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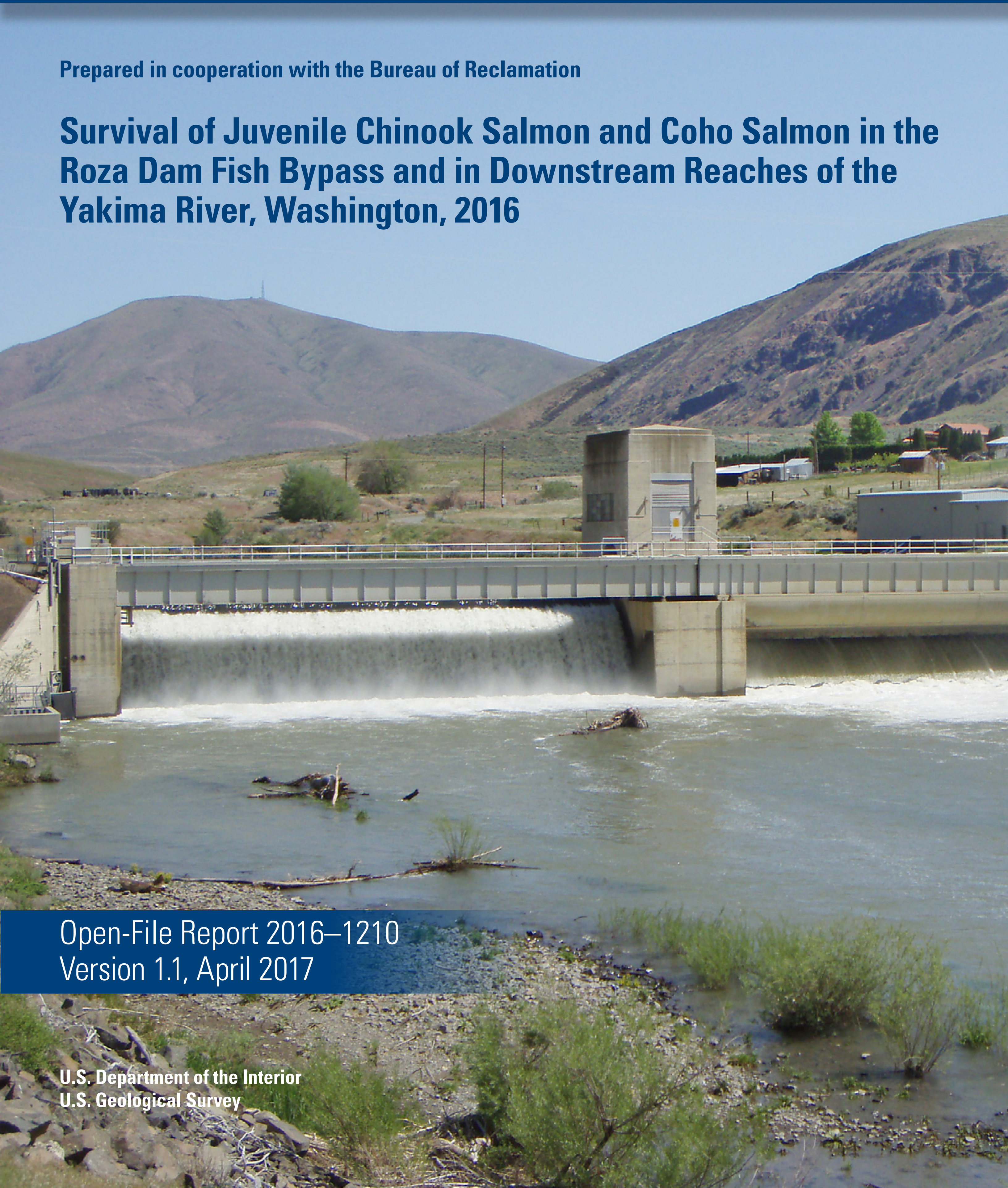
Survival of Juvenile Chinook Salmon and Coho Salmon in the Roza Dam Fish Bypass and in Downstream Reaches of the Yakima River, Washington, 2016



Open-File Report 2016–1210
Version 1.1, April 2017

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph showing Roza Dam on the Yakima River, Washington.
Photograph by Toby Kock, U.S. Geological Survey, May 18, 2012.

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

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Executive Summary

Estimates of juvenile salmon survival are important data for fishery managers in the Yakima River Basin. Radiotelemetry studies during 2012–14 showed that tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*) that passed through the fish bypass at Roza Dam had lower survival than fish that passed through other routes at the dam. That study also identified flow-survival relationships in the reaches between the Roza Dam tailrace and Sunnyside Dam. During 2012–14, survival also was estimated through reaches downstream of Sunnyside Dam, but generally, sample sizes were low and the estimates were imprecise. In 2016, we conducted an evaluation using acoustic cameras and acoustic telemetry to build on information collected during the previous study. The goal of the 2016 research was to identify areas where mortality occurs in the fish bypass at Roza Dam, and to estimate reach-specific survival in reaches downstream of the dam. The 2016 study included juvenile Chinook salmon and coho salmon (*O. kisutch*).

Three acoustic cameras were used to observe fish behavior (1) near the entrances to the fish bypass, (2) at a midway point in the fish bypass (convergence vault), and (3) at the bypass outfall. In total, 504 hours of acoustic camera footage was collected at these locations. We determined that smolt-sized fish (95–170 millimeters [mm]) were present in the highest proportions at each location, but predator-sized fish (greater than 250 mm) also were present at each site. Fish presence generally peaked during nighttime hours and crepuscular periods, and was low during daytime hours. In the convergence vault, smolt-sized fish exhibited holding behavior patterns, which may explain why some fish delayed while passing through the bypass.

Some of the acoustic-tagged fish were delayed in the fish bypass following release, but there was no evidence to suggest that they experienced higher mortality than fish that were released at the bypass outfall or downstream of the dam. Most of the tagged fish that were released in the fish bypass moved downstream and re-entered the river within 12 hours, but 9.8 percent of the Chinook salmon and 15.7 percent of the coho salmon remained in the bypass for 2.5–17.4 days. We developed a set of models for Chinook salmon and coho salmon and used model selection to determine if release site was an important predictor of survival of tagged fish. The models that provided the best fit to the Chinook salmon and coho salmon datasets did not include release site as a covariate. Furthermore, survival estimates for groups of fish from the various release sites were nearly identical for both species. Based on these observations, it appears that passage through the fish bypass did not result in increased mortality relative to groups of fish released downstream of the bypass.

Juvenile Chinook salmon migrated downstream faster than juvenile coho salmon and survival for each species varied with release timing. Median travel time from release at Roza Dam to arrival at a detection gate located at river kilometer (rkm) 527.8 on the Columbia River was 15.4 days for Chinook salmon and 37.4 days for coho salmon. Cumulative survival from Roza Dam to the Columbia River detection gate ranged from 0.299 to 0.678 for Chinook salmon, and from 0.321 to 0.627 for coho salmon. Survival was highest for both species when tagged fish were released in mid-April and lowest when tagged fish were released in early-May. Reach-specific survival estimates were standardized to create estimates that described survival per 100 rkm, which showed that survival was very low (less than 0.500) for some release groups, particularly in the Roza, Sunnyside, and Chandler diversion reaches. A more extensive analysis of reach-specific survival is planned for this dataset, which should provide insights into covariates that affected survival during 2016.

Introduction

The Yakima River Basin includes a series of reservoirs, dams, diversion canals, and tributary streams that are tightly regulated to support irrigation, hydropower, and fisheries interests. Dams and diversion canals use river water to support agriculture and generate electricity in the basin, but this can negatively affect Pacific salmon (*Oncorhynchus* spp.) populations. Empirical data on factors that affect survival of juvenile salmonids are coveted by resource managers who can use this data to enhance fish populations. A multi-year telemetry evaluation was done during 2012–14 at Roza Dam, and in downstream reaches, which provided a substantial amount of information on juvenile Chinook salmon (*O. tshawytscha*) survival (Courter and others, 2015; 2016; Perry and others, 2016). Perry and others (2016) determined that direct mortality occurred as fish passed through Roza Dam, and indirect mortality was documented as fish passed through the Roza reach. This study also determined that survival was lowest for fish that passed through the fish bypass and some tagged fish were delayed while passing through that route (Perry and others, 2016). More than one-third of the tagged Chinook salmon that entered the fish bypass spent two or more days in the structure (Courter and others, 2015; fig. 1). In downstream reaches, Courter and others (2016) estimated migration survival (from the Roza Dam tailrace to the mouth of the Yakima River) and determined that increasing flow resulted in increased survival in two upstream reaches, whereas flow increases failed to improve survival in two downstream reaches. However, an earlier study by Pyper and Smith (2005) showed that flow increases resulted in improved survival of juvenile fall Chinook salmon and coho salmon (*O. kisutch*) throughout the lower Yakima River.

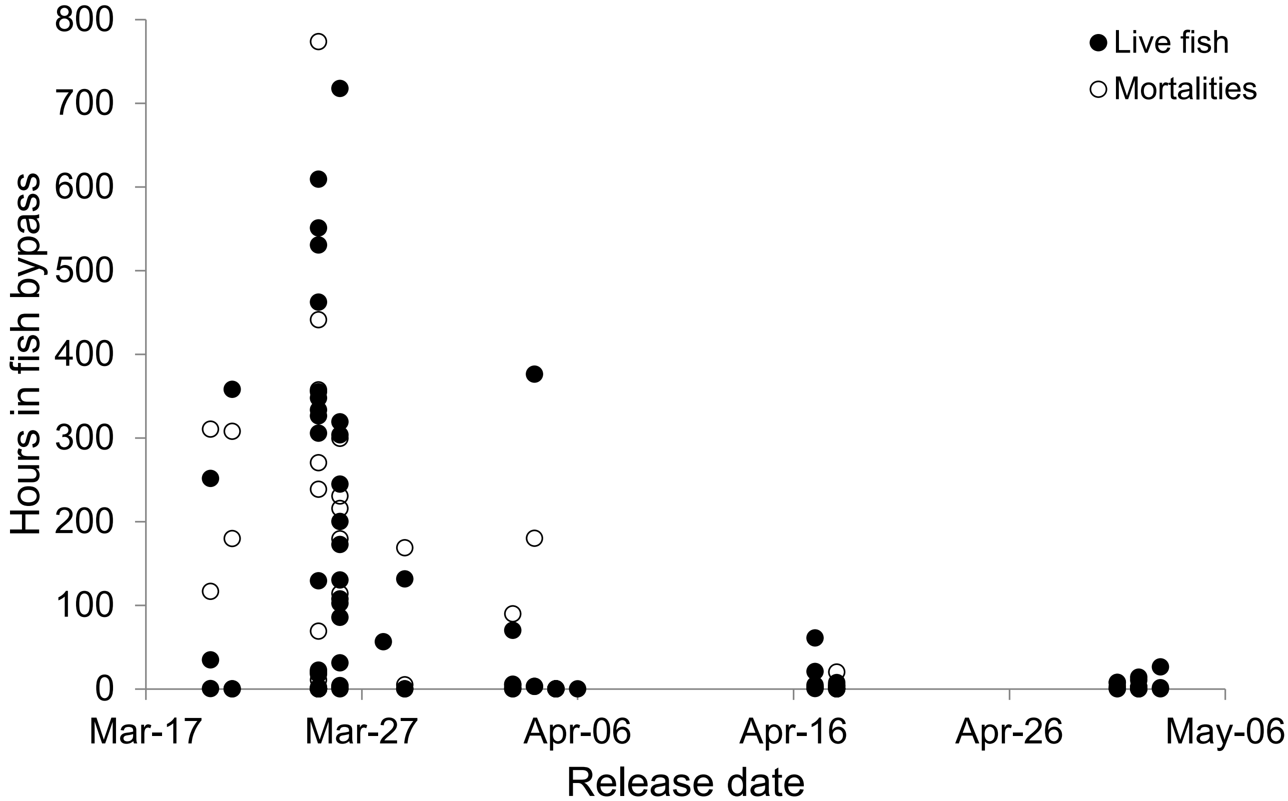

Figure 1. Graph showing residence times for radio-tagged juvenile Chinook salmon in the fish bypass at Roza Dam, Yakima River, Washington, 2013–14. Data are shown for fish that survived and moved downstream through the study area (live fish) and for fish that were presumed dead (mortalities) based on a lack of downstream detections.

Research during 2012–14 identified factors that affected salmon survival in the Yakima River; however, the error associated with survival estimates confounded the interpretation of the effects. Perry and others (2016) showed that passage survival and delay in the fish bypass were problematic, but sample sizes of tagged fish passing through the structure were lowest among passage routes at the dam: 19 (124 fish) percent of the tagged fish that passed Roza Dam used the fish bypass, whereas 30 percent (198 fish) used the east gate and 51 percent (338 fish) used the west gate (Courter and others, 2015). Consequently, the confidence intervals of survival estimates through the fish bypass were relatively large, and additional research was deemed necessary to better assess fish behavior and survival in the structure (Perry and others, 2016). Passage mortality has been documented in bypass systems at main stem dams on the Columbia and Snake Rivers, where factors such as migration delay, stress, and the concentrating effects of predators near outfall locations have been attributed to decreased survival (Muir and others, 2001; Budy and others, 2002; Ferguson and others, 2007). These findings are important because bypass systems are designed to provide safe and efficient passage routes for juvenile salmon at dams. The 2012–14 study was designed to focus on behavior and survival at Roza Dam and in the Roza reach, so sample sizes in reaches downstream of this focal area often were low (15 fish or less per group) as migration mortality occurred in the system (Courter and others, 2016). Thus, survival estimates in downstream reaches were imprecise and future evaluations were recommended to better estimate mortality rates in these reaches. We designed a study for 2016 to address specific questions at Roza Dam and in downstream reaches of the lower Yakima River. Our objectives were to evaluate the survival of juvenile salmon in the fish bypass at Roza Dam and in eight reaches downstream of the dam.

Study Area

Our study began at Roza Dam, and extended downstream 200 river kilometers (rkms), which included the main stem Yakima and Columbia Rivers (fig. 2). At Roza Dam, acoustic telemetry and acoustic cameras were used to evaluate fish behavior and survival in the fish bypass and at the bypass outfall (see section, “Monitoring Techniques”). Roza Dam is a major water diversion and the fish bypass was designed to remove fish from the diverted water and return them to the river, downstream of the dam. Fish enter the bypass through one of five entrances, and each entrance transports fish downstream through an underground pipe. The total volume of water passing through the five pipes is about 260 cubic feet per second (ft^3/s). The pipes then converge and surface, at a location hereinafter referred to as the “convergence vault,” where most of the water (220 ft^3/s) is passed through screens and returned to the river (fig. 3). Fish and the remaining water (40 ft^3/s) are then transported downstream through an underground pipe and are returned to the river, 0.17 rkm downstream of Roza Dam (fig. 3).

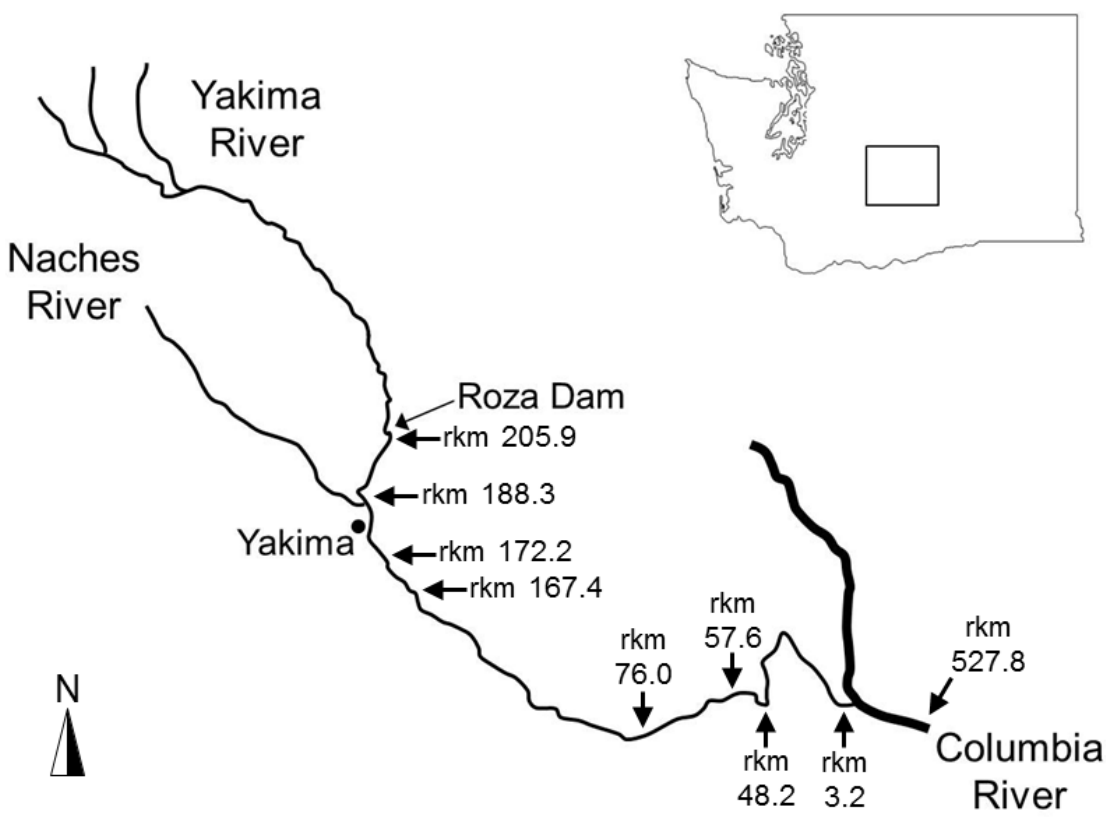

Figure 2. Schematic showing locations of acoustic telemetry monitoring sites used to detect tagged Chinook salmon and coho salmon in the Yakima River Basin, Washington, 2016.

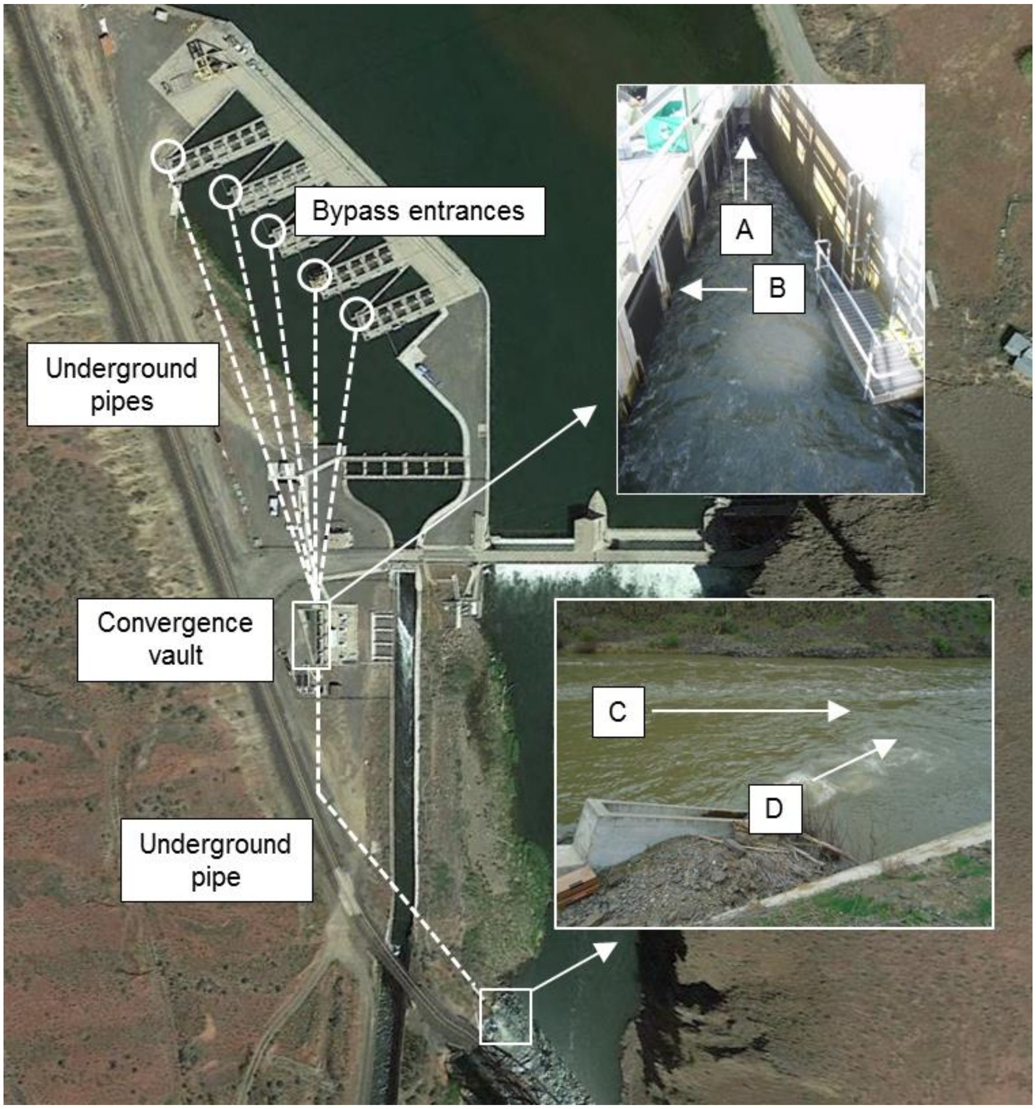

Figure 3. Photographs showing Roza Dam, the convergence vault (inset top), and the bypass outfall (inset bottom), Yakima River, Washington. The photograph of the convergence vault shows the direction of movement for fish and approximately 15 percent of the bypass flow (A) and the direction of movement for the remaining 85 percent of the bypass flow (B) where screening occurs. The photograph of the bypass outfall shows the direction of flow for the main stem Yakima River (C) and the outfall flow (D).

In the main stem Yakima and Columbia Rivers, acoustic telemetry was used to evaluate fish behavior and survival (see section, “Monitoring Techniques”). We divided the rivers into a series of reaches to determine if there were behavior and survival differences in various regions of our study area (tables 1–2). Reach lengths varied from 4.8 to 91.4 rkm because monitoring site locations were selected based on key geographical features in the study area. Reaches monitored in this study differed slightly from those that were monitored by Courter and others (2016). The first reach (Roza reach) began at Roza Dam (rkm 205.9) and extended downstream to the mouth of the Naches River (rkm 188.3; fig. 2). The second reach (Wapato reach) began at the mouth of the Naches River and ended just upstream of Wapato Dam (rkm 172.2). The third reach (Sunnyside reach) began upstream of Wapato Dam and ended just upstream of Sunnyside Dam (rkm 167.4). The fourth reach (Prosser reach) began just upstream of Sunnyside Dam and extended downstream to Prosser Dam (rkm 76.0). The fifth reach (Chandler diversion reach) began just upstream of Prosser Dam and extended downstream to the Chandler diversion outfall (rkm 57.6). The sixth reach (Benton City reach) began at the Chandler diversion outfall and ended at Benton City (rkm 48.2). The seventh reach (Richland reach) began at Benton City and extended downstream to Richland, Washington, near the mouth of the Yakima River (rkm 3.2). Finally, the eighth reach began near the mouth of the Yakima River and extended downstream to rkm 527.8 on the Columbia River. Data collection in this reach was possible because sites in the Columbia River were established and maintained by a consulting firm, Blue Leaf Environmental, Inc., for a study funded by the Grant County Public Utility District.

Table 1. Locations of acoustic telemetry detection gates and number of acoustic receivers present at each gate, Yakima and Columbia Rivers, Washington.

[rkm, river kilometer]

Detection gate description	Location (rkm)	Number of acoustic receivers
Roza Dam fish bypass outfall	205.9	2
River Ridge golf course upstream of Naches River mouth	188.3	3
Interstate 82 bridge upstream of Wapato Dam	172.2	3
Parker bridge upstream of Sunnyside Dam	167.4	3
Prosser bridge upstream of Prosser Dam	76.0	4
Chandler canal downstream of Prosser Dam	75.0	3
Chandler outfall	57.6	2
First street bridge in Benton City	48.2	2
Railroad bridge upstream of the Yakima River mouth	3.2	3
Main stem Columbia River	527.8	4

Table 2. Descriptions of reaches on the Yakima River where survival was estimated for juvenile salmon in the Yakima and Columbia Rivers, Washington, 2016.

[Starting locations, ending locations, and reach lengths are in river kilometers (rkms). The ending location for the Columbia reach refers to the river kilometer location on the Columbia River and all other references are to locations on the Yakima River]

Reach No.	Reach name	Starting location (rkm)	Ending location (rkm)	Length (rkm)
1	Roza reach	205.9	188.3	17.6
2	Wapato reach	188.3	172.2	16.1
3	Sunnyside reach	172.2	167.4	4.8
4	Prosser reach	167.4	76.0	91.4
5	Chandler diversion reach	76.0	57.6	18.3
6	Benton City reach	57.6	48.2	9.4
7	Richland reach	48.2	3.2	45.0
8	Columbia reach	3.2	527.8	14.4

Monitoring Techniques

Acoustic telemetry and acoustic cameras were used to monitor juvenile salmon during the study. The juvenile salmon acoustic telemetry system (JSATS; McMichael and others, 2010) was used to monitor tagged juvenile salmon. Autonomous JSATS hydrophone/receiver combinations (hereafter receivers; Model SR5000; Advanced Telemetry Systems, Inc., Asanti, Minnesota) were deployed at our monitoring sites and consisted of three components: (1) a hydrophone mounted underwater, (2) a receiver housed above the surface where data could be downloaded, and (3) a cable that connected the hydrophone to the receiver. We installed multiple receivers at each detection gate to maximize detection probabilities (table 1). The acoustic transmitters (Model SS300; Advanced Telemetry Systems, Inc., Asanti, Minnesota) were 10.7 millimeters (mm) long, 5.0 mm wide, 2.8 mm tall, and weighed 0.38 gram (g) in air. The receivers operated at a pulse rate interval of 3.0 seconds and had an estimated operating life of 48 days.

The actual operating life of the transmitters was empirically determined in a laboratory evaluation at the Columbia River Research Laboratory in Cook, Washington. Twenty-one acoustic transmitters were removed from the batch of transmitters that was available for tagging and activated on May 19, 2016. Transmitters were placed into a 1.8-meter (m) circular fiberglass tank that was filled with temperature-controlled water to simulate Yakima River water temperatures during the study period. A single receiver monitored the transmitters until they all stopped functioning. The experiment was terminated on July 15, 2016. The primary goal of the taglife study was to determine the 90th percentile of the taglife for transmitters in the study. This information was then used to truncate telemetry detection records during the data proofing process (see section, “Data Analysis”).

Three acoustic cameras were used to observe fish behavior in the fish bypass and near the bypass outfall. Two of the cameras (Model ARIS® and Model DIDSON®; Sound Metrics Corporation, Bellevue, Washington) operated at 1.8 megahertz (MHz), had a maximum imaging range of 15 m, and beam widths of 29 and 30 degrees, respectively. The third camera (Model P900®; Teledyne BlueView, Inc.; Bothell, Washington) operated at a lower frequency (0.9 mHz), had a maximum imaging range of 100 m, and a beam width of 130 degrees. The ARIS® camera was used in the entrance bays, the DIDSON® camera was used in the convergence vault and at the bypass outfall, and the P900 camera was used at the bypass outfall (fig. 4, table 3). The acoustic cameras were used to observe fish behavior inside the fish bypass and at the bypass outfall, and to describe fish size distributions at these locations.

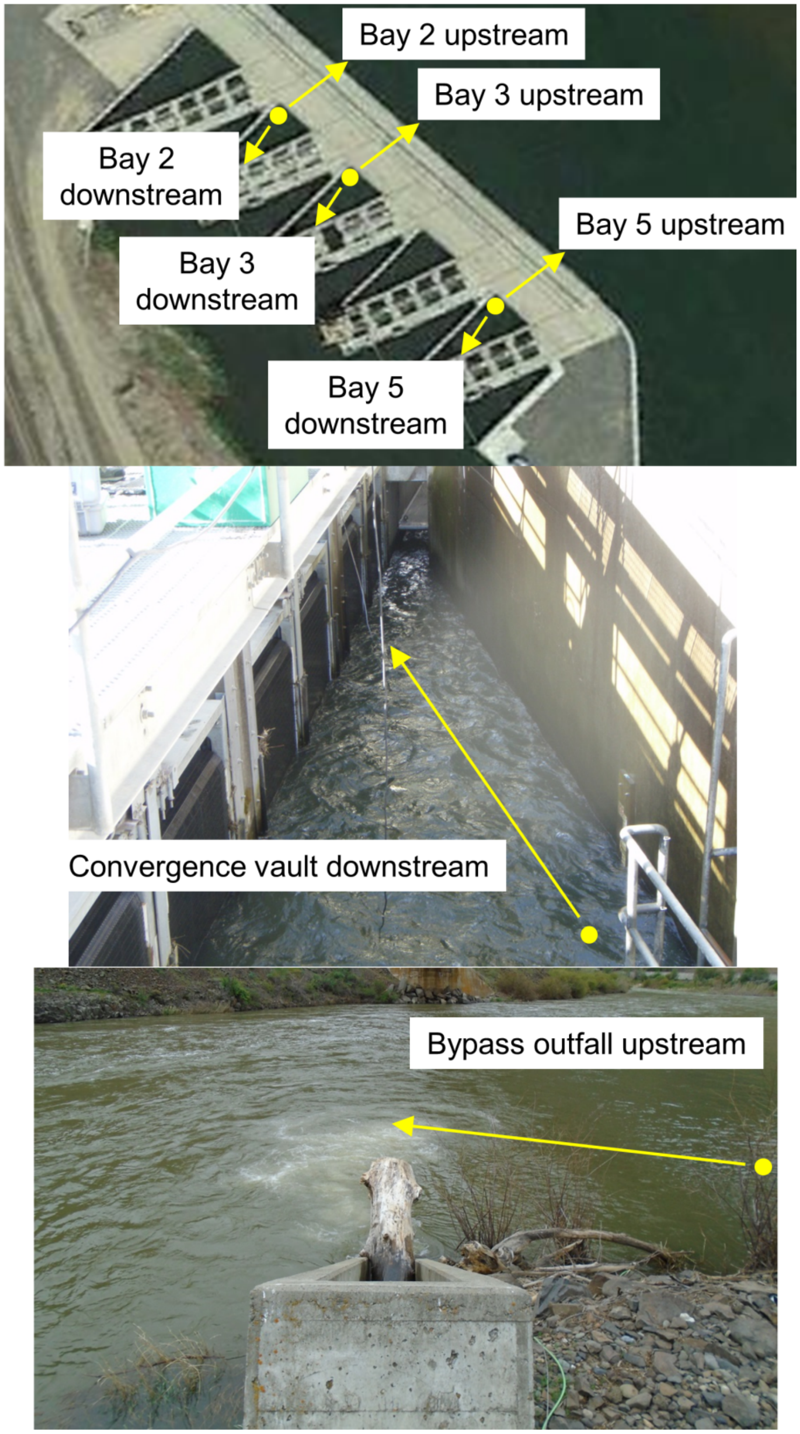

Figure 4. Photographs showing acoustic camera sampling sites at the bypass entrance bays, in the convergence vault, and at the bypass outfall, Roza Dam, Yakima River, Washington. Circles show the location of the camera and arrows show the direction of the field-of-view.

Table 3. Sampling sites, sample dates, and hours of video footage collected with acoustic cameras in the fish bypass and at the bypass outfall, Yakima River, Washington.

Acoustic camera	Location	Start date	End date	Hours of footage
ARIS®	Bay 2 upstream	April 12, 2016	April 13, 2016	27
	Bay 2 downstream	April 13, 2016	April 14, 2016	25
	Bay 2 upstream	April 14, 2016	April 15, 2016	22
	Bay 2 downstream	April 15, 2016	April 16, 2016	18
	Bay 5 upstream	April 19, 2016	April 20, 2016	24
	Bay 5 downstream	April 20, 2016	April 21, 2016	23
	Bay 5 upstream	April 21, 2016	April 23, 2016	40
	Bay 3 upstream	April 27, 2016	April 28, 2016	24
	Bay 3 downstream	April 28, 2016	April 29, 2016	26
DIDSON®	Convergence vault	April 12, 2016	April 16, 2016	90
	Convergence vault	April 19, 2016	April 23, 2016	87
	Convergence vault	April 27, 2016	April 28, 2016	25
	Bypass outfall	April 28, 2016	April 29, 2016	17
P900®	Bypass outfall	April 14, 2016	April 15, 2016	14
	Bypass outfall	April 20, 2016	April 22, 2016	42

Fish Collection, Tagging, and Release

Juvenile Chinook salmon and coho salmon were collected for tagging in the downstream migrant trap in the Roza Dam fish bypass. The trap is operated on weekdays during March–June each year. On each collection date, juvenile hatchery-reared Chinook salmon and coho salmon were removed from the trap and placed into holding troughs where they were held for about 24 hours prior to tagging. On each tagging date, fish were removed from the holding troughs and surgically tagged with an acoustic transmitter and passive-integrated transponder (PIT-tag; Model HDX 12; Biomark, Inc., Boise, Idaho) using methods described by Liedtke and others (2012). Tagged fish were then transferred into floating 18.9-liter plastic containers (maximum of five Chinook salmon per container; maximum of four coho salmon per container) and placed into a holding tank where they were held for at least 16 hours to monitor for short-term mortality.

Tagged fish were released into entrance bays of the fish bypass, into the convergence vault, at the bypass outfall, and downstream of the bypass outfall during daytime and nighttime periods to expose fish to a variety of bypass conditions (fig. 5). Fish that were released into the bypass entrances were exposed to passage through the entire fish bypass. Fish that were released into the convergence vault were exposed to passage through the lower one-half of the fish bypass. Fish released at the bypass outfall did not have to pass through the fish bypass but were exposed to the outfall location, an area where piscivorous predators are known to congregate (Mark Johnston, Yakima Nation Fisheries, oral commun., March 2016). Finally, fish were released directly into the Yakima River approximately 0.15 kilometer (km) downstream of the bypass outfall. Fish released at this location were not exposed to passage through the fish bypass or to areas of known predator concentrations near Roza Dam. In some cases, it was necessary to stratify releases at a given area: groups of tagged fish that were released at the bypass entrances were split evenly to ensure that tagged fish were introduced into the fish bypass through each entrance; at the bypass outfall groups of tagged fish were split evenly between releases on the upstream and downstream sides of the outfall; and the downstream release groups were split evenly between the west bank and east bank of the Yakima River (fig. 5). Release periods also were split between nighttime and daytime hours.

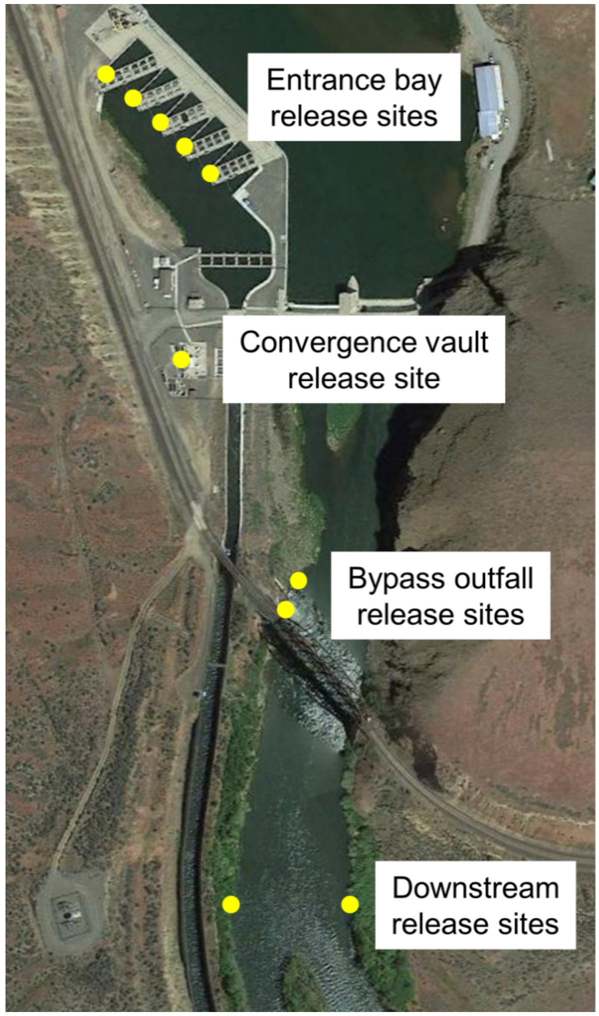

Figure 5. Aerial photograph showing release site locations (circles) for acoustic-tagged juvenile Chinook salmon and coho salmon at Roza Dam, Washington, 2016.

Data Analysis

A large amount of data were collected with the acoustic cameras and many fish had long residence times in the field-of-view so we subsampled the footage to quantify fish presence and describe size distributions. The acoustic camera footage was used to qualitatively evaluate fish presence and behavior, and to determine if smolt- and predator-sized fish were present at key locations in the bypass. Thus, short video clips that were randomly selected were analyzed to determine if fish were present and to describe size distributions of fish that were observed. For acoustic camera data analysis, we identified three groups of fish that included small fish (80–120 mm long), smolt-sized fish (95–170 mm long), and predator-sized fish (greater than 250 mm long). For the entrance bay footage, we randomly selected a two-minute clip from every hour within a 24-hour period in each of the three entrance bays where samples were collected. The same subsampling routine was used for footage from the convergence vault. Fish had shorter residence times at the bypass outfall and fewer fish were observed at that location, so all the footage from that location was processed without sub-sampling.

Acoustic telemetry data records were processed to remove false-positive detection events prior to analyzing fish movement data. False-positive records indicate detection of a transmitter when the transmitter was not present, and are common in most active telemetry systems (Beeman and Perry, 2012). We used a procedure developed by the Pacific Northwest National Laboratory (Mark Weiland, Pacific Northwest National Laboratory, written commun., June 17, 2010) to remove false-positive records. This procedure removed records if (1) the detection record was from a tag code that was not released during the study; (2) the record matched criteria that indicated the detection likely resulted from reflections of valid tag signals (multipath); (3) the detection record did not match a multiple of the tag pulse interval; or (4) the record was not followed by at least three valid records on each receiver (McMichael and others, 2010). The 90th percentile of the transmitter operating life, as measured in the taglife study, then was used to truncate detection records of individual fish. Any records that occurred beyond the 90th percentile of the transmitter operating life were removed from the dataset.

A final dataset was created by merging telemetry detection records with PIT-tag detection records. The final telemetry dataset was developed by removing false-positive records from the preliminary telemetry dataset. A final PIT-tag dataset was created by querying the Columbia Basin PIT Tag Information System (PTAGIS) Web site (http://www.ptagis.org) for detection events of tagged fish at PIT tag sites in the Yakima and Columbia Rivers. These monitoring sites included antennas at Roza Dam and Prosser Dam on the Yakima River, and at McNary Dam, John Day Dam, Bonneville Dam, and in the PIT-tag trawls near the estuary on the Columbia River. The tagging and release data, final telemetry dataset, and PIT tag detection records were then merged and sorted chronologically for each fish in the study. The final dataset was then queried to summarize fish detections at specific sites in the study area. These summaries were used to describe movement patterns of tagged fish and to create capture histories that were analyzed using mark-recapture survival models.

Capture histories were short numeric (3 or 10 digits) strings that represented whether fish were detected (1) or undetected (0) at monitoring sites in the study area. Three-digit capture histories were used for the analysis of survival through the fish bypass and 10-digit capture histories were used for the analysis of reach-specific survival. Each fish's capture history began with a 1 to represent release at Roza Dam and subsequent locations in the capture history represented detection or non-detection at the following locations: (1) Naches River mouth, (2) Wapato Dam, (3) Sunnyside Dam, (4) Prosser Dam, (5) Chandler outfall, (6) Benton City, (7) Yakima River mouth, (8) rkm 527.8 on the Columbia River, and (9) at least one of the PIT tag antennas located at McNary Dam, John Day Dam, Bonneville Dam, or on one of the estuary trawls. As an example, the capture history 1101100000, indicated that a fish was released at Roza Dam, detected at the Naches River mouth, not detected at Wapato Dam, detected at Sunnyside Dam, detected at Prosser Dam, and not detected at any sites downstream of Prosser Dam. Ten-digit capture histories included release as the first character in the string along with detection or non-detection at each of the nine sites previously described. Three-digit capture histories included release as the first character in the string, detection or non-detection at the Naches River mouth as the second character in the string, and detection or non-detection on all sites downstream of the Naches River mouth (pooled) for the third character in the string.

Data were analyzed within the framework of a Cormack-Jolly-Seber (Cormack. 1964; Jolly. 1965; Seber. 1965 [CJS]) model using the RMark package (Laake, 2013), which calls program MARK (White, 1999) from within R (R Core Team, 2013). The effects of several covariates were examined including release site (entrance bays; convergence vault; bypass outfall; downstream), release week (April 10; April 17; April 24; May 8) and fork length (continuous variable). To examine the effects of these variables we created a set of candidate models and compared their fit to the data using Akaike's Information Criterion, with an adjustment for effects of sample size (AIC_C; Burnham and Anderson, 2002). In this approach, the best-fitting model is the one that has the lowest AIC_C value. Selection of the best-fitting CJS model generally involves a two-step process. The first step in the process involves identifying the best-fitting model for detection probability parameters. The second step in the process uses the best-fitting detection probability model to identify the best-fitting model for survival probability parameters. Parameter estimates for detection and survival probabilities are then obtained from the best-fitting model identified in the second step of the process. We completed this process separately for Chinook salmon and coho salmon datasets.

Survival and Delay in the Fish Bypass

A set of candidate models was developed to determine if there were differences in survival between groups of fish released in the fish bypass and groups released at the bypass outfall or downstream of the bypass outfall. This analysis was used to determine if passage through the fish bypass resulted in increased mortality of tagged fish. For Chinook salmon, we developed two models to assess detection probability and seven models to assess survival probability. The first of the detection probability models included release week and detection site, whereas the second model included only detection site. The first survival model did not include any covariates, and the next two models included one covariate each, release week and release site. Two additional models were created by adding fork length to each of the models with release week or release site. Finally, the last two models included release week and release site together: one model allowed the two covariates to vary independently (release site x release week) and the other model constrained them to interact additively (release site + release week).

Detection probabilities for coho salmon were 1.0 on the pooled monitoring sites downstream of the Naches River mouth; therefore, detection probabilities on those sites were fixed to 1 during the modeling process. This reduced the number of covariates that could be incorporated into the detection probability models for coho salmon. Consequently, detection probability models for coho salmon included a model with release week and a model with no covariates. The seven coho salmon models that assessed survival probability were identical to those used for Chinook salmon data.

Travel time and migration delay in the fish bypass were assessed using tagged fish that were released at the entrance bays and the convergence vault. We calculated residence times in the fish bypass for all tagged fish that were detected at the bypass outfall after being released at one of the two upstream release sites. Residence times were calculated by subtracting the release date and time of each fish from the first detection date and time of each fish at the bypass outfall.

Travel Times and Survival in the Yakima River

Reach-specific travel times were calculated for individual tagged fish downstream of Roza Dam. Travel times through each reach were calculated by subtracting the date and time of the first detection event of each tagged fish at the upstream site of a given reach from the date and time of the first detection event at the downstream site in that same reach. Median travel time (by species) were then calculated for each reach.

We used a fully parameterized CJS model to estimate reach-specific survival of juvenile Chinook salmon and coho salmon downstream of Roza Dam. The 10-digit capture histories were used to provide detection information at each detection gate. The fully parameterized models allowed detection probability and survival probability to vary by release week and detection site. Reach lengths varied substantially, so we calculated standardized survival estimates that described survival per 100 rkm. To do this, we used the following equation:

$$S_{Si} = Si^{\,(100/li)} \tag{1}$$

where

S_S	is standardized survival estimate of reach i;
S	is survival estimate of reach i; and
l	is length of reach i.

Results

Fish Tagging and Release

A total of 549 juvenile Chinook salmon and 260 juvenile coho salmon were tagged during the study. Two of the Chinook salmon (0.4 percent) and two of the coho salmon (0.8 percent) died during the post-tagging holding period. A small number of the tagged fish (6 Chinook salmon; 2 coho salmon) were sacrificed and then released to provide information on downstream drift of dead fish within the study area. The remaining tagged fish (541 Chinook salmon; 256 coho salmon) were released alive and monitored as they moved downstream. Releases were stratified by location and period (daytime and nighttime) and numbers were generally similar between groups (table 4). Juvenile Chinook salmon that were tagged had a mean fork length of 125.9 centimeters (cm) (standard deviation = 9.7 cm), a mean weight of 20.5 g (standard deviation = 5.1 g), and a mean tag burden of 2.5 percent (tag weight/body weight; standard deviation = 0.6 percent). Juvenile coho salmon were slightly larger and had a mean fork length of 142.4 cm (standard deviation = 10.6 cm), a mean weight of 28.1 g (standard deviation = 6.2 g), and a mean tag burden of 1.8 percent (standard deviation = 0.4 percent). Releases occurred during four periods from mid-April to mid-May and included the weeks of April 10, April 17, April 24 and May 8, 2016 (fig. 6).

Table 4. Number of Chinook salmon and coho salmon that were tagged and released at each release location at Roza Dam, Yakima River Basin, Washington, 2016.

[Light, daytime hours; Dark, nighttime hours]

Species	Period	Entrance bays						Vault	Outfall	Downstream
		1	2	3	4	5	Total			
Chinook	Light	19	14	16	16	15	80	72	67	69
	Dark	12	14	14	15	12	67	63	64	59
	Totals	31	28	30	31	27	147	135	131	128
Coho	Light	9	7	12	7	5	40	31	38	23
	Dark	5	7	3	7	9	31	40	25	28
	Totals	14	14	15	14	14	71	71	63	51

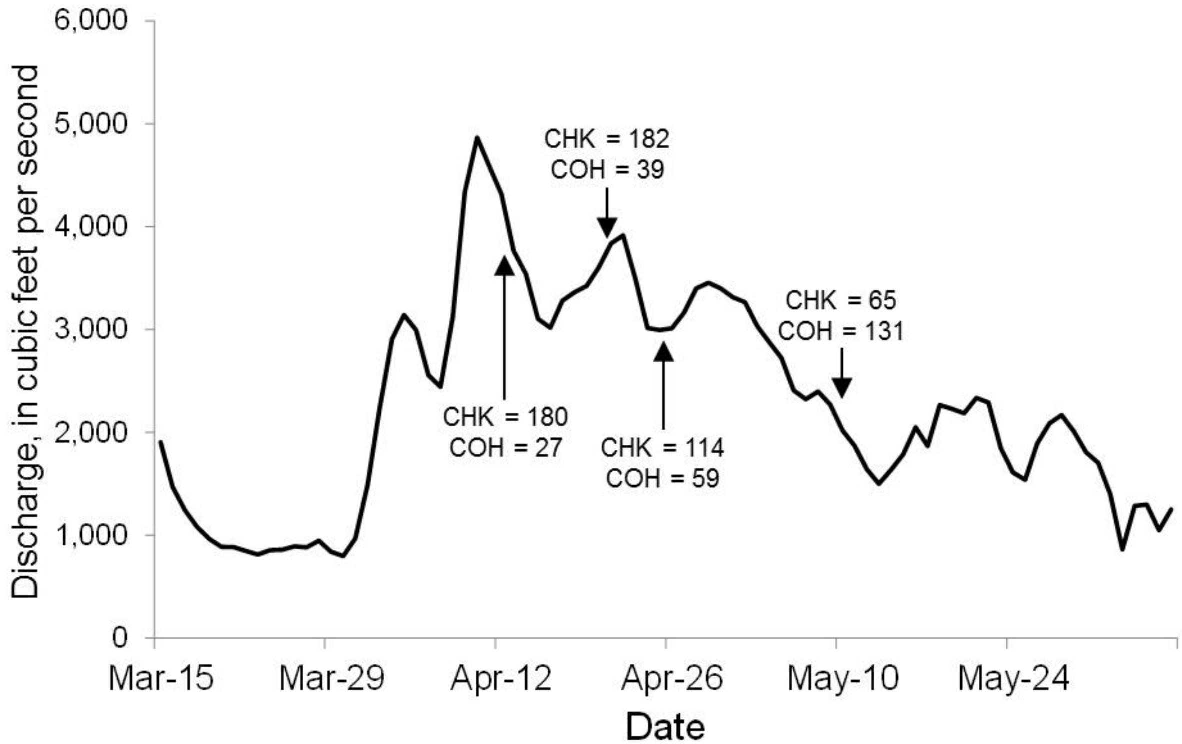

Figure 6. Graph showing discharge, date of fish releases (indicated by arrows), and number of Chinook salmon (CHK) and coho salmon (COH) tagged and released during each period in the Roza reach of the Yakima River, Washington, 2016.

Taglife Study and Downstream Movement of Sacrificed Fish

All the acoustic transmitters operated for at least 32 days. The first transmitter stopped working after 32.2 days of operation and the last transmitter expired after 53.7 days of operation (fig. 7). The 90th percentile of the transmitter operating life was 42.9 days; therefore, detection records of individual tagged fish were removed if they occurred more than 42.9 days after a given transmitter was activated for tagging. No sacrificed fish were detected at sites downstream of the bypass outfall at Roza Dam.

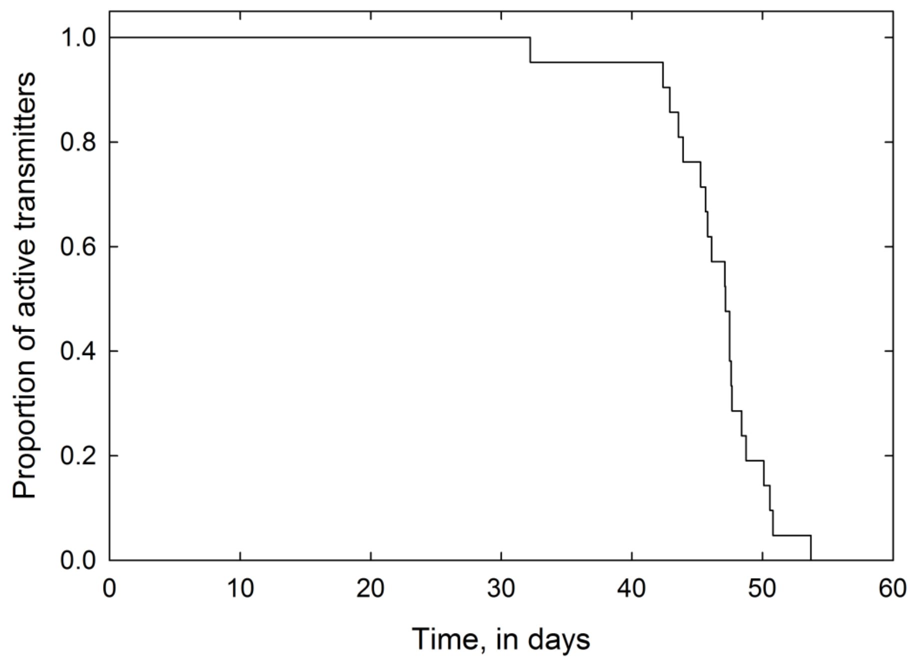

Figure 7. Graph showing proportion of active transmitters in relation to time since activation for acoustic transmitters used during the evaluation on the Yakima River, Washington, 2016.

Acoustic Camera

A total of 504 hours of acoustic camera footage was collected in the fish bypass and at the bypass outfall during the study period. The footage included 229 hours at the entrance bays, 202 hours in the convergence vault, and 73 hours at the bypass outfall (table 3). Image quality was very good at the entrance bays where entrained air was not an issue. Conversely, entrained air bubbles were present in the convergence vault and at the bypass outfall, which degraded the image quality at these sites. This decreased the effective range of the camera and increased the uncertainty in fish size and quantity estimates at these locations.

A total of 710 fish were observed in the sub-sample of video footage that was reviewed from the entrance bays. Fish in the 80–120 mm size class were most abundant (fig. 8). Of the fish observed, 63.7 percent (452 fish) were similar in size (95–170 mm) to fish that were tagged with an acoustic transmitter and PIT-tag. Thirteen fish (1.8 percent) were predator-sized (greater than 250 mm) and several of these were in the 300–400 mm size range (fig. 8). Fish presence generally was higher during nighttime hours than during daytime hours, regardless of fish size (fig. 9).

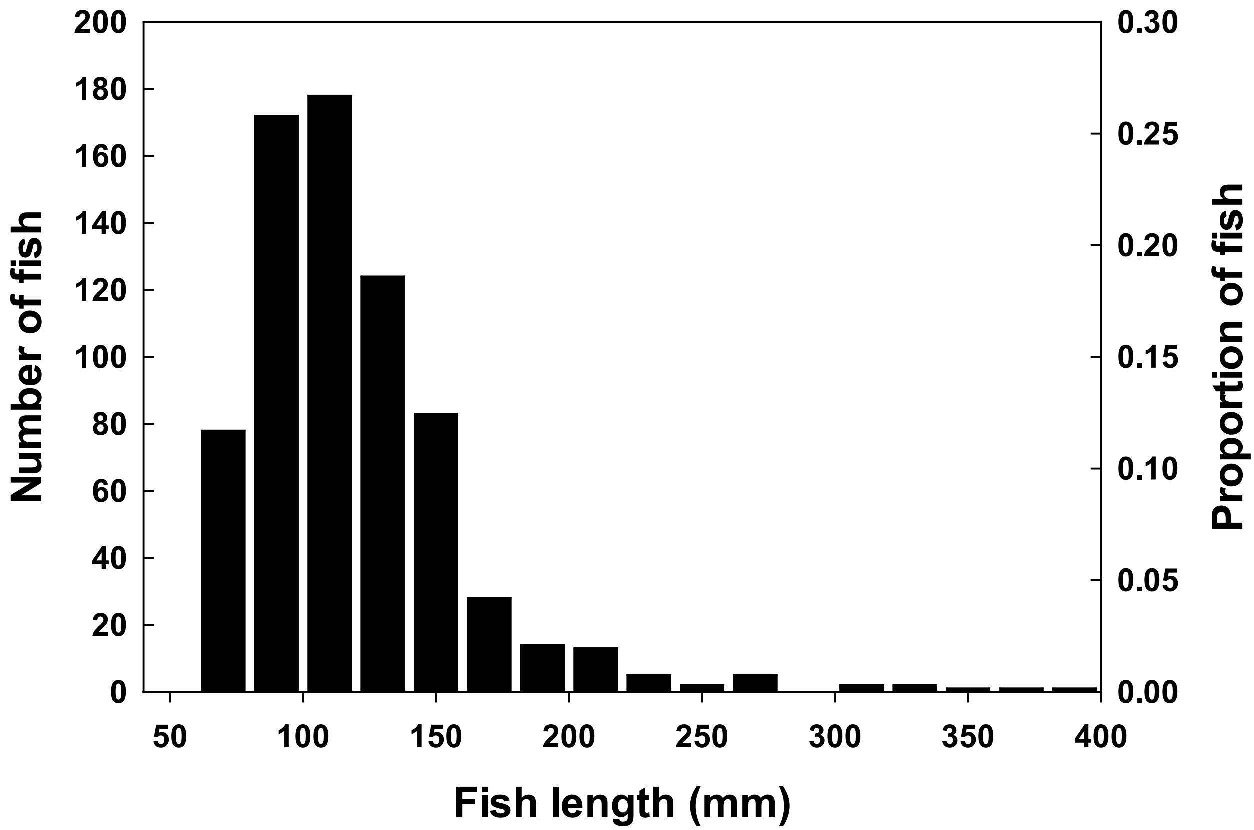

Figure 8. Graph showing number and proportion of fish (by size class) observed at the entrance bays to the fish bypass at Roza Dam, Yakima River, Washington, April 2016.

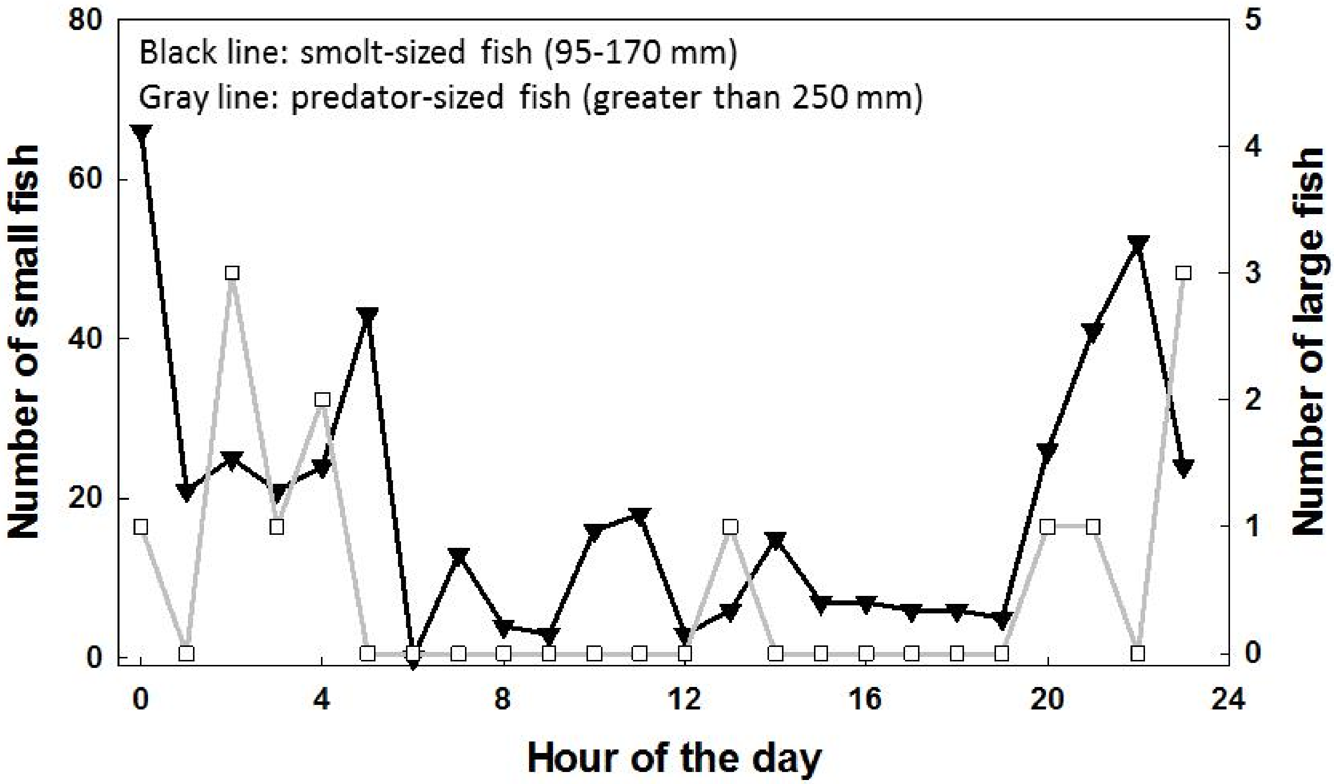

Figure 9. Graph showing number of smolt-sized and predator-sized fish observed per hour at the entrance bays to the fish bypass, Yakima River, Washington, April 2016.

We observed 931 fish in the convergence vault footage, but the presence of entrained air bubbles at that location degraded the quality of the images severely enough that accurate fish-size data were not obtained. The number of fish observed at convergence vault peaked during crepuscular periods (fig. 10). A small number of predator-sized fish were observed in the convergence vault (fig. 10). Generally, observations from the convergence vault indicated that fish were present in schools and exhibited holding behavior patterns at that location. Additionally, fish appeared to be oriented to the flow of the water that was returned to the river through screens in the convergence vault (fig. 11).

A total of 1,477 fish were observed on video footage collected at the bypass outfall. Most fish were in the 80–140 mm size class; 62.7 percent (926 fish) of the fish were similar in size to fish that were tagged during our study (fig. 12). Predator-sized fish comprised 2.4 percent of the population and some of those fish were large (550 mm). The presence of smolt-sized fish (95–170 mm) and predator-sized fish (> 250 mm) was highest during the morning crepuscular period (4:00–5:00 a.m.; fig. 13). Footage was not collected between the hours of 10:00 a.m. and 3:00 p.m. (fig. 13).

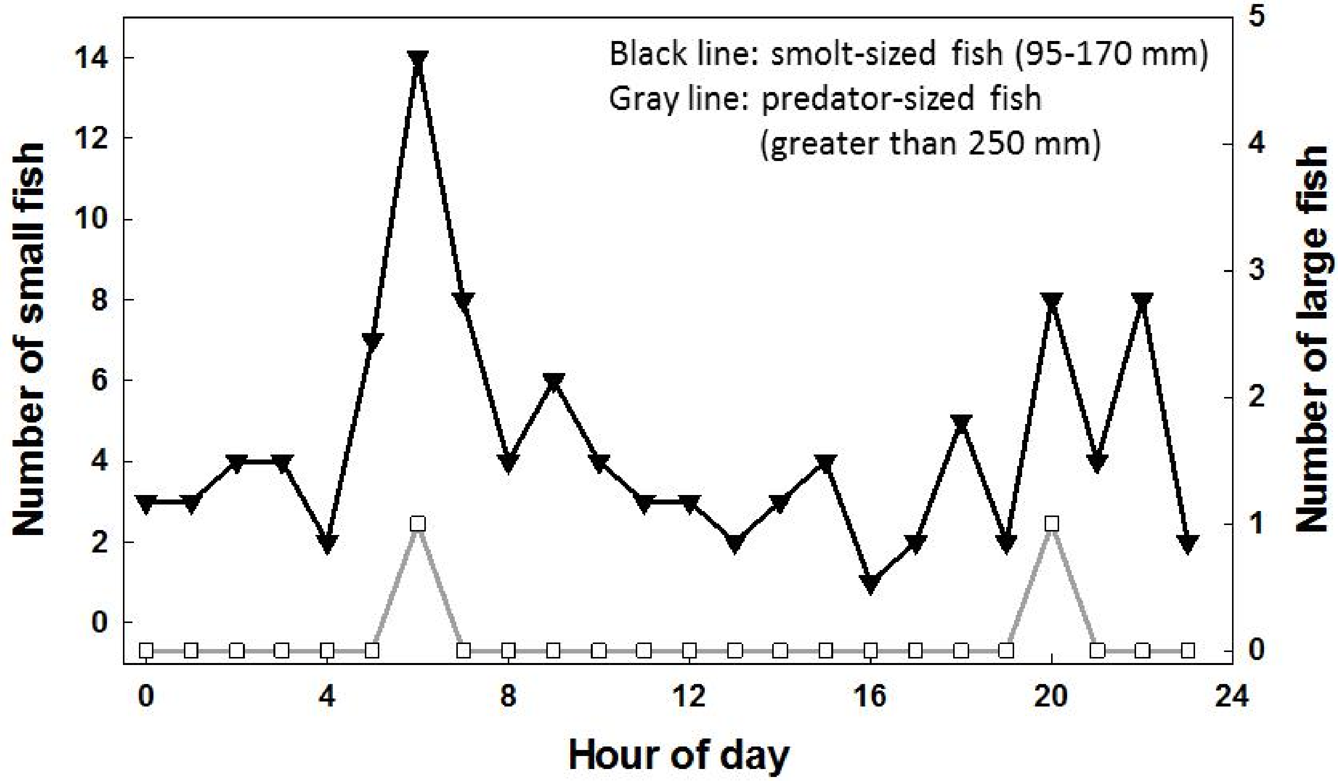

Figure 10. Graph showing number of smolt-sized and predator-sized fish observed per hour in the convergence vault of the fish bypass, Yakima River, Washington, April 2016.

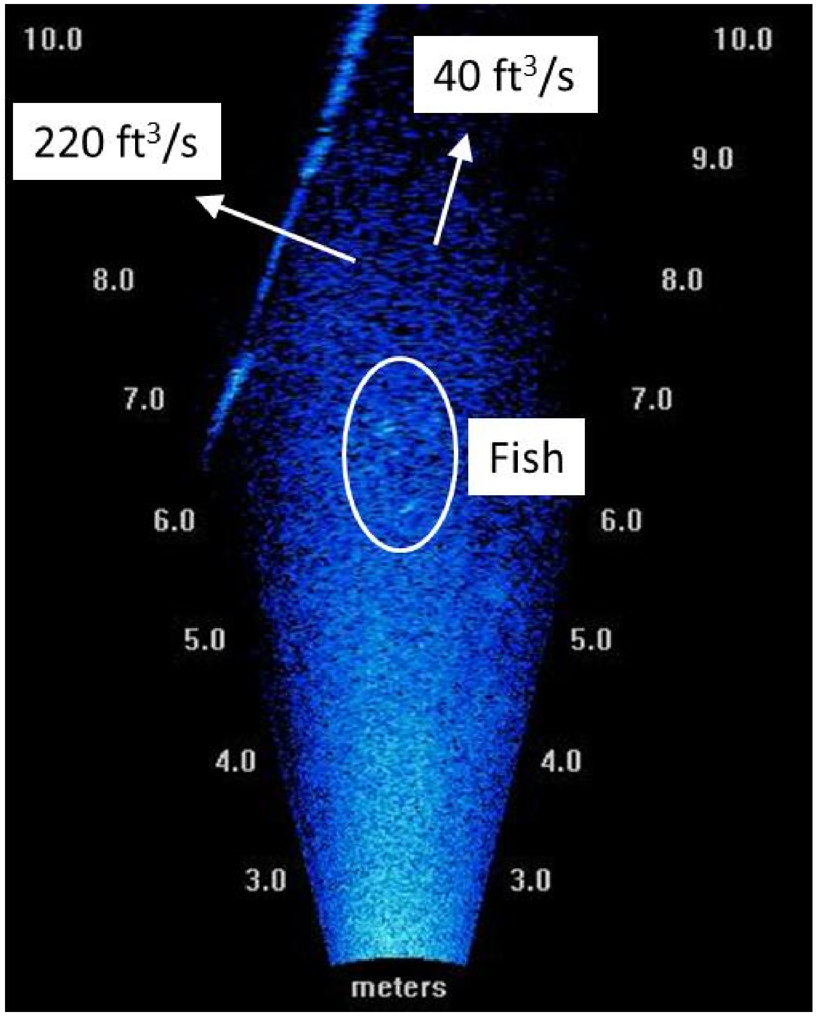

Figure 11. Image from acoustic camera footage in the convergence vault of the fish bypass at Roza Dam, Yakima River, Washington, 2016. Direction of flow is shown for water that is screened from the fish bypass and returned to the river (220 cubic feet per second [ft^3/s]) and for water that passes through the remainder of the fish bypass (40 ft^3/s). Smolt-sized fish (95-170 mm) are circled.

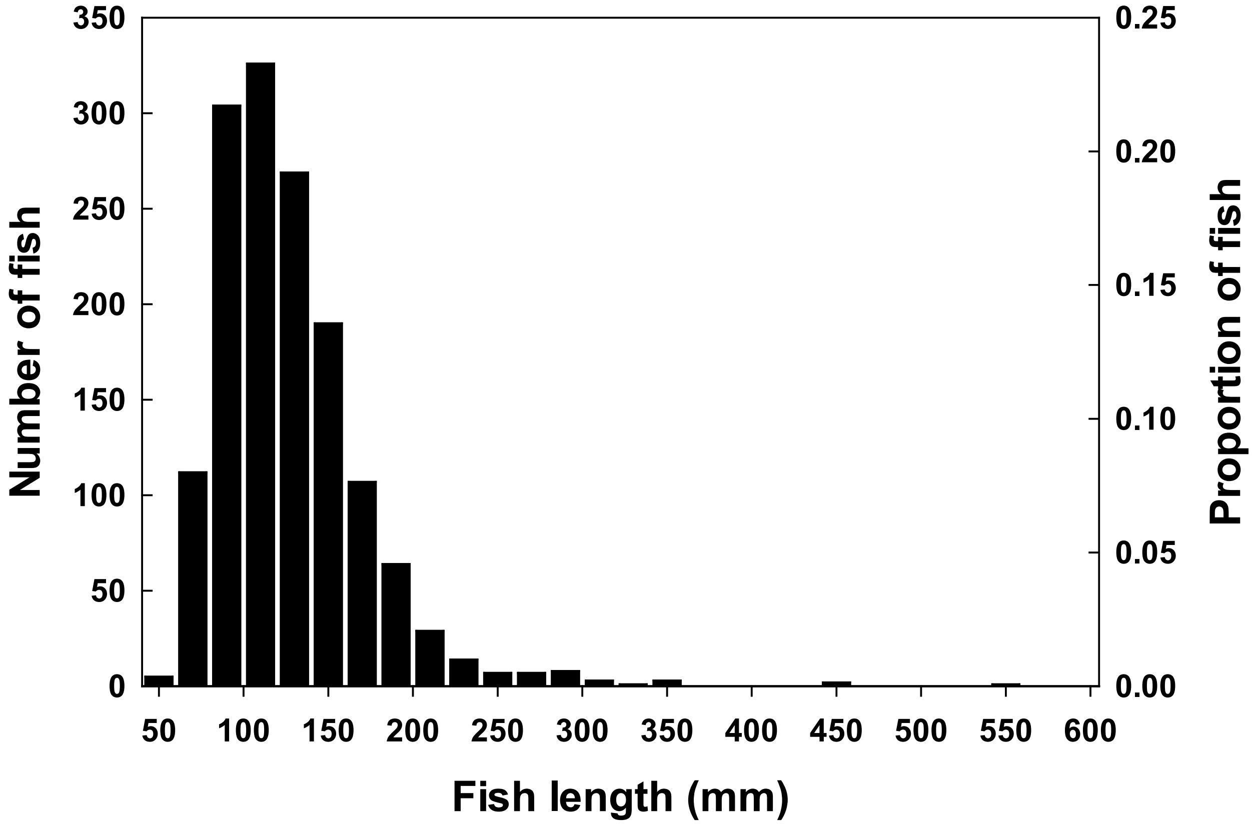

Figure 12. Graph showing number and proportion of fish (by size class in 20 mm intervals) observed at the bypass outfall at Roza Dam, Yakima River, Washington, April 2016.

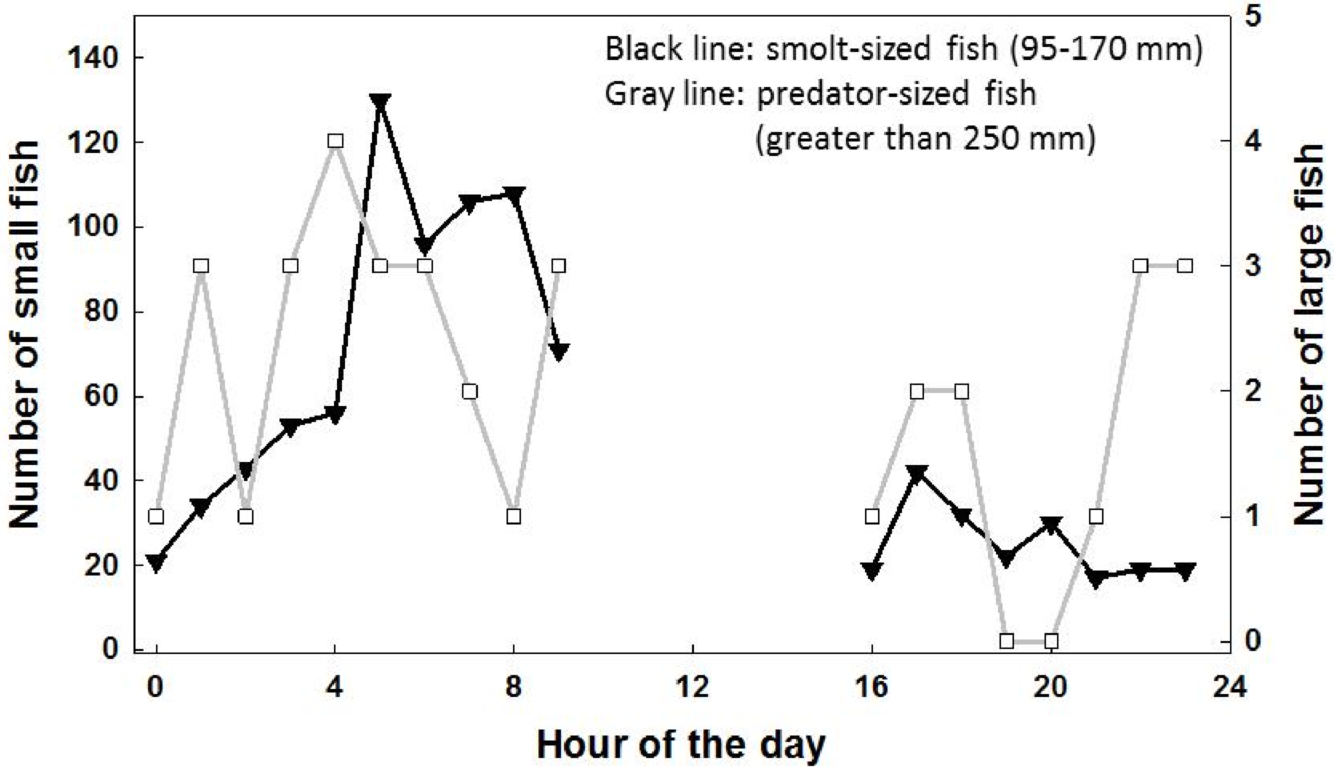

Figure 13. Graph showing number of smolt-sized (95–170 mm; black line, triangle symbols) and predator-sized (greater than 250 mm; grey line, square symbols) fish observed per hour in the convergence vault of the fish bypass, Yakima River, Washington, April 2016.

Acoustic Telemetry

Survival and Delay in the Fish Bypass

Release site was not a significant predictor of survival for juvenile Chinook salmon during 2016. The detection probability model that provided the best fit to the Chinook salmon data allowed detection probabilities to vary independently for release week and detection site (table 5). This model was used to identify the best-fitting survival model, which was the model that had a single covariate, release week (table 6). Thus, the best-fitting model indicated that detection probabilities varied by release week and detection site, whereas survival varied by release week. This demonstrated that release site was not a significant predictor of survival for Chinook salmon during 2016, and that tagged Chinook salmon had similar survival from each release site to detection at the Naches River monitoring site. Survival estimates and 95-percent confidence intervals for groups of fish from each release site are presented in figure 14 for display purposes only because the model with release site was not supported as the best-fitting model.

Table 5. Models of detection probability for the analysis of fish bypass survival of juvenile Chinook salmon and coho salmon at Roza Dam, Yakima River, Washington, 2016.

[**Model:** Rweek, release week; Site, detection site. **K:** Number of parameters. **AIC$_C$:** Akaike's Information Criterion. **Delta AIC$_C$:** Difference from model with smallest AIC$_C$]

Model	K	Deviance	AIC$_C$	Delta AIC$_C$
		Chinook salmon		
Rweek x Site	20	15.3	524.8	0.0
Site	17	25.6	528.8	4.0
		Coho salmon		
No covariates (constant rate)	13	15.7	273.8	0.0
Rweek	16	15.1	279.7	5.9

Table 6. Models of survival probability for the analysis of fish bypass survival of juvenile Chinook salmon and coho salmon at Roza Dam on the Yakima River, Washington, 2016.

[**Model:** Rweek, release week; FL, fork length, in centimeters; Rsite, release site. **K:** number of parameters. **AIC$_C$:** Akaike's Information Criterion. **Delta AIC$_C$:** Difference from model with smallest AIC$_C$]

Model	K	Deviance	AIC	Delta AIC$_C$
		Chinook salmon		
Rweek	9	24.6	511.4	0.0
Rweek + FL	10	493.0	513.3	1.8
Rsite + Rweek	12	24.4	517.3	5.9
Rsite x Rweek	20	15.3	524.8	13.4
No covariates (constant rate)	6	67.9	548.6	37.2
Rsite	9	67.5	554.3	42.9
Rsite + FL	10	535.6	555.8	44.4
		Coho salmon		
No covariates (constant rate)	2	27.5	262.9	0.0
Rsite	5	24.4	265.9	3.0
Rweek	5	26.0	267.5	4.6
Rsite + FL	6	255.8	267.9	5.1
Rweek + FL	6	257.3	269.5	6.7
Rsite + Rweek	8	23.5	271.2	8.4
Rsite x Rweek	13	15.7	273.8	10.9

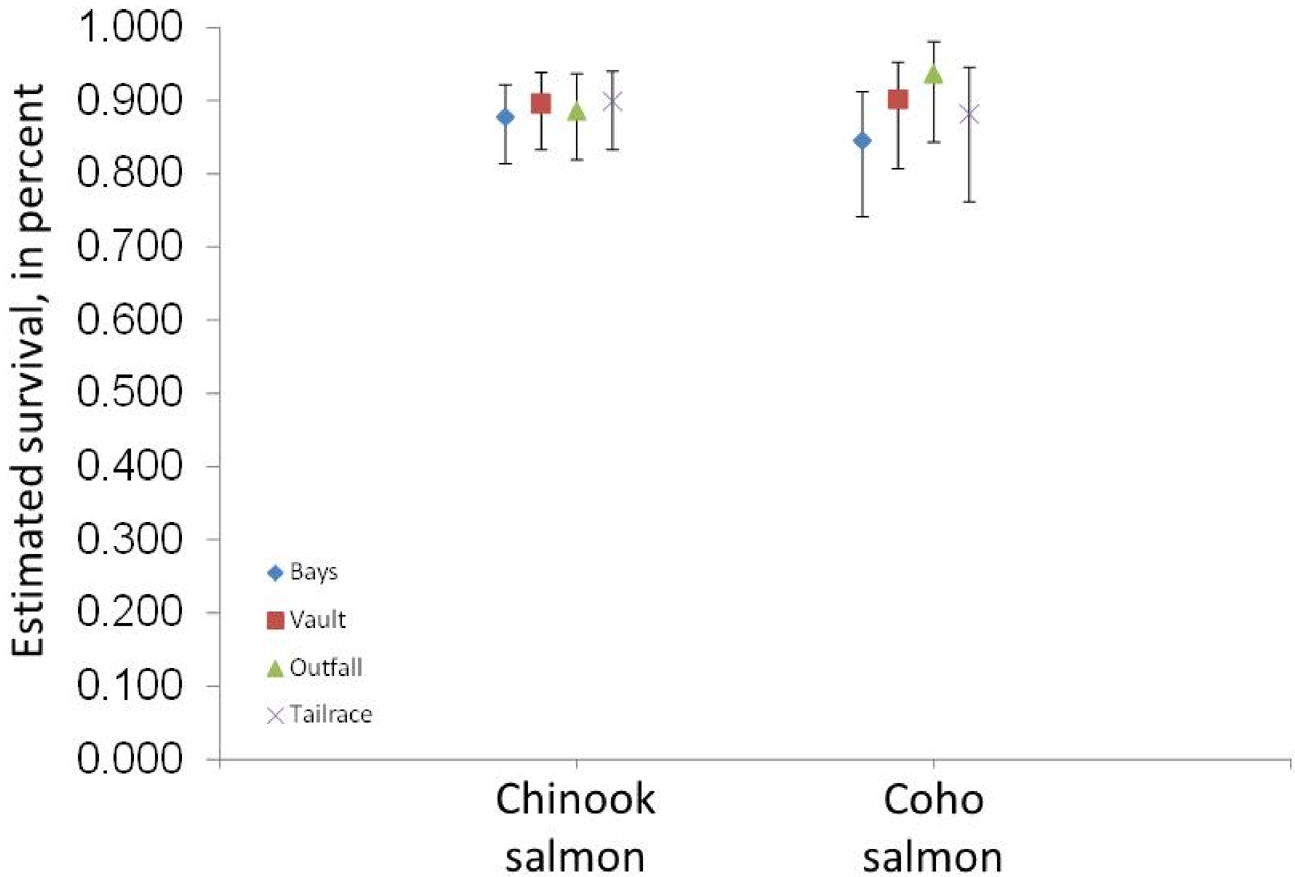

Figure 14. Graph showing survival estimates for juvenile Chinook salmon and coho salmon released in the entrance bays (bays), the convergence vault (vault), the bypass outfall (outfall) and downstream (tailrace) of Roza Dam, Yakima River, Washington, 2016. Survival was estimated from release to the mouth of the Naches River. Whiskers indicate the 95 percent confidence intervals of the survival estimates.

Coho salmon survival probabilities were not affected by release site, release week, and fork length. The null model for detection probability of coho salmon fit the data better than the model that included release week (table 5). This indicated that detection probabilities of tagged coho salmon were constant throughout the study period. The null model for survival probability of coho salmon fit the data better than other models that included covariates such as release site, release week, and fork length (table 6). Survival estimates and 95-percent confidence intervals for groups of fish from each release site are presented in figure 14 for display purposes only because the model with release site was not supported as the best-fitting model.

We compared travel times from the entrance bay and convergence vault release sites to first detection at the bypass outfall and found no difference for Chinook salmon (Wilcoxon test $\chi^2 = 2.438$, $P = 0.1184$) or coho salmon (Wilcoxon test $\chi^2 = 0.243$, $P = 0.623$). Median travel time through the fish bypass was 22.2 minutes for Chinook salmon released at the entrance bays and 9.6 minutes for Chinook salmon released into the convergence vault. For coho salmon, median travel times from the two release sites were 11.2 hours and 7.7 hours, respectively. Most of the tagged Chinook salmon and coho salmon that were released into the fish bypass were detected at the bypass outfall shortly after release but 9.8 percent of the Chinook salmon and 15.7 percent of the coho salmon remained in bypass for 2.5–17.4 days (fig. 15).

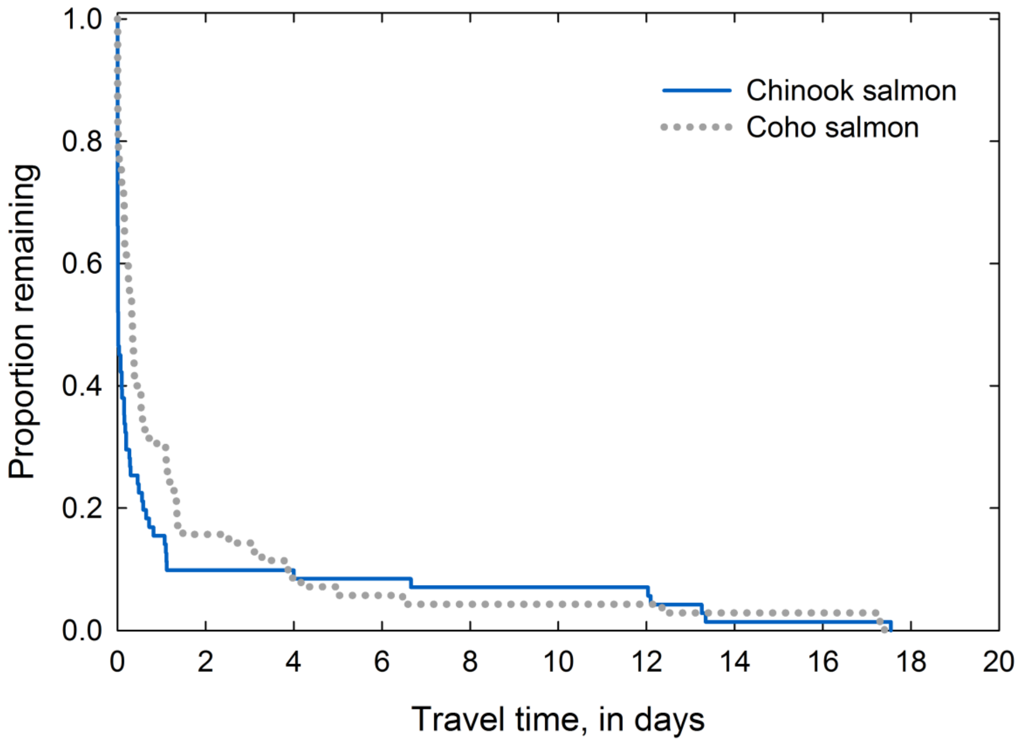

Figure 15. Graph showing proportion of tagged fish remaining in the fish bypass from release to first detection at the outfall (travel time) at Roza Dam, Yakima River, Washington, 2016. Data are shown for acoustic-tagged juvenile Chinook salmon and coho salmon.

Travel Times and Survival in the Yakima River

Juvenile Chinook salmon migrated downstream through the Yakima River faster than juvenile coho salmon (fig. 16). Median travel time for juvenile Chinook salmon from Roza Dam to rkm 527.8 on the Columbia River was 15.4 days (range = 1.9 to 39.9 days), and median travel time for juvenile coho salmon was 37.4 days (range = 1.9 to 41.4 days). Reach-specific travel times for Chinook salmon and coho salmon juveniles are presented in table 7.

Survival varied by reach and release timing for Chinook salmon and coho salmon. Reach-specific survival ranged from 0.738 to 1.000 for Chinook salmon (table 8) and from 0.651 to 1.000 for coho salmon (table 9). Overall survival of juvenile Chinook salmon (table 8) from Roza Dam to rkm 527.8 was highest for fish released during the week of April 17 (0.678) and lowest for groups of fish released during the week of May 8 (0.299). The same was true for coho salmon (table 9); fish released during the week of April 17 had the highest survival (0.627) and fish released during the week of May 8 had the lowest survival (0.321) of the coho salmon release groups.

Standardized (survival per 100 rkm) reach-specific survival estimates are presented in tables 10 and 11 to allow comparison among reaches. For Chinook salmon, standardized survival estimates exceeded 0.740 (range = 0.747–1.000) in the Wapato, Prosser, Benton City and Richland reaches for groups of fish from all four release weeks (table 10). However, standardized survival estimates in the Roza, Chandler diversion, and Columbia reaches were low (less than 0.450) for several of the release groups (table 10). For coho salmon, standardized survival estimates exceeded 0.850 (range = 0.857–1.000) in the Benton City and Columbia reaches, but were low in the Roza and Chandler diversion reaches (table 11).

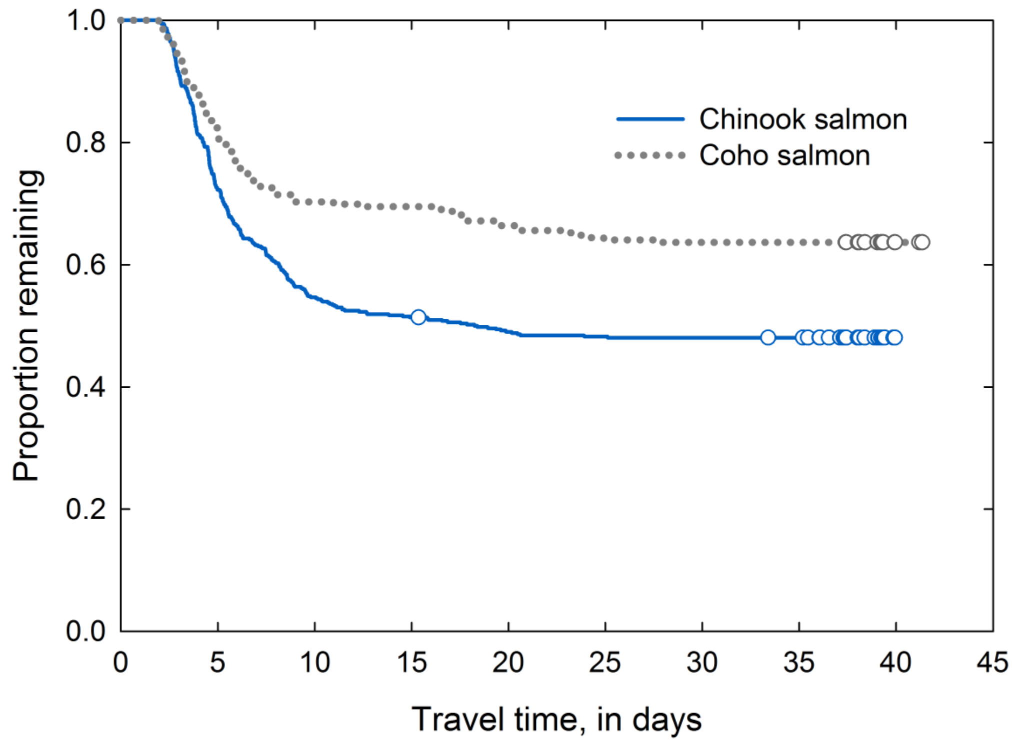

Figure 16. Graph showing proportion of tagged fish remaining between Roza Dam at the Yakima River release site and rkm 527.8 on the Columbia River from the time of release to first detection at the downstream site (travel time). Data are shown for acoustic-tagged juvenile Chinook salmon and coho salmon during 2016.

Table 7. Travel time of Chinook salmon and coho salmon detected at acoustic telemetry monitoring sites in the Yakima and Columbia Rivers, Washington, 2016.

[rkm, river kilometer]

Reach name	Reach length (rkm)	Species	Median (days)	Minimum–maximum (days)
Roza reach	17.6	Chinook	0.16	0.09–39.9
		Coho	0.72	0.09–39.9
Wapato reach	16.1	Chinook	0.10	0.07–15.6
		Coho	0.12	0.07–14.8
Sunnyside reach	4.8	Chinook	0.02	0.01–4.15
		Coho	0.03	0.02–2.25
Prosser reach	91.4	Chinook	2.18	0.87–22.3
		Coho	1.71	0.82–28.1
Chandler diversion reach	18.3	Chinook	0.14	0.10–4.48
		Coho	0.16	0.10–3.39
Benton City reach	9.4	Chinook	0.07	0.05–0.75
		Coho	0.07	0.05–0.29
Richland reach	45.0	Chinook	0.40	0.29–5.48
		Coho	0.36	0.28–2.00
Columbia reach	14.4	Chinook	0.24	0.13–5.98
		Coho	0.23	0.13–4.15

Table 8. Survival estimates for juvenile Chinook salmon in eight reaches of the Yakima River, Washington, 2016.

[Data are shown as proportions for four release weeks in 2016: April 10 (Rweek 1), April 17 (Rweek 2), April 24, (Rweek 3), and May 8 (Rweek 4). Numbers in parentheses are 95 percent confidence intervals of survival estimates]

Reach name	Rweek 1	Rweek 2	Rweek 3	Rweek 4
Roza reach	0.828 (0.766-0.876)	0.984 (0.950-0.995)	0.921 (0.855-0.958)	0.738 (0.619-0.831)
Wapato reach	0.988 (0.942-0.998)	0.963 (0.916-0.984)	0.962 (0.903-0.986)	0.979 (0.866-0.997)
Sunnyside reach	0.971 (0.905-0.991)	1.000	0.980 (0.924-0.995)	1.000
Prosser reach	0.818 (0.743-0.875)	0.771 (0.702-0.829)	0.909 (0.834-0.952)	0.766 (0.625-0.865)
Chandler diversion reach	0.983 (0.934-0.996)	0.962 (0.912-0.984)	0.933 (0.859-0.970)	0.750 (0.585-0.864)
Benton City reach	1.000	0.984 (0.940-0.996)	0.988 (0.920-0.998)	1.000
Richland reach	0.974 (0.922-0.992)	0.992 (0.946-0.999)	0.904 (0.819-0.951)	0.926 (0.748-0.981)
Columbia reach	0.883 (0.772-0.944)	0.987 (0.264-1.00)	0.931 (0.766-0.982)	0.777 (0.486-0.928)
Overall	0.549 (0.468-0.630)	0.678 (0.597-0.759)	0.612 (0.512-0.713)	0.299 (0.172-0.425)

Table 9. Survival estimates for juvenile coho salmon in eight reaches of the Yakima River, Washington, 2016.

[Data are shown as percentages for four release weeks in 2016: April 10 (Rweek 1), April 17 (Rweek 2), April 24, (Rweek 3), and May 8 (Rweek 4). Numbers in parentheses are 95 percent confidence intervals of survival estimates]

Reach name	Rweek 1	Rweek 2	Rweek 3	Rweek 4
Roza reach	0.852 (0.665-0.943)	0.923 (0.787-0.975)	0.915 (0.812-0.964)	0.878 (0.810-0.924)
Wapato reach	0.959 (0.737-0.995)	0.945 (0.802-0.987)	0.944 (0.841-0.982)	0.965 (0.911-0.987)
Sunnyside reach	0.952 (0.729-0.993)	0.992 (0.031-1.000)	0.961 (0.856-0.990)	0.996 (0.657-1.000)
Prosser reach	0.857 (0.639-0.953)	0.800 (0.621-0.907)	0.776 (0.638-0.871)	0.651 (0.558-0.735)
Chandler diversion reach	0.889 (0.648-0.972)	0.963 (0.779-0.995)	0.947 (0.813-0.987)	0.806 (0.698-0.881)
Benton City reach	1.000	1.000	1.000	0.966 (0.872-0.991)
Richland reach	1.000	0.962 (0.772-0.995)	0.917 (0.771-0.973)	0.750 (0.621-0.846)
Columbia reach	1.000	0.978 (0.459-1.000)	0.985 (0.000-1.000)	1.000
Overall	0.593 (0.407-0.778)	0.627 (0.469-0.784)	0.551 (0.371-0.730)	0.321 (0.241-0.401)

Table 10. Standardized (survival per 100 rkm) survival estimates for Chinook salmon in eight reaches of the Yakima River, Washington, 2016.

[Data are shown as percentages for four release weeks in 2016: April 10 (Rweek 1), April 17 (Rweek 2), April 24, (Rweek 3), and May 8 (Rweek 4)]

Reach name	Rweek 1	Rweek 2	Rweek 3	Rweek 4
Roza reach	0.342	0.912	0.627	0.178
Wapato reach	0.928	0.791	0.786	0.876
Sunnyside reach	0.544	1.000	0.658	1.000
Prosser reach	0.803	0.752	0.901	0.747
Chandler diversion reach	0.911	0.809	0.685	0.208
Benton City reach	1.000	0.842	0.879	1.000
Richland reach	0.943	0.982	0.799	0.843
Columbia reach	0.421	0.913	0.609	0.173

Table 11. Standardized (survival per 100 rkm) survival estimates for coho salmon in eight reaches of the Yakima River, Washington, 2016.

[Data are shown as percentages for four release weeks in 2016: April 10 (Rweek 1), April 17 (Rweek 2), April 24, (Rweek 3), and May 8 (Rweek 4)]

Reach name	Rweek 1	Rweek 2	Rweek 3	Rweek 4
Roza reach	0.403	0.634	0.604	0.477
Wapato reach	0.771	0.704	0.699	0.801
Sunnyside reach	0.361	0.847	0.439	0.920
Prosser reach	0.845	0.783	0.758	0.625
Chandler diversion reach	0.526	0.814	0.743	0.308
Benton City reach	1.000	1.000	1.000	0.958
Richland reach	1.000	0.918	0.825	0.528
Columbia reach	1.000	0.857	0.900	1.000

Route of Passage at Prosser Dam

We determined that 369 tagged Chinook salmon and 141 tagged coho salmon passed Prosser Dam during the study period. Of those, 45 Chinook salmon (12.2 percent) and 37 coho salmon (26.3 percent) were detected in the canal. Canal passage in relation to discharge was not quantitatively assessed, but the relationship between discharge and number of fish passing through Prosser Canal is shown in figure 17. Canal passage generally peaked during periods when discharge was low.

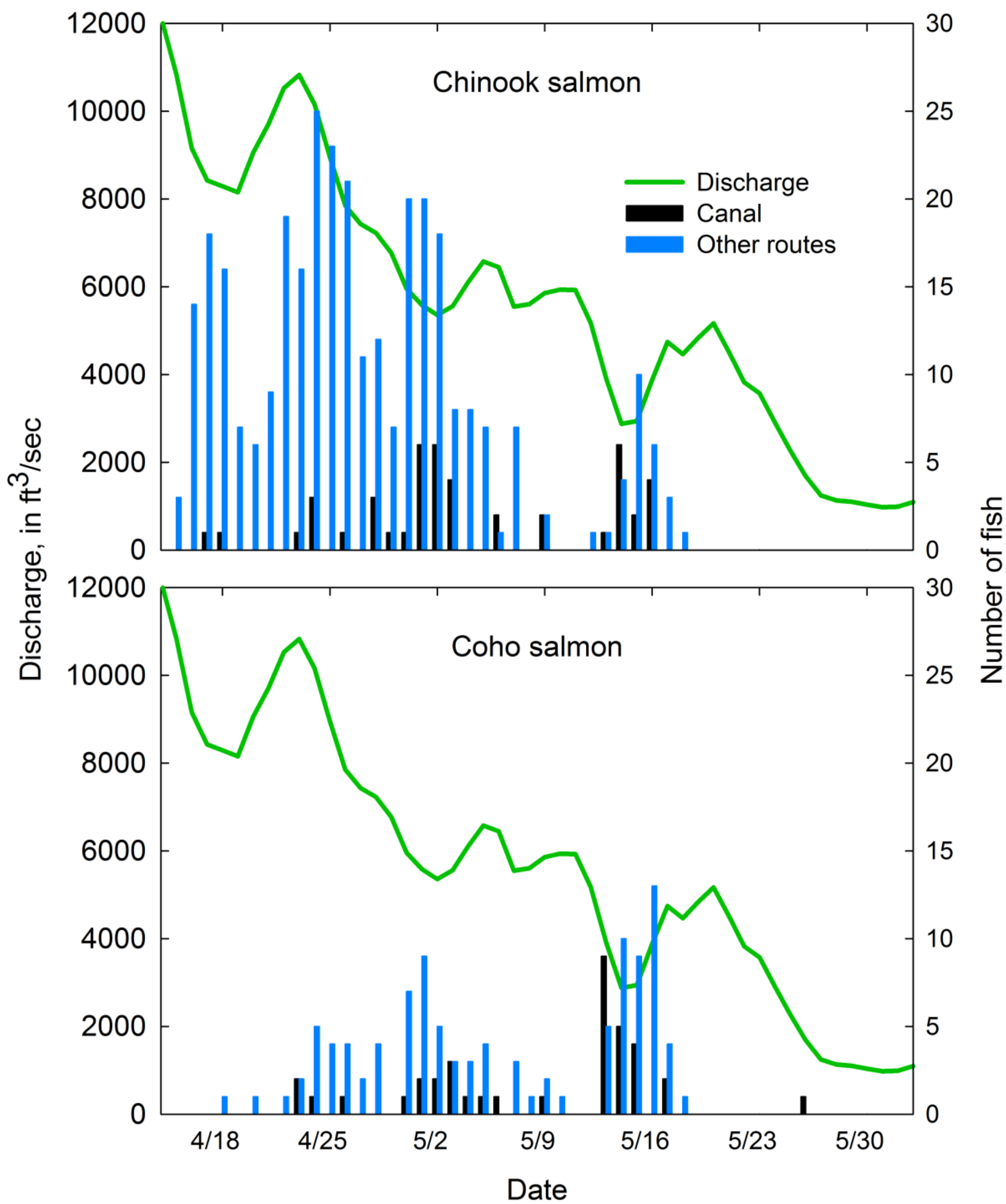

Figure 17. Graphs showing discharge and daily counts of Chinook salmon and coho salmon passing through the Prosser canal, or through other routes at Prosser Dam, Yakima River, Washington, 2016.

Discussion

Some tagged fish were delayed in the Roza Dam fish bypass, which was consistent with previous determinations, but there was no evidence of passage-related mortality during 2016. Many tagged fish passed through the structure in less than 12 hours, but some fish (less than 16 percent) spent from 2.5 to 17.4 days in the fish bypass, following release. These results corroborate findings from the 2012–14 study when we determined that 35 percent of the tagged Chinook salmon that entered the fish bypass spent 2.5–32.2 days in the structure (Courter and others, 2015). Acoustic camera footage in 2016 indicated that delay occurred in the convergence vault. Most of the fish bypass is composed of underground pipes that convey high velocity water downstream. The exception occurs in the convergence vault where the pipes surface and most (85 percent) of the water is screened and returned to the river. Footage from the acoustic camera showed that schools of fish were present at this location and that they primarily exhibited holding behavior. This holding behavior included orientation into the primary flow, water passing through the screens, which could be the cause of the migration delay. Juvenile salmon are known to use flow cues for migration (Coutant, 2001; Tiffan and others, 2009) and flows in the convergence vault appear to confuse some fish as they pass through the fish bypass. Although this study found evidence of migration delay, no significant mortality due to passing through the structure in 2016 was observed. Survival was similar between groups of fish that were released into the fish bypass and groups that were released into the river downstream of the bypass outfall. This result suggests that the fish bypass was not a source of direct mortality, which contrasts with results from 2012–14 (Perry and others, 2016).

There are several possible explanations for the differences in results from the two studies. The 2016 study began in mid-April, whereas the 2012–14 studies began in late-March. This is important because fish use of the bypass was higher during late-March to early-April than it was during mid-April to mid-May in 2012–14. During the earlier studies, 22.5 percent of the tagged fish volitionally entered the bypass in the early period, but entry rates declined to 12.1 percent during the latter period (Courter and others, 2015). Thus, the 2016 study began when bypass use and delay would be expected to be low, based on 2012–14 results. Other possible explanations for differences in the results between the two studies include sample sizes, the method in which fish accessed the bypass, and the type of transmitters that were used. A total of 124 tagged fish volitionally entered the fish bypass during March–May in 2012–14, whereas 424 fish were released directly into the fish bypass during a 4-week period in 2016. The bypass survival estimates from 2012–14 were relatively uncertain (Perry and others, 2016) and it is also possible that weaker individuals were more likely to enter the bypass volitionally, rather than remaining in the river and passing over the dam. Furthermore, juvenile Chinook salmon were tagged with radio transmitters during 2012–14, which included an antenna that extends approximately 15 cm outside of the fish's body cavity. A substantial amount of screening material is present in the fish bypass and it is possible that some antennas became entangled in the screen and trapped tagged fish in the structure. Conversely, the acoustic transmitters that were used during 2016 are completely encapsulated inside the body cavity of tagged fish. The factors listed above are possible explanations for differences in survival estimates between the 2012– 14 and 2016 studies. The 2016 study was designed to specifically identify potential areas where mortality occurs, and to provide rigorous estimates of bypass survival. The development of the study design focused on identifying appropriate sample sizes, release strategies, and research technologies to meet those goals. Thus, we consider the 2016 study to provide the best evaluation of bypass survival to date, and results from that study seem to indicate that bypass mortality is negligible.

Data collected with acoustic cameras showed that predator-sized fish were present at bypass entrances, in the convergence vault, and at the bypass outfall. We are not able to determine which species of fish were observed with the acoustic cameras, but we can validate that predator-sized fish were present. Footage reviewed contained fish in the 250–550 mm size range, and large piscivorous fish such as northern pikeminnow (*Ptychocheilus oregonensis*) have been captured at the bypass outfall. We also observed an attempted predation event by a predator-size fish on a school of smolt-sized fish near the entrance bays (Kock and others, 2016). These results show that predator-size fish are present in and around the fish bypass at Roza Dam. Previous studies at dams on the Columbia River have shown that predators such as northern pikeminnow congregate near bypass outfalls, and predation in dam tailraces has been high (Faler and others, 1988; Rieman and others, 1991; Petersen, 1994; Shively and others, 1996). Survival estimates from the 2016 study indicate that predation-related mortality is negligible in and around the fish bypass at Roza Dam, but the documented presence of predator-sized fish suggests that predation is possible.

Migration survival was relatively high during April 2016 through reaches downstream of Roza Dam, but mortality increased substantially for fish released in May 2016. Cumulative survival from Roza Dam to rkm 527.8 on the Columbia River ranged from 0.549 to 0.678 for Chinook salmon and from 0.551 to 0.627 for coho salmon that were released during April 2016. By comparison, cumulative survival of Chinook salmon from Roza Dam to the mouth of the Yakima River averaged 0.320 during 2012–14 (Courter and others, 2015). High migration survival in April 2016 probably is related to higher-than-normal discharge that occurred throughout the spring months of 2016 in the Yakima River Basin (Joel Hubble, Bureau of Reclamation, oral commun., June 2016). Previous studies have illustrated the relation between river flow and juvenile salmon survival in the Yakima River (Pyper and Smith, 2005; Courter and others, 2015; 2016). However, migration survival decreased sharply for tagged fish that were released in May 2016. Cumulative survival estimates during that period were 0.299 for Chinook salmon and 0.321 for coho salmon. The increased mortality in fish released in May likely is due to predation. Piscivorous fish populations abound in the lower Yakima River; Fritts and Pearson (2004) determined that smallmouth bass abundance in the river increased monthly from March to June during 1998–2001, and that predation on juvenile salmonids peaked during May. Passage data from Prosser Dam show that May-released fish were migrating through the lower Yakima River during a period when discharge was low (less than 3,000 ft^3/s; fig. 17), which has been identified as a factor that results in increased predation of juvenile salmon (Fast and others, 1991). Standardized survival estimates through the Chandler diversion reach, just downstream of Prosser Dam, were 0.208 per 100 rkm for Chinook salmon and 0.308 per 100 rkm for coho salmon released in May. These estimates suggest that predation is significant in the lower Yakima River, and future activities may be required to better understand and address this issue.

Summary

In summary, we found that some fish were delayed in the Roza Dam fish bypass, but direct mortality within the structure was not evident. We did find that predator-sized fish were present in and around the fish bypass, which may be of interest in the future. Results of this study showed that migration survival through the Lower Yakima River was relatively high, in relation to previous years, for fish that were released in April, but fish released in May experienced high migration mortality. The reach-specific survival estimates presented in this report may be useful for directing future efforts, and we are continuing to explore the effects of covariates such as water temperature, discharge, and migration timing on survival of juvenile Chinook salmon and coho salmon.

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