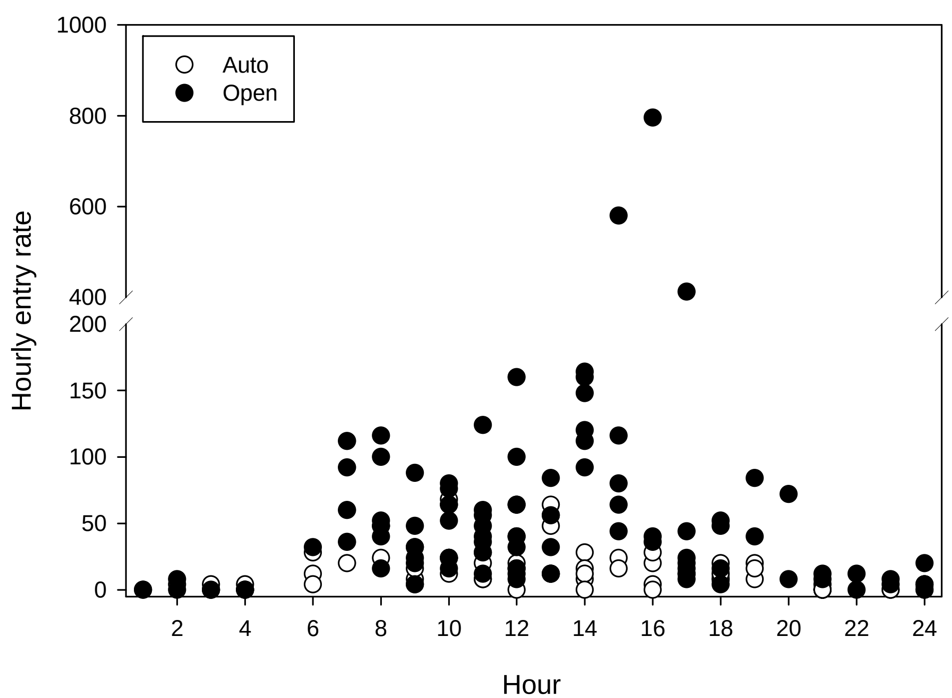

Figure 15. Fish entrance rates by treatment and hour of day for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated using DIDSON during the experimental period in 2016.

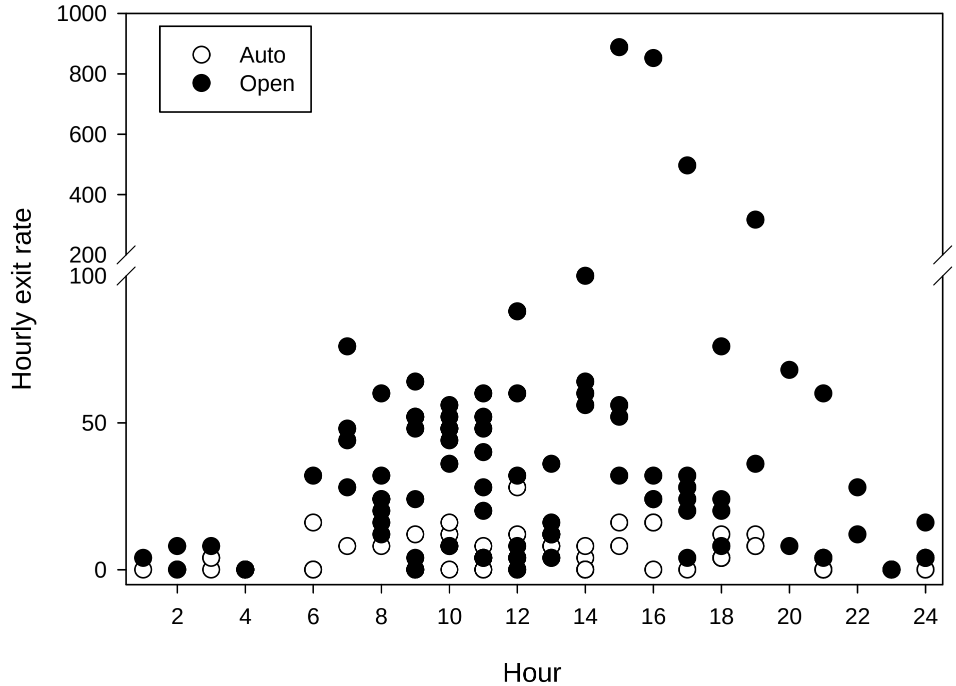

Figure 16. Fish exit rates by treatment and hour of day for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated using DIDSON during the experimental period in 2016.

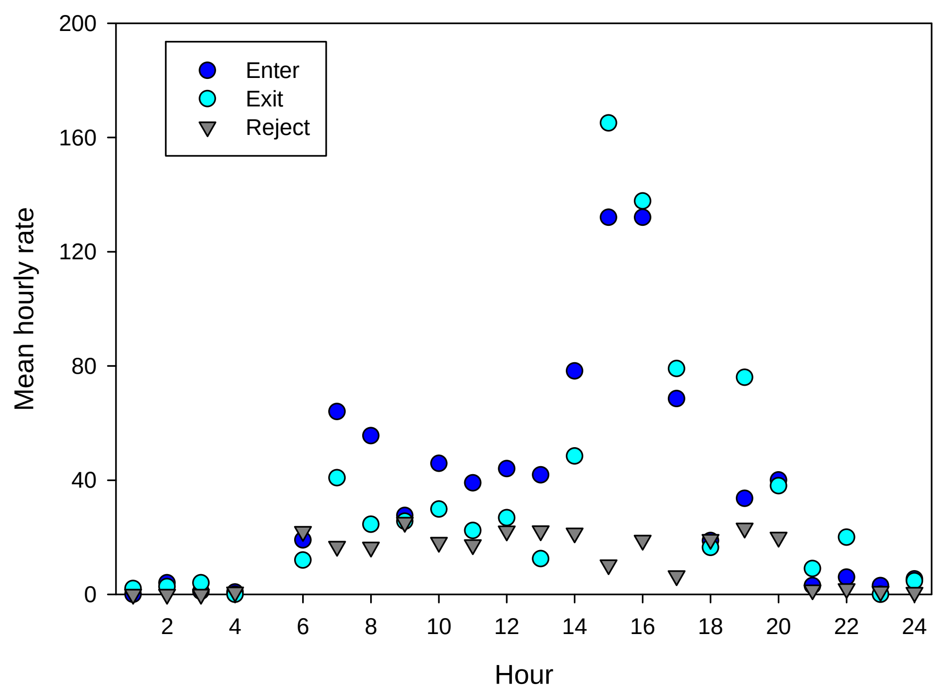

Figure 17. Fish entrance, exit, and rejection rates by hour of day for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated using DIDSON during the experimental period in 2016.

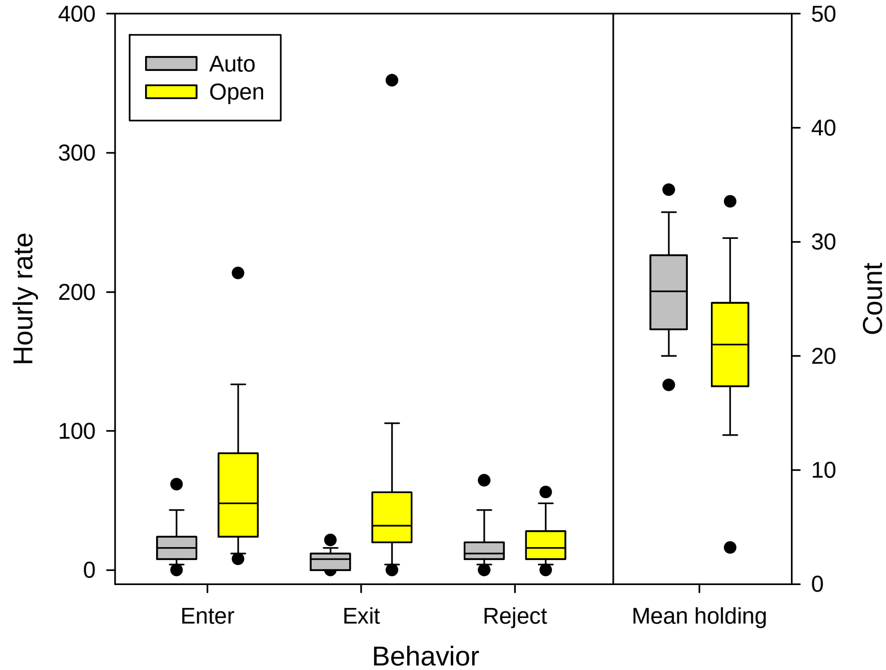

Figure 18. Fish entrance, exit, and rejection rates by treatment and mean holding events for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated using DIDSON during the experimental period in 2016.

Table 6. Results of Kruskal-Wallis and Welch's ANOVA tests for fish behavior metrics at the Foster AFF main entrance during the experimental period in 2016, as assessed using DIDSON.

							Kruskal-Wallis		Welch's ANOVA	
Behavior	Treatment	Diel	*n*	Median	Mean	SD	χ^2	*P*	F	*P*
Holding	Auto	Day	45	26.0	26.0	4.6	**17.72**	**<0.001**	**21.68**	**<0.001**
	Open	Day	75	21.0	20.8	7.6				
	Auto	Night	18	19.0	19.7	2.1	**21.64**	**<0.001**	**66.93**	**<0.001**
	Open	Night	18	11.0	11.9	3.4				
Entering	Auto	Day	45	16.0	18.7	15.6	**36.78**	**<0.001**	**46.32**	**<0.001**
	Open	Day	75	48.0	77.4	117.9				
	Auto	Night	18	0.0	1.3	1.9	**4.41**	**0.036**	**4.89**	**0.036**
	Open	Night	18	4.0	8.7	16.8				
Exiting	Auto	Day	45	8.0	7.5	6.7	**44.12**	**<0.001**	**57.92**	**<0.001**
	Open	Day	75	32.0	70.0	149.5				
	Auto	Night	18	0.0	1.1	1.8	**8.23**	**0.004**	**10.36**	**0.004**
	Open	Night	18	4.0	12.4	20.1				
Rejection	Auto	Day	45	12.0	18.0	16.9	0.59	0.442	0.46	0.501
	Open	Day	72	16.0	20.0	17.0				
	Auto	Night	18	0.0	0.4	1.9	**5.05**	**0.025**	**4.95**	**0.035**
	Open	Night	18	0.0	3.3	8.4				

Entrance and fishway channel: Optical cameras

The highest mean hourly rate of fish movement (upstream and downstream) by hour was observed at the upstream channel, followed by the downstream channel, and then the turnpool location. When spill stopped on July 14, the highest upstream (248 events/hour) and downstream (243 events/hour) rates were recorded at the upstream channel (Figures 19-20). Mean hourly rates (upstream and downstream) were higher at the upstream channel site in the late afternoon and early evening (range: 45-248 events/hour) than in the early morning and afternoon (range: 12-46 events/hour). Mean hourly upstream and downstream event rates were similar at the turnpool and downstream channel locations with a slight increase in events at the downstream channel site in the late afternoon and evening hours (Figures 19-20).

We observed mixed behavioral results between treatments at different camera locations. Fish behaviors observed at the turnpool camera were similar regardless of treatment with no differences in the hourly rate of fish moving upstream ($\chi^2 = 0.46$, $P = 0.497$), downstream ($\chi^2 = 0.42$, $P = 0.521$), or holding ($\chi^2 = 3.13$, $P = 0.077$) (Figure 21; Table 7). At the downstream channel site, the rate of upstream ($\chi^2 = 3.5$, $P = 0.060$) and downstream ($\chi^2 = 6.3$, $P = 0.014$) movement was higher during the 'Auto' treatment; there was no difference in holding between treatments ($\chi^2 = 0.4$, $P = 0.543$) (Figure 22; Table 8). At the upstream channel site, upstream hourly rates ($\chi^2 = 3.9$, $P = 0.048$) and the number of fish holding ($\chi^2 = 10.4$, $P = 0.001$) were higher during the 'Open' treatment suggesting adults entering during the treatment period traveled up the fishway to this location, while no differences were detected between treatments for downstream movements ($\chi^2 = 0.7$, $P = 0.410$) (Figure 23; Table 9). Regardless of treatment, there were more upstream events on average at the turnpool and upstream channel cameras and more downstream movements at the downstream channel camera during the experimental period (Figure 24). We note that differences in observed up- vs. downstream movements may be related in part to limitations of monitoring because the entire fishway cross section could not always be imaged due to constraints of lighting and water clarity. Results could be biased in either direction if, for example, salmon were more likely to move upstream in one portion of the channel and downstream in a different (unobserved) portion of the channel, or vice versa.

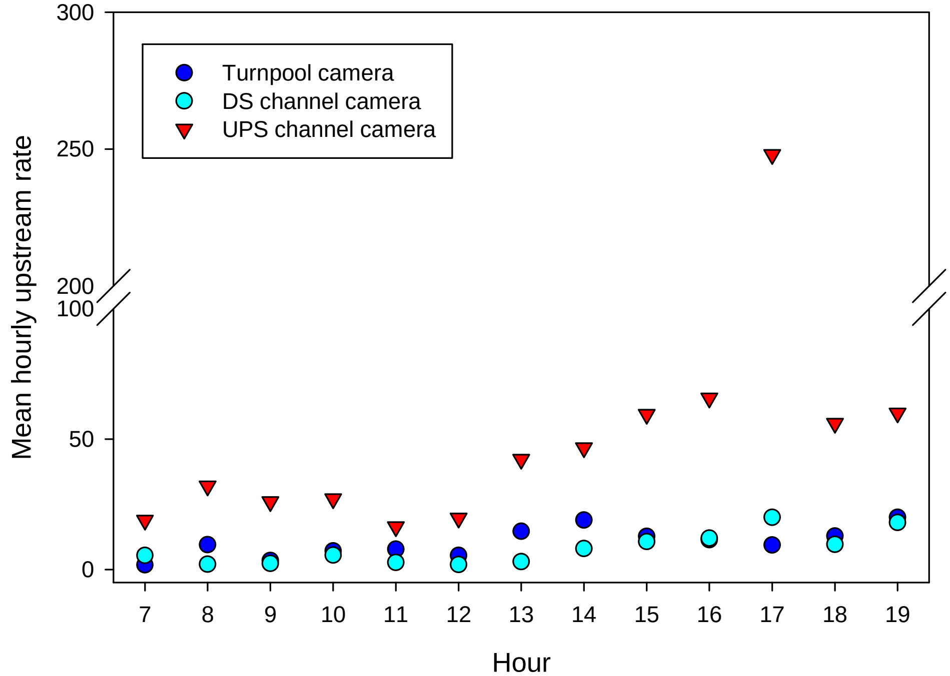

Figure 19. Fish upstream rates by camera location and hour of day for presumed adult Chinook salmon in the Foster fishway, as estimated using optical cameras during the experimental period in 2016.

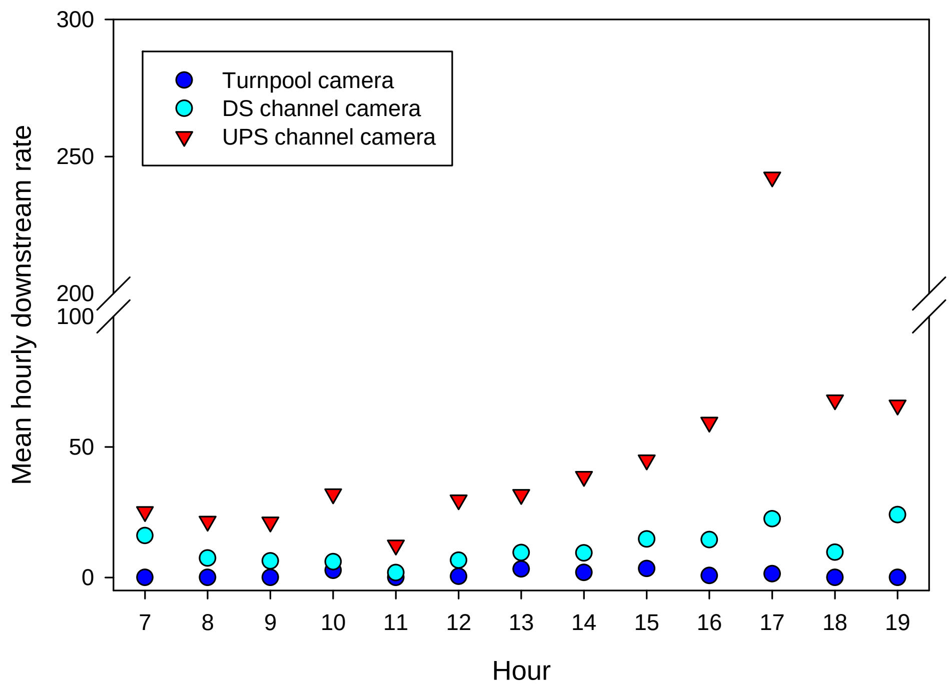

Figure 20. Fish downstream rates by camera location and hour of day for presumed adult Chinook salmon in the Foster fishway, as estimated using optical cameras during the experimental period in 2016.

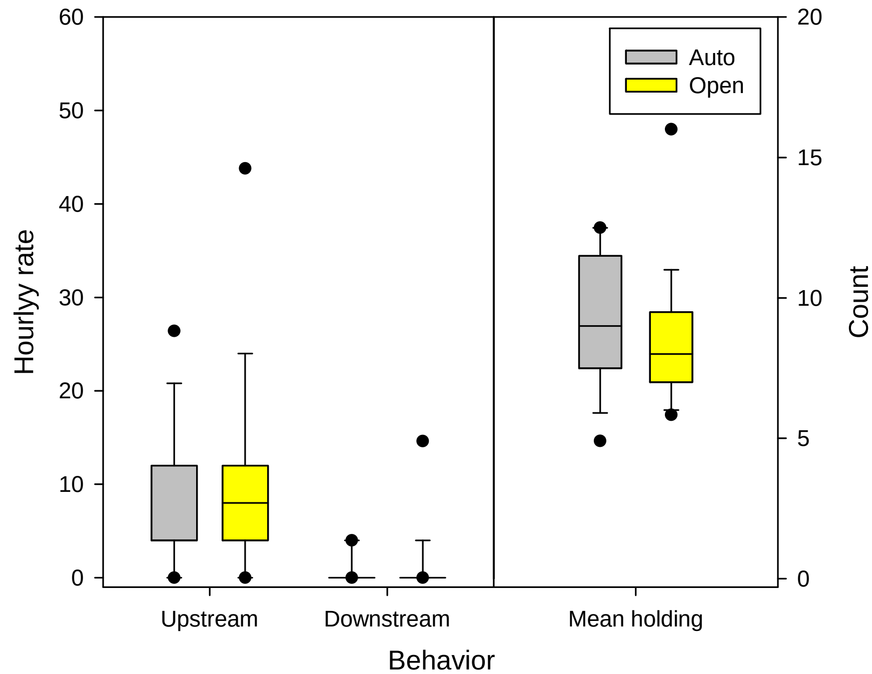

Figure 21. Fish upstream and downstream rates by treatment and mean holding events for presumed adult Chinook salmon at the turnpool camera during the experimental period in 2016.

Table 7. Results of Kruskal-Wallis and Welch's ANOVA tests for fish behavior metrics at the Foster turnpool during the experimental period in 2016, as assessed using Optical video.

							Kruskal-Wallis		Welch's ANOVA	
Behavior	Treatment	Diel	*n*	Median	Mean	SD	χ^2	*P*	F	*P*
Holding	Auto	Day	47	9.0	9.3	2.7	3.13	0.077	0.53	0.469
	Open	Day	73	8.0	8.9	2.9				
Upstream	Auto	Day	47	4.0	8.3	8.1	0.46	0.497	0.35	0.555
	Open	Day	67	8.0	10.4	12.0				
Downstream	Auto	Day	47	0.0	0.6	1.7	0.42	0.521	0.94	0.334
	Open	Day	67	0.0	1.4	4.0				

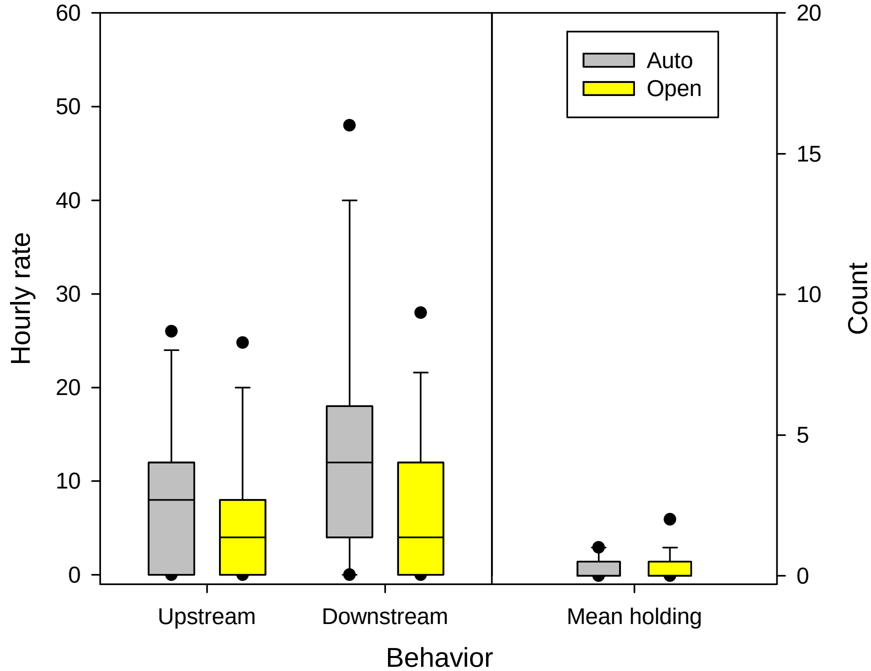

Figure 22. Fish upstream and downstream rates by treatment and mean holding events for presumed adult Chinook salmon at the downstream channel camera during the experimental period in 2016.

Table 8. Results of Kruskal-Wallis and Welch's ANOVA tests for fish behavior metrics at the Foster downstream channel during the experimental period in 2016, as assessed using Optical video.

							Kruskal-Wallis		Welch's ANOVA	
Behavior	Treatment	Diel	*n*	Median	Mean	SD	χ^2	*P*	F	*P*
Holding	Auto	Day	29	0.0	0.4	0.5	0.4	0.543	0.8	0.372
	Open	Day	55	0	0.5	0.6				
Upstream	Auto	Day	29	8.0	8.3	8.3	3.5	0.060	2.8	0.103
	Open	Day	55	4.0	5.4	8.1				
Downstream	Auto	Day	29	12.0	13.5	13.4	**6.1**	**0.014**	**7.0**	**0.010**
	Open	Day	55	4.0	7.4	10.0				

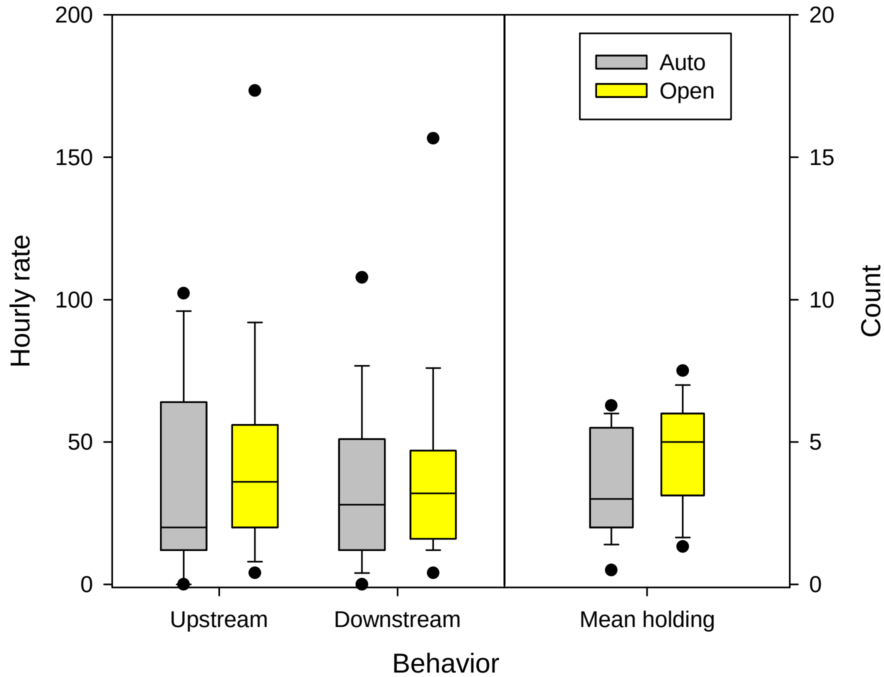

Figure 23. Fish upstream and downstream rates by treatment and mean holding events for presumed adult Chinook salmon at the upstream channel camera during the experimental period in 2016.

Table 9. Results of Kruskal-Wallis and Welch's ANOVA tests for fish behavior metrics at the Foster upstream channel during the experimental period in 2016, as assessed using Optical video.

							Kruskal-Wallis		Welch's ANOVA	
Behavior	Treatment	Diel	*n*	Median	Mean	SD	χ^2	*P*	F	*P*
Holding	Auto	Day	48	3.0	3.8	1.9	**10.4**	**0.001**	**11.4**	**0.001**
	Open	Day	72	5.0	5.0	2.0				
Upstream	Auto	Day	48	20.0	35.3	34.1	**3.9**	**0.048**	**5.4**	**0.022**
	Open	Day	72	36.0	59.6	110.1				
Downstream	Auto	Day	48	28.0	35.1	30.6	0.7	0.410	2.0	0.160
	Open	Day	72	32.0	54.3	109.0				

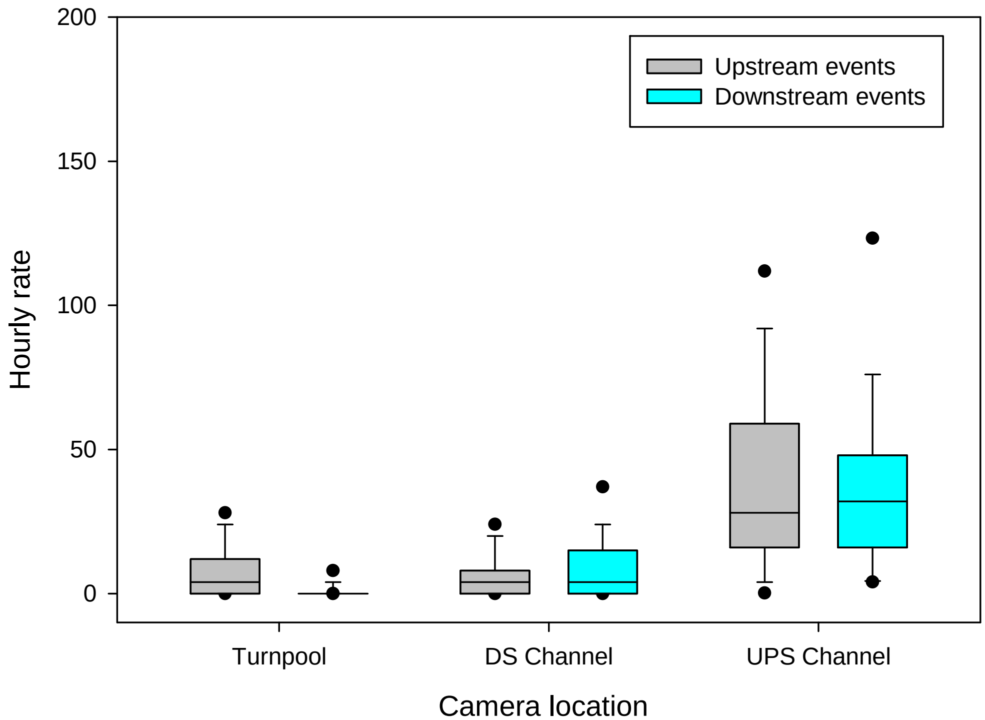

Figure 24. Fish upstream and downstream rates by optical camera location for presumed adult Chinook salmon in the Foster fishway during the experimental period in 2016.

Fish behavior –2016 non-experimental period

Fishway entrance: DIDSON

The pattern of fish entrance and exit events by hour during the late summer non-experimental period (24 July-1 October) was generally similar throughout the day with slightly more entries in the morning and a drop in rates around noon (Figures 25-26). The highest mean hourly rate of movement by hour was for fish entries, followed by exits, and then rejections (Figure 27). All three behaviors showed a similar pattern of mean hourly rates by hour of the day.

We observed similar patterns in behavior during the ad hoc 'Open' trial as during the experimental period in the DIDSON data recorded at the main fish entrance. Overall, more fish entered than exited during the non-experimental period (Figure 28). However, more fish entered (mean n = 41) and exited (mean n = 33) during the ad hoc 'Open' trial than during the 'Auto' setting (mean n = 15, n = 7, respectively). We observed no differences in rejections between the weir gate settings ('Open' trial mean n = 15; 'Auto' mean n = 14). The number of fish holding was greater during the 'Auto' setting (mean n = 30) than the ad hoc 'Open' 'setting (mean n = 15).

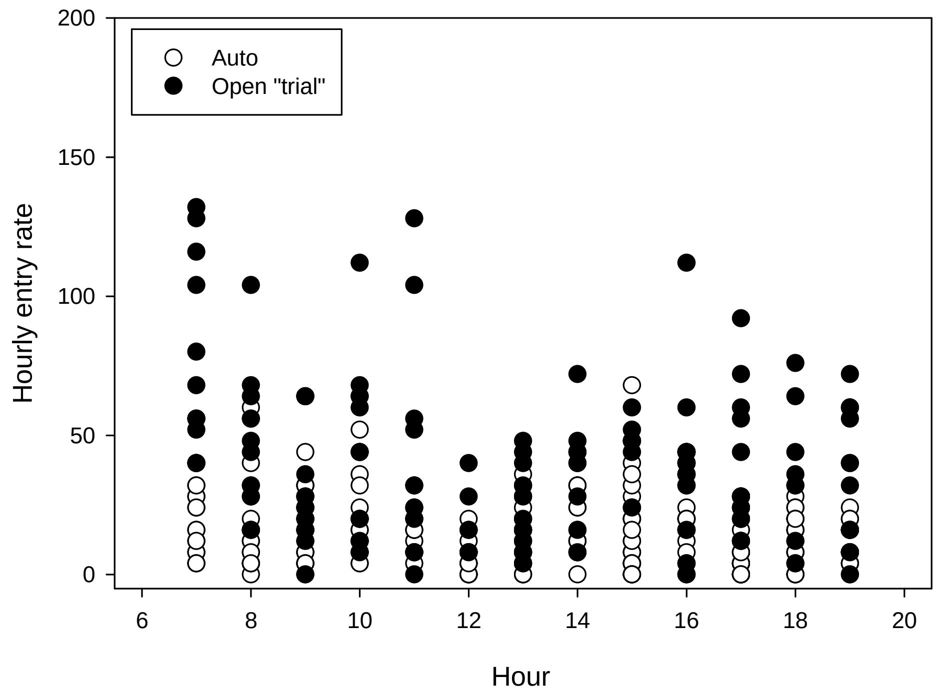

Figure 25. Fish entrance rates by weir gate setting and hour of day for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated by DIDSON during the non-experimental period in 2016.

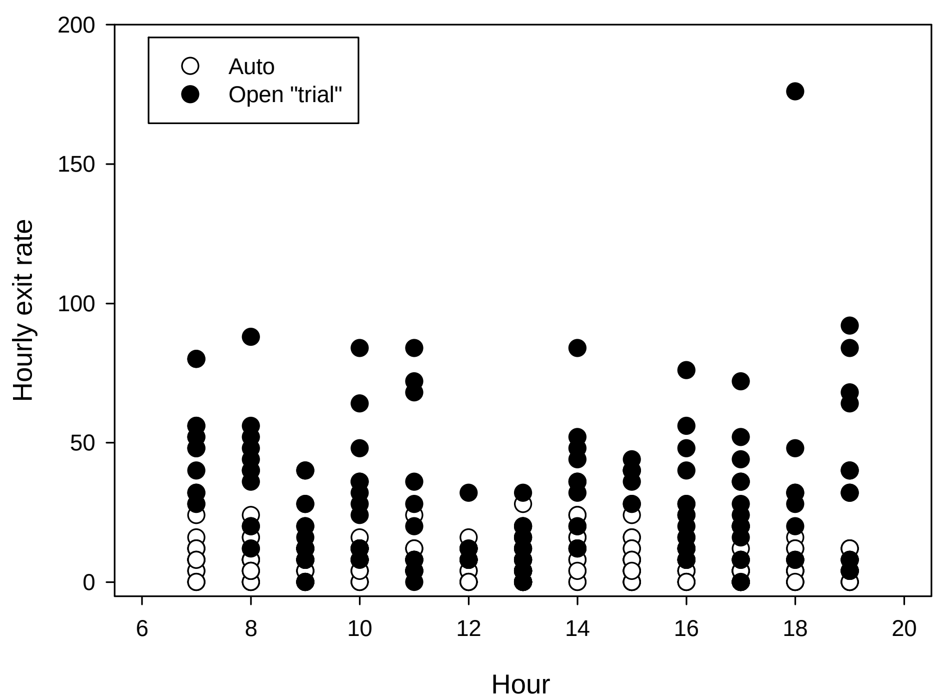

Figure 26. Fish exit rates by weir gate setting and hour of day for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated by DIDSON during the non-experimental period in 2016.

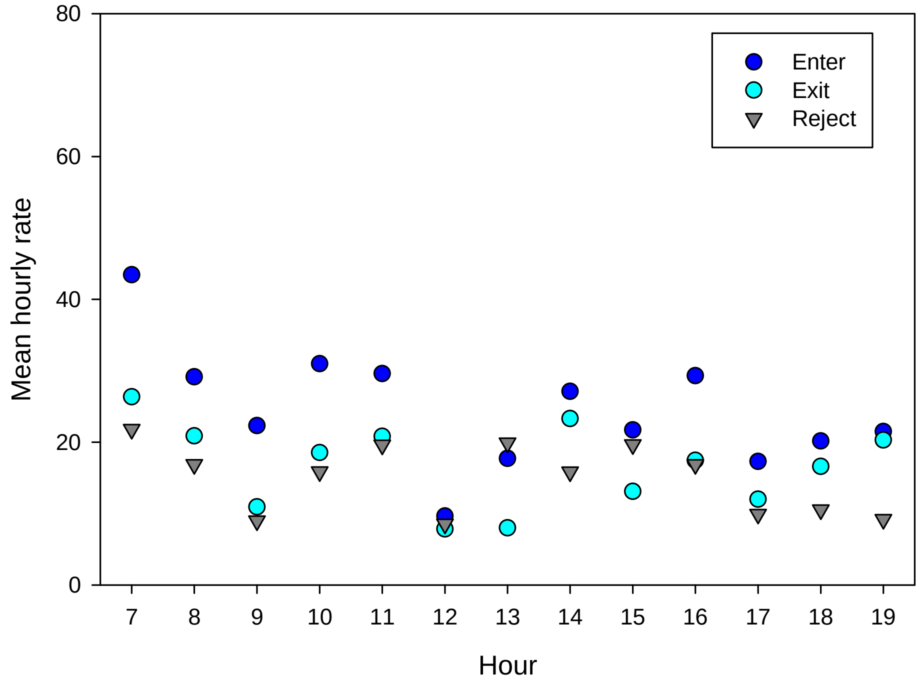

Figure 27. Fish entrance, exit, and rejection rates by hour of day for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated using DIDSON during the non-experimental period in 2016.

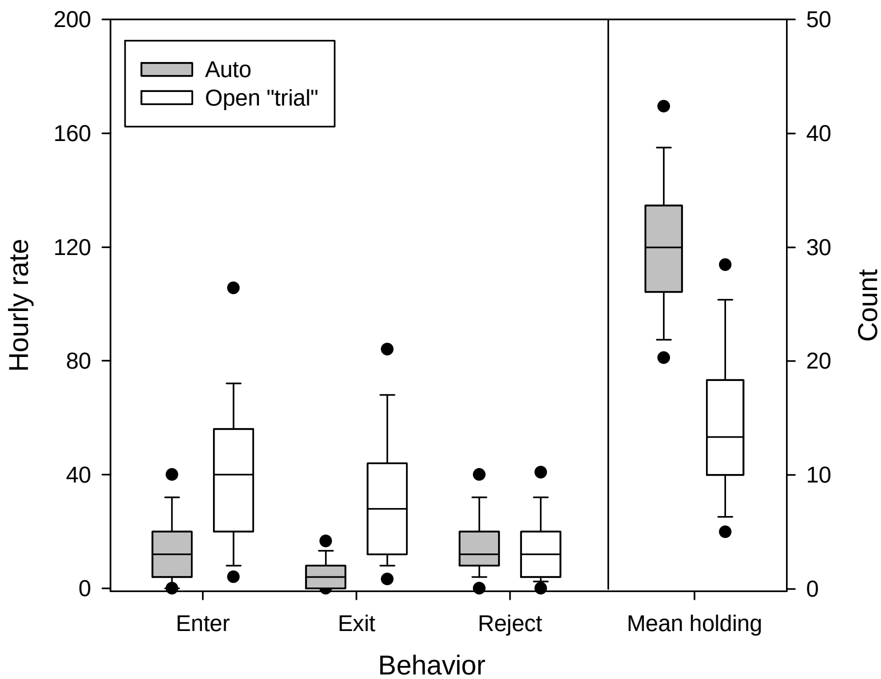

Figure 28. Fish entrance, exit, and rejection rates by weir gate setting and mean holding events for presumed adult Chinook salmon at the main Foster AFF entrance, as estimated using DIDSON during the non-experimental period in 2016. The Open condition was part of ad hoc trials after the experimental period.

Entrance and fishway channel: Optical cameras

The highest mean hourly rate of fish movement (upstream and downstream) by hour was observed at the upstream channel, followed by the downstream channel, and then the turnpool location. Mean hourly rates (upstream and downstream) steadily increased from noon until early evening (1700 h) at the upstream channel camera (Figures 29-30). Mean hourly upstream and downstream event rates were similar between the turnpool and downstream channel locations with a slight increase in events at the downstream channel site in the late afternoon and evening hours (Figures 29-30).

We observed generally similar fish behaviors between weir gate settings and at the different camera locations. At the turnpool camera, slightly more fish moved upstream during the 'Auto' period (mean n = 9) than during the 'Open' trial period (mean n = 6) (Figure 31). At the downstream channel camera, hourly rates of upstream and downstream movements were higher during the 'Auto' weir gate setting than the 'Open' trial and low numbers of fish were observed holding (Figure 32). Mean upstream and downstream hourly rates occurring at approximately twice the rate during the 'Auto' weir gate setting as those during the 'Open' trial at the upstream channel camera (Figure 33). Regardless of weir gate setting, there were more upstream than downstream movements, on average, at the turnpool and downstream channel cameras; upstream and downstream movement rates were approximately equal at the upstream channel camera (Figure 34).

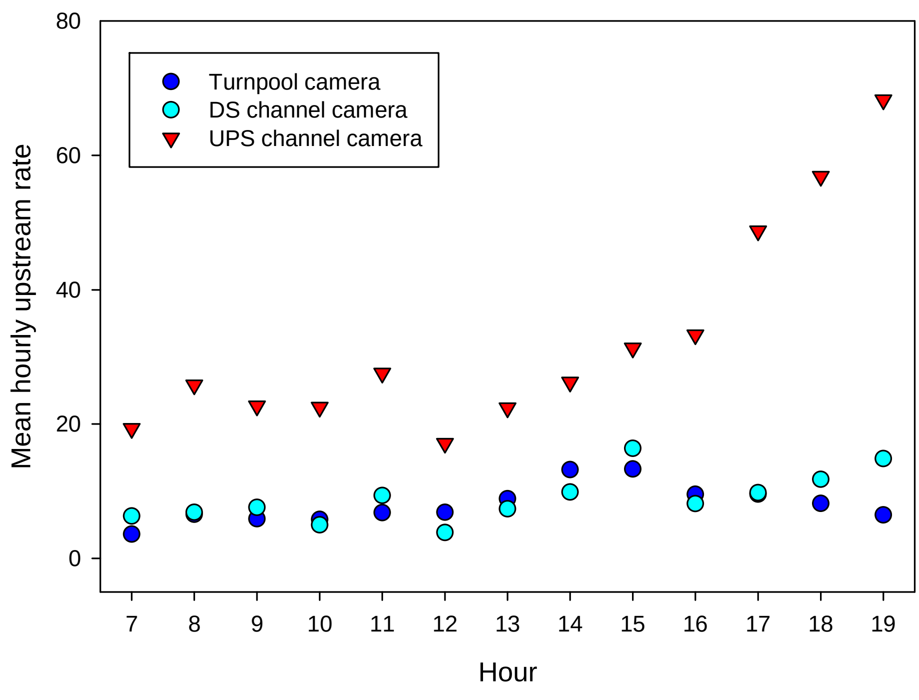

Figure 29. Fish upstream rates by camera location and hour of day for presumed adult Chinook salmon in the Foster fishway, as estimated using optical cameras during the non-experimental period in 2016.

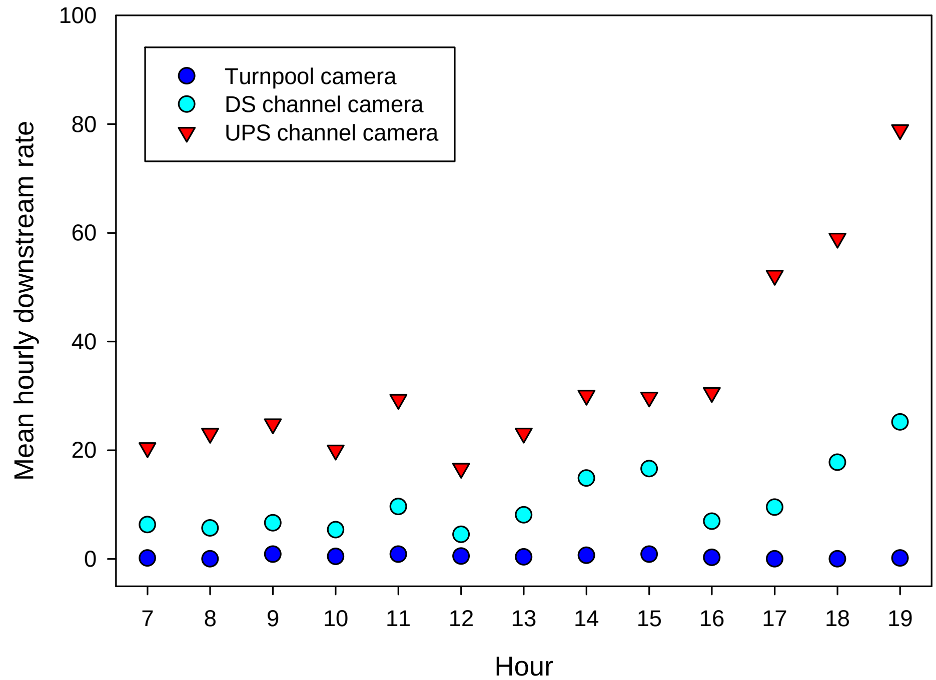

Figure 30. Fish downstream rates by camera location and hour of day for presumed adult Chinook salmon in the Foster fishway, as estimated using optical cameras during the non-experimental period in 2016.

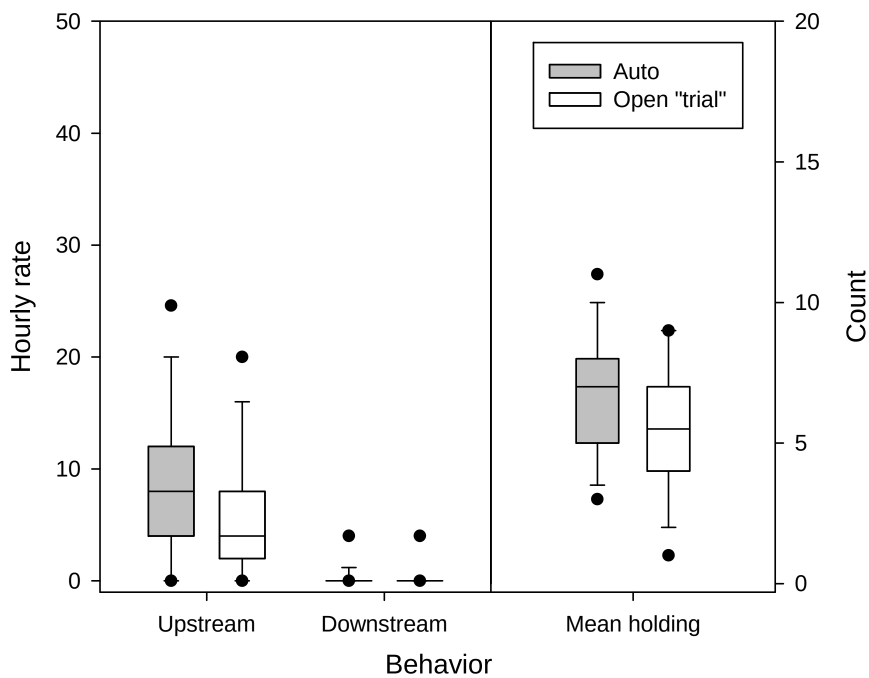

Figure 31. Fish upstream and downstream rates by weir gate setting and mean holding events for presumed adult Chinook salmon at the turnpool camera during the non-experimental period in 2016. The Open condition was part of ad hoc trials after the experimental period.

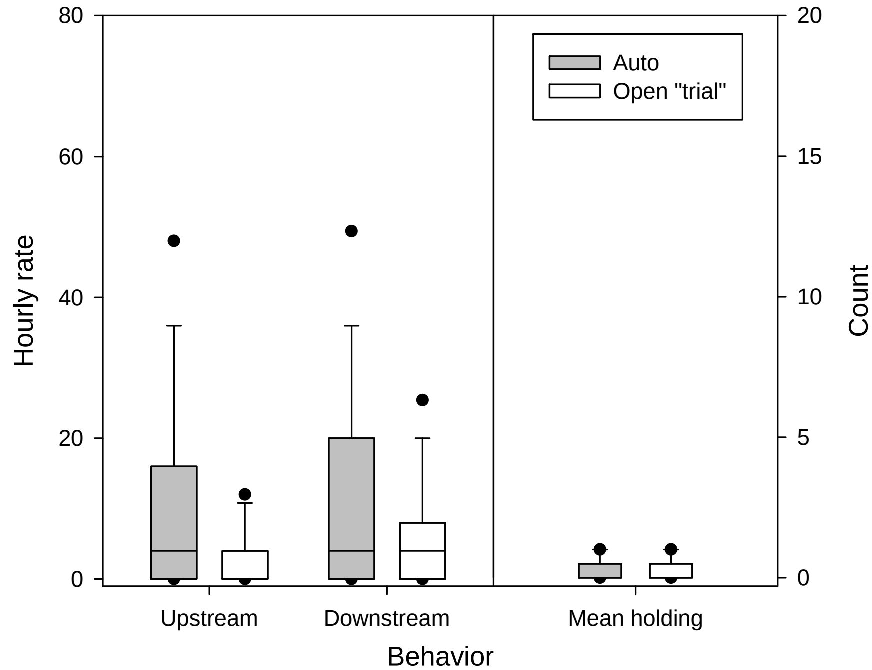

Figure 32. Fish upstream and downstream rates by weir gate setting and mean holding events for presumed adult Chinook salmon at the downstream channel camera during the non-experimental period in 2016. The Open condition was part of ad hoc trials after the experimental period.

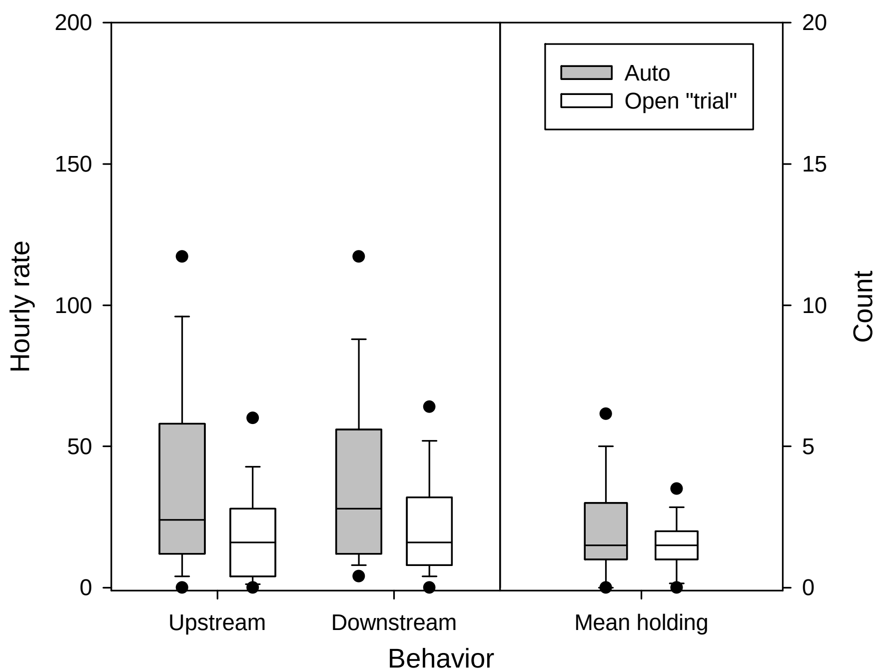

Figure 33. Fish upstream and downstream rates by weir gate setting and mean holding events for presumed adult Chinook salmon at the upstream channel camera during the non-experimental period in 2016. The Open condition was part of ad hoc trials after the experimental period.

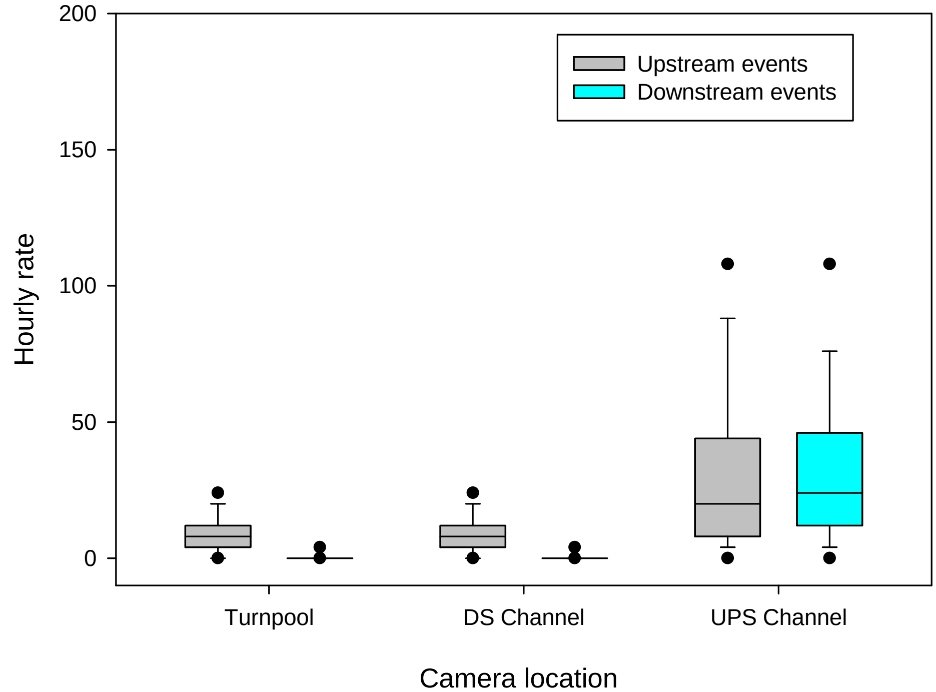

Figure 34. Fish upstream and downstream rates by optical camera location for presumed adult Chinook salmon in the Foster fishway during the non-experimental period in 2016.

Environmental correlations with fish behavior

We detected several statistically significant relationships, uncorrected for multiple comparisons, between water temperature and fish entry and holding rates estimated from the DIDSON data at the Foster AFF main entrance. Observation date (seasonal effect) was negatively correlated with fish entry rate when the weir gate was partially lowered ('Auto' treatment) (Table 10). There was also a negative relationship between temperatures in the fishway (presort pool and lower ladder sites) and tailrace (powerhouse and tailrace sites) with fish entry rates during the 'Auto' weir gate setting (i.e., as temperature increased fewer fish entered). There were also several negative correlations between temperature and when fish were holding outside the main entrance during the 'Open' treatment (Table 10). We caution that these relationships are challenging to interpret because the analysis does not account for the density of fish available to enter (i.e., tailrace density of salmon).

Table 10. Pearson correlation coefficients (*r*) between environmental variables and behaviors (enter, exit, and holding) of presumed adult Chinook salmon at the Foster AFF main entrance as assessed using DIDSON in 2016. Bold indicates $P < 0.05$.

	Enter		Exit		Holding	
Variable	Auto	Open	Auto	Open	Auto	Open
Date	**-0.505**	-0.364	-0.159	-0.312	0.173	-0.407
Barometric pressure	0.201	0.342	0.181	0.312	-0.006	0.358
Solar radiation	-0.019	0.205	0.123	0.187	0.017	-0.044
Middle Fork Santiam temp[1]	-0.259	-0.044	0.198	-0.029	-0.075	0.024
South Fork Santiam temp[2]	-0.090	-0.148	0.167	-0.135	-0.029	-0.291
Presort pool temp	**-0.489**	-0.358	-0.173	-0.311	0.192	**-0.468**
Lower ladder temp	**-0.480**	-0.353	-0.204	-0.310	0.216	**-0.499**
Powerhouse temp	**-0.420**	-0.032	-0.152	0.023	0.226	-0.413
Tailrace temp	**-0.411**	-0.259	-0.130	-0.211	0.243	**-0.452**

[1] Middle Fork Santiam temperature at Sunnyside
[2] South Fork Santiam temperature at Menear's Bend

Discussion

Observations of adult salmon during 2015 and 2016 were largely consistent with patterns described in previous years, with substantial numbers of adult Chinook salmon holding in the tailrace of Foster Dam during summer and a substantial numbers of hatchery origin adults spawning below Foster Dam. Comparison of numbers trapped and redd counts did not reveal a clear change in pattern after completion of modifications to the Foster Dam Adult Fish Facility. Evaluations at the entrance and within the fishway revealed adult salmon frequently move into the fishway entrance, but also exit frequently and that entrance behaviors are influenced by hydraulics. Operation in the 'Open' position increased entrance rate (2016) and collection rate (2015). However, optical video observations indicated substantial milling of adults in the upper fishway channel at the base of the upper ladder. The underlying mechanisms preventing movement of adults into the fish trap remain unclear. Potential on-going factors include cooler than natural temperatures below Foster Dam and in the fishway, a gradient of cooling water temperature moving from the tailrace to the fish trap, and a fishway water source composed primarily of water from a non-natal upstream tributary (Middle Santiam River). Overall, the available data suggests entrance rates are not limiting collection of adult salmon and that the primary bottleneck is in the upper ladder. However, a key limitation of this study was the inability to track individual salmon. For instance, a relatively small number of individuals may have been responsible for high apparent event rates at the entrance and upper ladder. This limitation will be addressed in 2017 using radiotelemetry.

Foster AFF trap counts

Since the modification of the Foster AFF trap (winter 2013-2014), trap collection efficiency has been variable and apparently low, particularly for natural origin Chinook salmon, with the exception of a high trap/redd ratio in 2015 for hatchery Chinook salmon. Review of historic trap counts showed the 2016 count to have been the second lowest recorded in the last ten years. Numerous factors could be contributing to low trap apparent collection rate during summer such as poor attraction flow, natal origin effects, water temperature gradients, and olfactory cues from different water sources. In 2015, we found adult salmon collection at the AFF increased during a randomized block treatment velocity test at the main entrance, with higher collection during periods of lower velocity. However, ~100-500 fish were still routinely observed holding in the tailrace on treatment days (George Naughton, UI, *unpublished data*) which suggests that additional factors likely influenced trap collection rates.

The natal origin of adult Chinook salmon could contribute to their holding in the tailrace. The majority of hatchery fish are released ~7-23 km downstream from the dam (between Waterloo and Pleasant Valley; Brett Boyd, ODFW, *pers. comm.*) and may be unmotivated to move into the AFF trap. Ongoing research is using genetic pedigree analysis (Oregon State University and ODFW) to identify the natal location of natural origin (unclipped) fish collected in the Foster adult trap and at downstream spawning locations to test whether natal origin plays a role in trap collection efficiency.

Water temperature and chemistry

In 2016, we observed differences in absolute temperatures from different water sources, temperature gradients that occurred in the tailrace, and large temperature differences between the AFF fishway and tailrace before spill was stopped. Water temperatures in the Middle Fork Santiam (water released from Green Peter Dam) were much cooler (~8 °C), on average, than the South Fork Santiam River throughout the season. Temperature gradients were observed between the north and south shores in the Foster tailrace (2-4 °C) and large temperature differences were observed between the spill bay temperature and lower AFF ladder (6-8 °C) before spill was stopped (July 14). Temperature differences were likely the result of warm water in the upper part of the reservoir from the South Fork Santiam River and cooler water in the lower part of the reservoir that sourced into the fishway from the Middle Fork Santiam River. Once spill stopped, differences between the tailrace and fishway were generally one degree or less.

The influence of different upstream water sources was also evident in the water chemistry results. Differences between the fishway and tailrace were observed for pH, dissolved oxygen, and dissolved oxygen percent with values in the fishway being higher than those in the tailrace.

Fish Behavior

Based on DIDSON data review, the majority of adult fish moved during the day. Although only a small portion of the DIDSON night-time dataset was reviewed (5-10%) few fish were observed moving at night. This is not an uncommon behavior as it has been reported in many research studies that the majority of adult salmon pass dams during the day and rarely at night (Gowans et al. 2003; Naughton et al. 2005; Brown et al. 2006; Keefer et al. 2013). Rates of movement at the optical video camera sites occurred throughout the day with higher movement (upstream and downstream) observed at the upstream channel site in the early evening hours.

The higher rate of movement late in the day may be due to avoid moving at night or possibly due to more variable light conditions in the fishway.

Similar to the results we observed in 2015, when adult collection at the AFF trap was higher during the lower velocity ‘Open’ treatment, we observed generally higher rates of fish movement during the ‘Open’ treatment (experimental period) in 2016. At the main AFF entrance, higher rates of entry and less holding occurred during the lower velocity (‘Open’) treatment; higher AFF exit rates into the tailrace also occurred (Table 11). For instance, the observed entrance rates suggest that ~192-576 adults would enter over a twelve hour period each day during the ‘Auto’ and ‘Open’ conditions in 2016, respectively (Table 6). Assuming a majority of these adults were collected in the trap and each adult only entered once/day, the number of adults holding the tailrace would be expected to decline rapidly, as daily collection rates would be approximately one to several hundred per day. While this simple calculation suggests entrance rate may not be the primary factor limiting collection rate, the average event rate/salmon remains unknown, but will be estimated using radiotelemetry during 2017. Regardless, the experiment provided evidence of a benefit to the ‘Open’ operation.

Table 11. Summary of fish behavior and treatment during the experimental period of presumed adult Chinook salmon as assessed by DIDSON and Optical video in 2016.

	Fishway treatment	
	Auto	Open
DIDSON	Higher holding (day & night)	Higher entry rate (day & night) Higher exit rate (day & night) Higher rejection rate (night)
Optical-Turnpool		
Optical-Downstream	Higher downstream movement (day)	
Optical-Upstream		Higher holding (day) Higher upstream movement (day)

Several lines of evidence suggest passage bottleneck(s) upstream of the entrance induced milling and/or return to the tailrace, thus contributing to the observed tailrace holding. In particular, high movement rates at the upstream channel location indicated frequent holding and milling near the monitoring site and/or movement to the site followed by frequent downstream movement. Differences in movement rates within the fishway between entrance operation treatments suggested movement back and forth to the tailrace contributed at least in part to these patterns because the treatment at the entrance was unlikely to affect adults once in the weir-and-pool section of the fish ladder and upper fishway. In the optical data, no differences were observed between treatments at the turnpool, while less downstream movement occurred at the downstream channel site during the ‘Open’ treatment. At the upstream channel site, higher rates of upstream movement were observed during the lower velocities (‘Open’), but higher rates of holding were also observed, further suggesting a bottleneck associated with the upper ladder/trap entrance. We also found that fish behaved similarly during the ad hoc ‘Open’ trial weir gate setting, which indicated that fish responded to this lower water velocity regardless of time of year or other potential covariates (e.g. temperature, water chemistry, spill, etc.).

In evaluating fish behavior in relation to environmental variables other than trap operation, we did not find a definitive answer for low trap collection efficiency. Although we found some statistically significant negative correlations between water temperature and fish behavior, the difference in temperature scale was quite small (~1 °C) and the range of temperatures (11-12 °C) was well within the preferred range of Chinook salmon (Richter and Kolmes 2005). Importantly, we may have observed larger fish responses to the gradient in water temperatures if the camera studies (DIDSON and optical video) were initiated before spill was stopped; the period of large AFF-tailrace temperature gradients occurred through 14 July.

Future studies

In 2017, further research studies have been proposed to better assess the Foster AFF low trap collection efficiency. Plans have been implemented to radio/PIT tag adult Chinook salmon at Lebanon Dam in the South Santiam River so that their behaviors can be monitored in the Foster tailrace and both in and near the Foster AFF. Behavior of tagged fish will be used to estimate two key metrics requiring individually monitored salmon: 1) overall collection efficiency rate of the Foster Dam AFF, and 2) individual movement rates and passage time through the fishway. Continuation of water temperature and chemistry studies is also planned.

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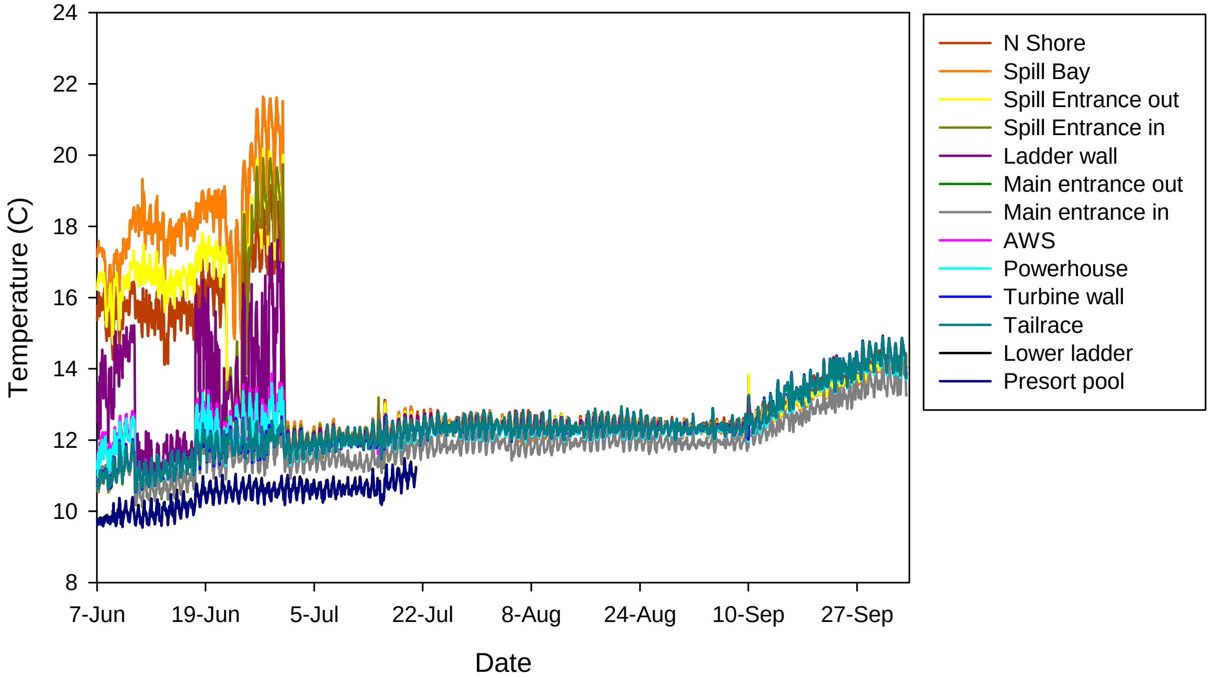
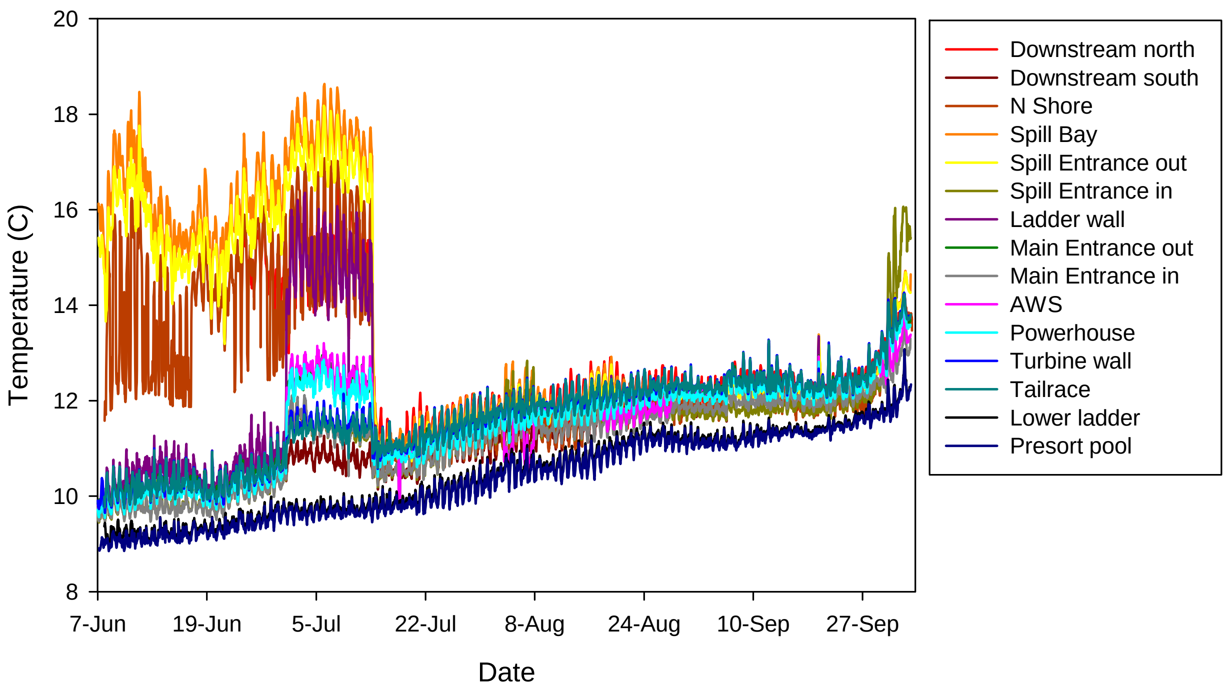
Appendix



.Appendix Figure 1. Foster AFF ladder and tailrace hourly water temperatures in 2015.



Appendix Figure 2. Foster AFF ladder and tailrace hourly water temperatures in 2016.