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EVALUATION OF ADULT CHINOOK AND SOCKEYE SALMON PASSAGE AT PRIEST RAPIDS AND WANAPUM DAMS - 1997

by

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Abstract

Radio-tagged adult spring and summer chinook salmon *Oncorhynchus tshawytscha* and sockeye salmon *O. nerka* were monitored to evaluate passage conditions at Priest Rapids and Wanapum dams, mid-Columbia River, during 1997. Passage conditions were assessed during two treatment conditions: half the powerhouse orifice gates open and all orifice gates closed. Six travel time variables were analyzed using ANOVA analysis and two non-parametric tests. We concluded that closing orifice gates at Priest Rapids and Wanapum dams did not have a significant effect on passage of chinook and sockeye salmon in 1997. Chinook and sockeye salmon passed through the Hanford Reach section of the Columbia River in 2 to 3 d. Of 217 chinook salmon that reached Priest Rapids Dam, 199 eventually passed the dam, in 37.6 h, and reached Wanapum Dam. One hundred and ninety chinook salmon are known to have crossed Wanapum Dam in 20.1 h. Of 440 sockeye salmon that reached Priest Rapids Dam, 427 eventually crossed the dam, in 18.6 h, and reached Wanapum Dam. Four hundred and nine sockeye salmon are known to have crossed Wanapum Dam in 29.7 h. A prototype fishway fence installed inside the west-powerhouse entrance (Lew2) at Priest Rapids Dam was not effective at reducing the number of salmon that exited from the fishway at that point. Salmon were not held up at the fish counting station in the east-shore ladder at Priest Rapids Dam. However, passage times were about three times longer to pass the coded-wire-tag trap near the top of the ladder when the trap was operating as compared to the same section of ladder when the trap was not operating, resulting in median delays 42 min for chinook salmon and 2.1 h for sockeye salmon. Salmon used the new vertical-slot gate placed at the west-shore fishway entrance (Rew2) as readily as the two other main entrances (Se2 and Se3) at Wanapum Dam. Six (3.0%) chinook salmon and 16 (3.9%) sockeye salmon fell back at Priest Rapids Dam. Five chinook salmon and 15 sockeye salmon eventually re-crossed Priest Rapids Dam after an average delay of about 26 h. Eight (4.1%) chinook salmon and 19 (4.5%) sockeye salmon fell back at Wanapum Dam. Seven chinook salmon and 12 sockeye salmon eventually re-crossed Wanapum Dam after average delays of about 42 to 48 h.

Introduction

Adult chinook and sockeye salmon migrating to spawning grounds or hatcheries in the mid-Columbia River must ascend five to nine dams (Figure 1). To identify and reduce delays of salmon passing dams, the U.S. Army Corps of Engineers and Bonneville Power Administration funded a radio-telemetry study of adult salmon and steelhead passage in the Columbia and Snake rivers in 1997. Taking advantage of salmon outfitted with transmitters at Bonneville Dam, Grant County Public Utility District funded a study to monitor passage of radio-tagged chinook and sockeye salmon at Priest Rapids and Wanapum dams with collection channel orifice gates open or closed, and to evaluate the effectiveness of a fishway fence to reduce the number of salmon exiting the collection channel at Priest Rapids Dam. Other study objectives were to monitor passage of fish through transition pool areas at both dams, evaluate time for salmon and steelhead to pass the fish counting station and coded-wire-tag (CWT) trap at Priest Rapids Dam, and to quantify fallback events at both dams. Chinook and sockeye salmon with transmitters were also monitored as they passed Rock Island, Rocky Reach, and Wells dams and to spawning areas in the upper Columbia River by Chelan and Douglas PUDs.

In a 1993 radio-telemetry study, conducted by the National Marine Fisheries Service at mid-Columbia River dams, Stuehrenberg et al. (1995) found that chinook salmon entered and exited the fishways multiple times before successfully ascending dams. They suggested that this wandering behavior may delay salmon passing the dams. Similar movements into and out of fishways were observed for salmon passing lower Snake River dams (Bjornn et al. 1994; 1995). Stuehrenberg et al. (1995) recommended closing all fishway entrances except those at the base of fish ladders, which are used the most, to reduce the number of fish that exit the fishways. In 1996, we conducted a study to determine if chinook salmon passage at Priest Rapids Dam would differ if orifice gates along the powerhouse collection channel were closed. We found no significant difference in time for chinook salmon to pass Priest Rapids Dam when half the orifice gates were open (standard operating pattern) and with all orifice gates closed (Bjornn et al. 1997). The study was repeated in 1997 because of the small number of replicate blocks of orifice

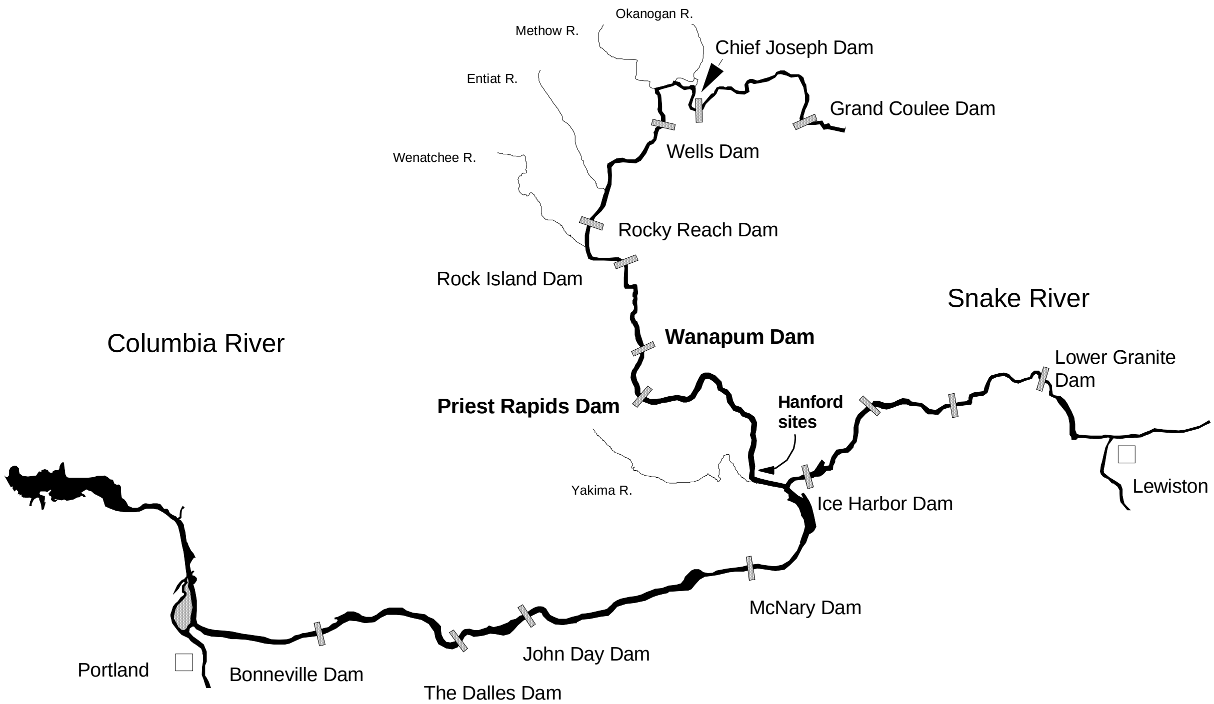

Figure 1. Location of Priest and Wanapum dams and radio receiver sites at start of Hanford Reach.

gate treatments obtained at Priest Rapids Dam during 1996 and to include Wanapum Dam in the evaluation.

In 1997, we investigated effects of closing orifice gates on passage of radio-tagged chinook and sockeye salmon at both Priest Rapids and Wanapum dams. Other sources of delay investigated were fallback of salmon over dams and time for salmon to pass through transition pools at the base of the east-shore fishways at both dams. Fallback is when a fish passes over a dam and then moves downstream and passes back over the dam through the spillway, powerhouse or navigation lock. Transition pools are areas between collection channels and fish ladders where some adult salmon change direction of movement and move back downstream. Hence, transition pools may be a potential area of passage delay for salmon at Columbia River dams. Fish must pass through two constricted areas while moving up the east-shore ladder at Priest Rapids Dam, at the counting station and at the CWT trap (when operated). We monitored passage of salmon and steelhead through the east-shore ladder to determine if delays occurred at these two areas. In addition, we evaluated the effectiveness of a new fishway fence to reduce the number of salmon that exit through the main entrance at the downstream (western) end of the powerhouse collection channel at Priest Rapids Dam.

Methods

Adult chinook salmon and sockeye salmon with transmitters were monitored as they passed Priest Rapids and Wanapum dams during periods of time when half the orifice gates were open (normal operation) and when all gates were closed, during spring and summer 1997. Orifice gates were alternately opened and closed to create replicate blocks of treatments. Fixed-site receivers were used to record routes and time of passage into and through fishways by radio-tagged salmon at the two dams. Chinook and sockeye salmon used for this study were released with radio transmitters at Bonneville Dam (river kilometer (rkm) 235.1) as part of the Lower Columbia River Adult Passage Project, funded by the U.S. Army Corps of Engineers and Bonneville Power Administration.

Study Site

Priest Rapids (rkm 638.9) and Wanapum (rkm 669.0) dams are located in the mid-Columbia River upstream from the confluence with the Snake River (rkm 521.6) (Figure 1). Priest Rapids Dam consists of a 22-bay spillway adjacent to the west shore and a ten-turbine powerhouse adjacent to the east shore (Figure 2). There are two fishways, one along either shore. The west fishway, adjacent to the spillway, has two entrances (Rew1 and Rew2) but only one (Rew2) is used. The east fishway has two entrances at the east end of the powerhouse, (Lew4-5 and Lew6-7) but only one (Lew4-5) is typically kept open. A collection channel runs the length of the powerhouse and there are three large entrances at the western end (Lew1, 2 and 3) and 18 orifice gates (OG1 to OG18) along its downstream face. Collection channel entrances that were open during this study were Lew2 at all times, and odd-numbered orifice gates on an alternating (open/closed) schedule. All other collection channel entrances were kept closed. The collection channel joins with the east fishway ladder at the southeast corner of the powerhouse. The

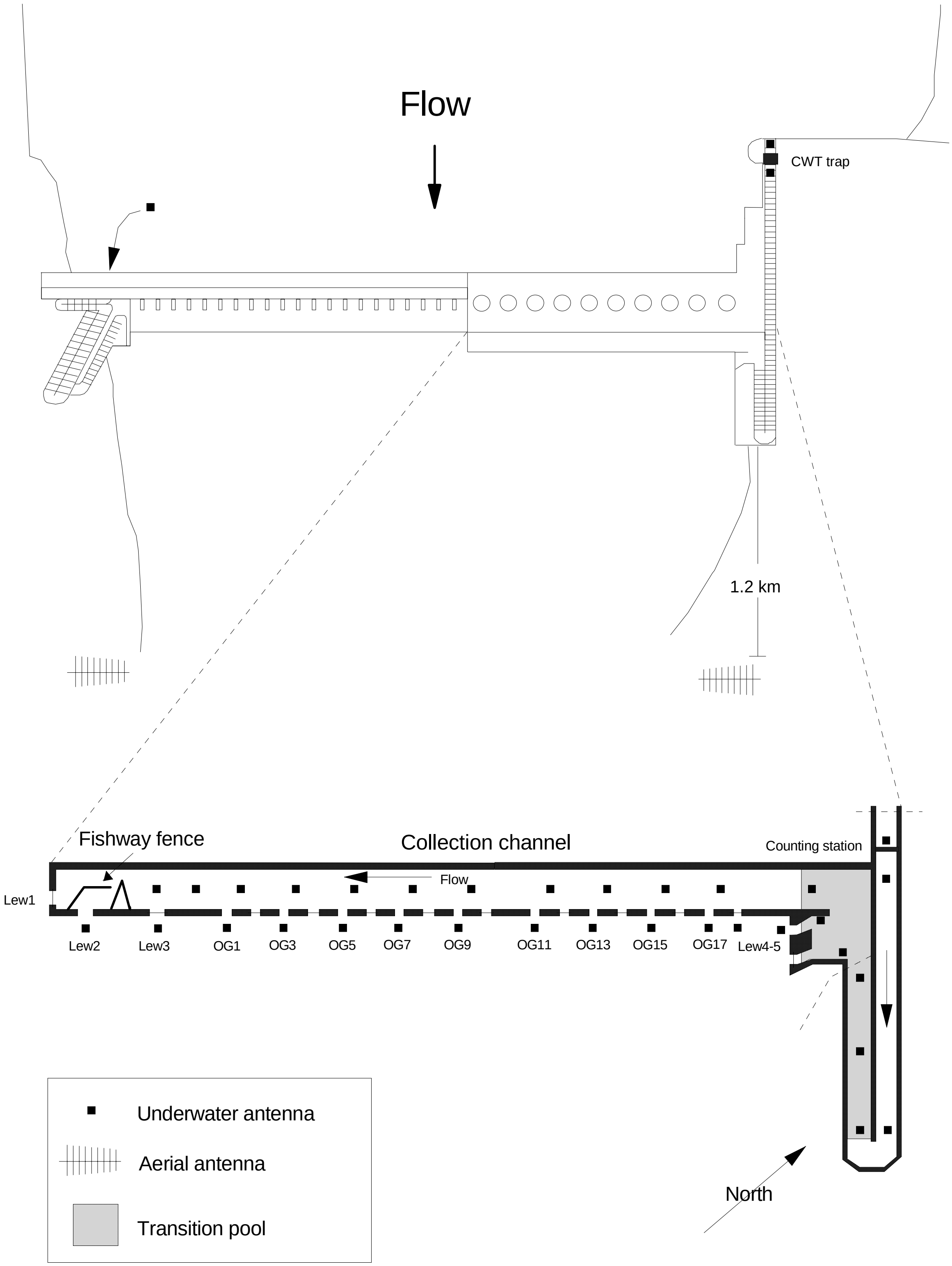

Figure 2. Study area at Priest Rapids Dam, showing placement of radio receiver antennas at dam and in fishway. Entrances Lew2, Lew4-5 and odd-numbered orifice gates were used during this study.

transition pool starts at the upstream end of the collection channel and extends up the base of the ladder, and varied in length depending on elevation of water in the tailrace.

Wanapum Dam consists of a 12-bay spillway adjacent to the west shore, a ten-turbine powerhouse positioned parallel to river flow, approximately in mid-channel, and an earth-fill section that runs from the north end of the powerhouse to the east shore (Figure 3). There are two fishways. The west fishway, adjacent to the spillway, has two entrances (Rew1 and Rew2) but only Rew2 is typically used. A slotted entrance gate was in use at Rew2 for the first time in 1997. The east fishway has two entrances at the north end of the powerhouse, (Se1 and Se2) but only one (Se2) is typically kept open. A collection channel runs the length of the powerhouse with two large entrances at the south end (Se3 and Se4) and 20 orifice gates (OG1 to OG20) facing the tailrace. Entrances Se2 and Se3 were open at all times, and even-numbered orifice gates on an alternating (open/closed) schedule. All other gates were kept closed. The transition pool extends from the collection channel up to the ladder, and varied in length depending on elevation of water in the tailrace.

Receiver sites were positioned at approximately rkm 553, to determine when radio-tagged salmon entered the Hanford Reach section of the Columbia River (Figure 1). This site allowed us to study times for salmon to pass through the free flowing section of the Columbia River between the upstream end of the McNary Dam pool and the tailrace of Priest Rapids Dam.

Tagging

Adult spring and summer chinook salmon were released with radio-transmitter tags near Bonneville Dam from 3 April to 16 July. Sockeye salmon were tagged and released during 9 June to 5 August. Fish were collected using the trap facility located adjacent to the Washington-shore ladder. During the day, a picketed-lead weir was dropped into the ladder to divert adult migrants into the trap holding pool. Salmon swam from the holding pool into chutes and were diverted into an anesthetic tank (tricaine methanesulfonate, 100 mg/l) via electronically controlled gates. Anesthetized fish were moved to a smaller tank where they were measured, examined for marks and injuries, and tagged. Each fish received a coded wire tag injected into

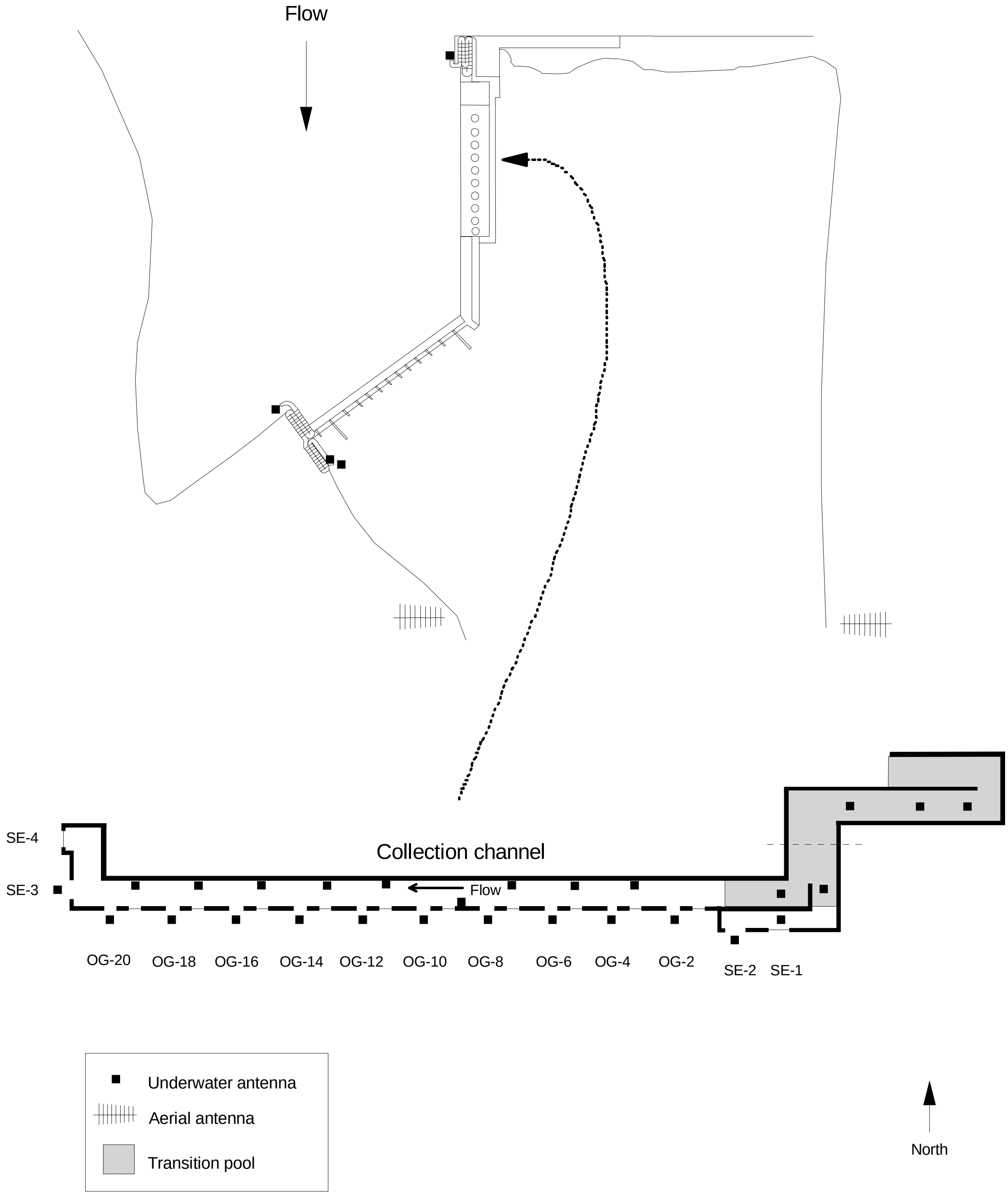

Figure 3. Study area at Wanapum Dam, showing placement of radio receiver antenna at dam and in fishway. Entrances Se2, Se3 and even-numbered orifice gates were used during this study.

the muscle near the dorsal fin, a numbered visual-implant (VI) tag injected under the clear tissue posterior to the eye, and a radio transmitter inserted into the stomach through the mouth. Fish were then placed in an aerated tank on a trailer to recover. Fish were transported 8 km downstream from Bonneville Dam after tagging and released using an exit chute attached to the rear of the trailer. Of 1,016 adult chinook salmon tagged at Bonneville Dam, 680 were selected at random from the spring run and 336 from the summer run. "Jack" salmon were not tagged. Fork lengths of chinook salmon tagged ranged from 61 to 112 cm. A total of 577 adult sockeye salmon were tagged at Bonneville Dam in 1997 ranging in length from 38 to 63 cm.

Telemetry Monitoring

Radio transmitters and receivers used in this study were manufactured by Lotek Engineering Inc., of New Market, Ontario, Canada. Transmitters (80 mm long x 16 mm diameter) emitted a digitally coded signal every 5 seconds. Transmitter signals were interpreted by radio receivers as a unique numerical code on the transmitted channel (frequency). Transmitter frequencies ranged from 149.480 (channel 9) to 149.740 MHz (channel 22) in 0.02 MHz increments.

At Priest Rapids Dam, SRX-400 sequentially scanning receivers, set to scan for 6 seconds on each channel, were connected to two, 9-element Yagi antennas (one pointed upstream and one downstream) placed on each shore about 1.2 km downstream from the dam to record when fish entered the tailrace. Eight SRX receivers linked with digital-spectrum processors (DSP/SRX) that scanned all channels simultaneously were used to monitor fishway entrances and exits, and movement in the collection channel, transition pool and east ladder (Figure 2). Each DSP/SRX receiver monitored up to six coaxial-cable underwater antennas. The west-shore ladder entrance was not monitored but fish exiting the top of the west ladder were recorded. Changes from the setup used in 1996 were the addition of an antenna upstream from the trap at the top of the east-shore ladder, and an antenna added upstream from the fish counting station near the bottom of the east-shore ladder.

At Wanapum Dam, two SRX receivers with Yagi antenna were located approximately 1.0 km downstream from the dam and 10 DSP/SRX receivers were used to monitor fishway entrances, movements within the collection channel, tops of ladders and the east-shore ladder transition pool. All receivers recorded and stored transmitter channel and code, relative power of signal, antenna receiving the signal, date and time. Stored information was downloaded from receivers to notebook computers once a week. Two SRX receivers, each with a Yagi antenna, one on either shore, were positioned at approximately rkm 553, to determine when radio-tagged salmon entered the Hanford Reach section of the Columbia River.

Orifice gate treatments (half-open or all-closed) were alternated through the monitoring season, 19 April to 10 August. Orifice gates were maintained at a treatment setting until it was determined that at least five radio-tagged fish had entered the east-shore fishway transition pools, based on nightly remote downloads of transition-pool receivers via modem. Once five or more salmon with transmitters had been recorded, orifice gates were then changed to the other treatment, at about midnight. It was possible that fewer than five fish could be available for analysis from each treatment period because of missing data (no tailrace record, first approach, or first entrance) or because it was exposed to more than one orifice gate treatment and so had to be removed from analysis for a particular variable (see below).

Data Analysis

Downloaded data files were electronically transferred to the NMFS office in Seattle for initial processing. This involved screening each file of records and removing obvious errors and records produced from background electronic noise. Screened files were then transferred to the University of Idaho for coding. Coding involved inspection of all records for a fish and assigning a code to appropriate records that defined behavior of the fish (e.g. an entrance or exit from a fishway). Coding was facilitated by using an automated program developed with ArcView software package (Version 2 for Windows).

Coded data were used to identify movement patterns of each radio-tagged fish at Priest Rapids and Wanapum dams, and were also used to calculate passage-time variables. Five passage variables used in the analysis were time for each fish from first record in the tailrace until: (1) it first approached an entrance, (2) first passed through a fishway entrance, (3) first entered the transition pool, and from time of first approach at a fishway entrance until: (4) it first entered the fishway and (5) first entered the transition pool at the two dams. Times to reach top of the east-shore ladder at Priest Rapids Dam were lost for many salmon because the receiver at that site was not downloaded often enough, became memory-full, and fish could exit the ladder without being recorded. Also, many fish with passage times could not be used in analysis because they were exposed to more than one orifice gate treatment prior to making their final entrance to fishways at both dams. Consequently, we were not able to analyze total time for chinook salmon to pass Priest Rapids Dam because of insufficient data.

Effects of orifice gate pattern were evaluated by comparing passage times by chinook and sockeye salmon (analyzed separately) during periods of time with orifice gates open and closed using ANOVA and two non-parametric statistics. A block of time with one period when orifice gates were open and one period with orifice gates closed was the experimental unit during this study. Mean travel times for fish in each period within a block represented a single replicate for analysis. Differences in travel times between periods when orifice gates were open and closed were tested using a blocked analysis of variance (ANOVA) model from SAS statistical package (SAS Institutes Inc. 1990). The block term was removed from the overall model if it was found to be insignificant and the analysis was rerun, testing for orifice gate status in a one-way ANOVA model. The number of fish included in each period depended on the orifice-gate pattern to which a fish was exposed (Figure 4). For example, if orifice-gate pattern changed between the time a fish first approached and first entered the collection channel, passage times for the fish were included in the analysis for first approaches, but not for first entrances (Figure 4). When needed, consecutive time periods with the same treatment (open or closed orifice gates) were clumped to produce replicate blocks that contained passage times for at least four (five when possible) salmon. Data from orifice gates tests were also tested using

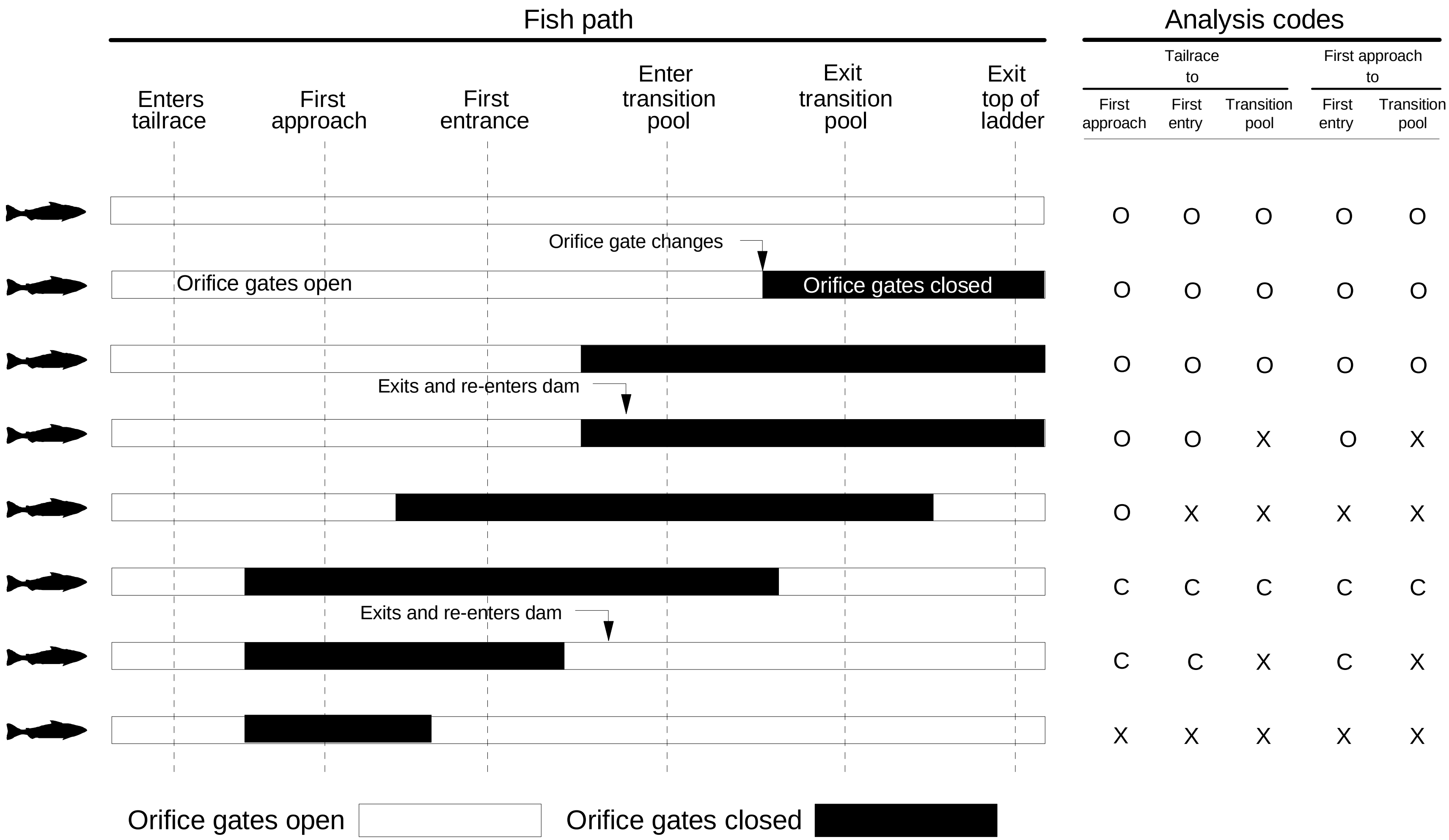

Figure 4. Illustration of process used to include or exclude passage time measurements from analysis. Horizontal bars represent potential travel paths by a radio-tagged salmon with changes in orifice gates from open (open bars) to closed (solid bars) treatments (or vice versa) during a fish's passage. Analysis codes indicate if a passage-time variable occurred during the open (O) or closed (C) orifice gate treatment, and if a fish was not used in analysis (X).

non-parametric Mann-Whitney test for ranked data and the median test for two samples (SAS Institutes Inc. 1990).

Behavior of radio-tagged salmon in and through the transition pool at Wanapum Dam was assessed by calculating intervals between first entrance to the pool and the last exit from the pool and by identifying patterns of behavior during that interval. Times to exit the upstream end of the transition pool at Priest Rapids Dam were lost for many fish because that receiver was not downloaded often enough, became memory-full, and salmon passed up the ladder without being recorded. Consequently, passage through the transition pool at Priest Rapids Dam could be evaluated for only a small number of salmon in 1997. Fallback of salmon over the dams was known to have occurred when fish that exited from top of the ladders were later recorded somewhere downstream of the dam. Delay caused from a fallback event was the time required to re-ascend the dam after the initial ladder exit. The fishway fence installed Priest Rapids Dam was evaluated by comparing the exit/entrance ratio at Lew2 in 1997 to that observed in 1996, prior to installation of the fence.

Effects of Orifice Gate Closure

Priest Rapids Dam Chinook Salmon

From 1 May until 20 August 1997, orifice gates at the Priest Rapids Dam powerhouse collection channel were alternately opened and closed a total of 16.5 times (17 opened periods and 16 closed periods) during which 217 chinook salmon with transmitters were recorded at receiver sites at the dam (Table 1). Clumping time periods resulted in 10 to 13 complete replicate blocks of orifice gate treatment for ANOVA analysis, depending on variable analyzed (Table 1). We found that chinook salmon passage times were not significantly increased by closing orifice gates at Priest Rapids Dam in 1997.

Times from first record in the tailrace to first approach at a fishway entrance were analyzed for 203 (out of total of 217) chinook salmon during 13 replicate blocks (Table 2). Mean times to first approach were 23.4 h when orifice gates were open and 11.5 h when orifice gates were

Table 1. Date ranges for orifice gate treatment periods, orifice gate treatment, number of salmon first recorded at dam (at any location), number used in analysis for the five passage-time variables, and periods used in each replicate for chinook salmon at Priest Rapids Dam, 1997.

Period	Orifice gate treatment	Fish recorded at dam	Tailrace to first approach		Tailrace to first entrance		Tailrace to transition pool		First approach to first entrance		First approach to transition pool	
			Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate
19 April-13 May	Open	6	2	1	2	1	2	1	5	1	5	1
14 May-21 May	Closed	19	19	1	7	1	7	1	7	1	7	1
22 May-25 May	Open	9	9	1	4	1	4	1	4	2	4	2
26 May-12 June	Closed	17	17	2	9	2	9	2	9	2	9	2
13 June-18 June	Open	7	7	2	4	2	4	2	4	3	4	2
19 June-29 June	Closed	3	3	3	3	3	3	3	3	3	3	3
30 June-1 July	Open	5	4	3	4	3	4	3	4	4	4	3
2 July-3 July	Closed	1	1	3	0	3	0	3	0	3	0	3
4 July	Open	3	3	4	3	4	3	4	3	5	3	4
5 July	Closed	4	4	4	4	3	4	3	4	3	4	3
6 July	Open	4	4	4	3	4	3	4	3	5	3	4
7 July-8 July	Closed	12	11	5	9	4	10	4	10	4	11	4
9 July	Open	11	10	5	7	5	7	5	7	6	7	5
10 July	Closed	7	7	6	5	5	6	5	5	5	6	5
11 July	Open	8	4	6	2	6	2	6	5	7	5	6
12 July	Closed	4	2	7	1	5	1	6	3	6	3	6
13 July	Open	7	6	7	3	6	3	6	3	8	3	6
14 July	Closed	6	6	7	5	6	5	6	5	6	5	6
15 July	Open	12	11	8	5	7	5	7	6	8	6	7
16 July	Closed	7	7	8	4	7	4	7	4	7	4	7
17 July	Open	6	6	9	4	8	3	8	4	9	3	8
18 July	Closed	13	13	9	8	8	8	8	8	8	8	8
19 July	Open	6	6	10	6	9	5	8	6	10	5	8
20 July	Closed	7	5	10	3	9	2	9	4	9	3	9
21 July	Open	5	5	11	2	10	2	9	2	11	2	9
22 July	Closed	5	4	11	3	9	3	9	4	10	3	9
23 July	Open	4	4	12	3	10	2	9	3	11	2	9
24 July	Closed	5	5	12	3	10	0	9	3	11	0	9

Table 1. Continued.

Period	Orifice gate treatment	Fish recorded at dam	Tailrace to first approach		Tailrace to first entrance		Tailrace to transition pool		First approach to first entrance		First approach to transition pool	
			Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate
25 July	Open	3	3	12	2	11	1	10	1	12	1	9
26 July-27 July	Closed	4	4	13	3	10	3	10	3	11	3	10
28 July-29 July	Open	6	6	13	4	11	4	10	4	12	4	10
30 July-10 August	Closed	5	4	13	4	11	4	10	4	12	4	10
11-20 August	Open	2	1	13	1	11	0	10	1	12	0	10

Table 2. Number of fish and mean and median times (h) for five passage variables from each replicate block of orifice gates treatment for chinook salmon at Priest Rapids Dam, 1997.

Replicate	Orifice gate treatment	Tailrace to first approach			Tailrace to first entrance			Tailrace to transition pool			First approach to first entrance			First approach to transition pool		
		n	mean	median	n	mean	median	n	mean	median	n	mean	median	n	mean	median
1	Open	11	66.6	10.3	6	157.8	50.4	6	157.9	50.5	5	28.0	41.6	5	28.2	42.0
1	Closed	19	20.1	6.3	7	72.9	69.6	7	73.0	69.9	7	26.8	2.0	7	26.9	2.0
2	Open	7	64.8	1.3	4	10.5	1.7	4	15.5	11.0	4	38.7	40.1	8	26.4	34.2
2	Closed	17	32.7	1.2	9	85.6	50.4	9	85.6	50.4	9	53.3	33.6	9	53.3	33.6
3	Open	4	120.7	6.0	4	124.1	9.9	4	124.3	10.1	4	9.2	0.3	4	3.6	3.1
3	Closed	4	28.7	28.8	7	21.2	6.8	7	21.3	6.9	7	3.7	0.2	7	3.8	0.2
4	Open	7	5.5	1.7	6	7.0	4.7	6	7.1	4.7	4	3.5	3.0	6	1.0	0.8
4	Closed	4	2.0	1.9	9	7.1	3.6	10	7.9	4.3	10	4.1	0.6	11	5.1	0.8
5	Open	10	2.1	1.5	7	4.9	4.9	7	5.0	4.9	6	0.9	0.8	7	2.3	2.6
5	Closed	11	2.6	1.8	6	6.9	7.6	6	7.4	7.7	5	3.2	3.2	6	3.4	3.5
6	Open	4	13.3	12.7	5	8.5	10.4	5	8.5	10.4	7	2.3	2.6	8	1.4	1.0
6	Closed	7	4.0	3.7	5	3.7	2.1	6	3.3	2.1	8	1.2	0.1	8	1.2	0.1
7	Open	6	3.0	1.7	5	6.3	6.3	5	6.3	6.3	5	1.4	0.9	6	1.2	0.6
7	Closed	8	2.0	1.3	4	11.1	10.6	4	11.2	10.6	4	4.7	1.4	4	4.8	1.5
8	Open	11	2.8	1.1	4	15.4	11.9	8	5.7	3.0	9	1.2	0.7	8	2.6	0.9
8	Closed	7	7.2	1.9	8	12.4	8.2	8	12.5	8.4	8	2.1	0.9	8	2.1	0.9
9	Open	6	3.1	1.4	6	10.4	4.1	4	6.3	5.6	4	11.0	4.9	5	3.9	2.5
9	Closed	13	6.9	1.3	6	12.1	10.3	5	12.4	9.5	4	2.1	1.7	6	2.6	1.7
10	Open	6	14.0	1.0	5	8.6	5.9	5	5.7	4.4	6	8.9	1.2	4	2.4	3.1
10	Closed	5	6.8	7.5	6	8.0	7.4	7	17.8	15.4	4	1.9	0.1	7	14.1	13.2
11	Open	5	1.7	1.0	6	6.7	4.8				5	5.2	4.2			
11	Closed	4	8.5	8.9	4	24.7	22.4				6	2.4	2.5			
12	Open	7	3.4	2.4							6	3.8	2.6			
12	Closed	5	4.0	2.2							4	22.4	20.2			
13	Open	7	2.9	1.2												
13	Closed	8	24.3	3.1												
Overall	Open	91	23.4	1.7	58	32.8	5.8	54	34.2	5.8	65	9.5	2.0	61	7.3	1.8
Overall	Closed	112	11.5	2.2	71	24.1	10.5	69	25.2	10.5	76	10.7	2.0	73	11.7	2.0

closed, and these values were not significantly different (ANOVA P = 0.8325). Removal of three fish that took 18.6, 19.3, and 19.6 d to first approach the dam changed the mean for open orifice gates to 6.5 h but the difference was still non-significant (P = 0.1508). Median times to first approach were 1.7 h when orifice gates were open and 2.2 h when orifice gates were closed and these values did not differ significantly (P = 0.3540); removal of the three fish that took 18.6, 19.3, and 19.6 d to first approach the dam reduced the median to 1.6 h when orifice gates were open but did not change results of analysis. Results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed did not rank different than when orifice gates were open (P = 0.1001). However, when the three outlier fish were removed, passage times with gates closed ranked lower (longer passage times) than when orifice gates were open (P = 0.0359).

A total of 217 chinook salmon were coded with first approaches during the study; 101 when orifice gates were open and 116 with orifice gates closed. When orifice gates were open, 11% of first approaches occurred at the west-powerhouse entrance (Lew2), 54% at the nine orifice gates, and 35% at the east-shore entrance (Lew4-5) (Figure 5). When orifice gates were closed, 21% of first approaches were at Lew2, 32% at orifice gates, 47% at Lew4-5, and one fish first approached the dam at an unknown location (Figure 5). Unknown approaches occur when fish are recorded at antenna sites inside the fishway without previously being recorded on an outside antenna.

Time and location of first entrances into the fishway are the primary variables of interest for this study. Time from first tailrace record until a fish first passed through a fishway entrance were analyzed for 129 (out of a total of 190) chinook salmon from 11 replicate blocks of orifice gate treatment (Table 2). Mean times for chinook salmon to first enter fishways were 32.8 h with orifice gates open and 24.1 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.5307). When two salmon with times to first entry of 19.8 and 21.0 d were removed from analysis, mean passage times were 15.8 h with orifice gates open, but the difference was still not significant (P = 0.1291). Median times for first entrances were 5.8 h with orifices open and 10.5 h with orifice gates closed, and these values were significantly

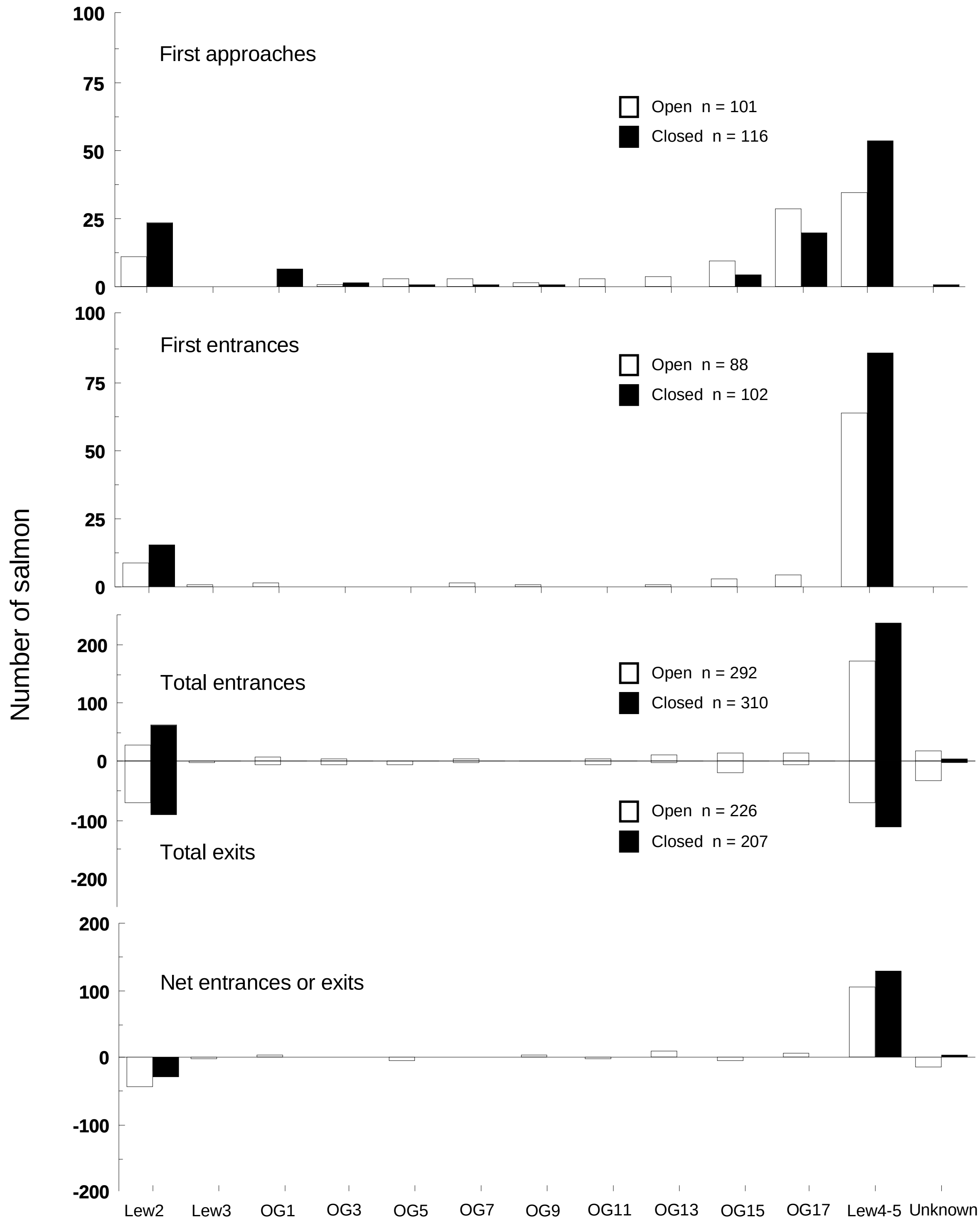

Figure 5. Number of first approaches, first entrances, total entries and exits, and net entrances or exits for radio-tagged chinook salmon at Priest Rapids Dam with orifice gates open and closed, 1997. Lew2 is the west-powerhouse entrance, Lew4-5 is the east-shore fishway entrance and OG's are orifice gates.

different (P = 0.0417). Likewise, results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed ranked lower (longer passage times) than when orifice gates were open (P = 0.0310). Removing the two salmon that took 19.8 and 21.0 d to enter with orifice gates open lowered the median to 5.5 h, but did not change results of analysis.

We analyzed times from first approach to first entrance by chinook salmon to separate time spent in tailrace prior to first approach from potential effects of orifice gate treatment on salmon passage. Times from first approach to first entrance to the fishway were analyzed for 141 fish during 12 replicate blocks of orifice gate treatment (Table 2). Times from first approach to first entrance were not significantly different with respect to orifice gate pattern, based on results from ANOVA (P = 0.8316), median (P = 0.9377), and Mann-Whitney (P = 0.5226) tests. Mean times from first approach to first entrance with orifice gates open and closed were 9.5 h and 10.7 h. Median times from first approach to first entrance with orifice gates open and closed were both 2.0 h.

Of 88 chinook salmon that first entered the fishway when orifice gates were open, 10% first entered at Lew2, 1% at Lew3 (during high flow), 16% at orifice gates, and 73% at Lew4-5 (Figure 5). When orifice gates were closed, 16% of the salmon first entered at Lew2 and 84% first entered at Lew4-5 (total of 102 salmon). There were 602 entries into the fishway by 190 chinook salmon; 292 entries by 125 fish (mean of 2.3 entries/fish) with orifice gates open and 310 entries by 134 fish (2.3 entries/fish) with orifice gates closed. With orifice gates open, 174 entries (60%) occurred at Lew4-5, 71 (24%) at orifice gates, 28 (10%) at Lew2 (plus one entry at Lew3) and 18 (6%) entries at unknown locations (Figure 5). When gates were closed, 239 (77%) of the total entries occurred at Lew4-5, 64 (21%) at Lew2 (plus one entry at Lew3), and 6 entries (2%) at unknown locations. The number of times chinook salmon exited the fishway and returned the tailrace totaled 433; 226 times by 92 salmon (2.5 exits/fish) when orifice gates were open, and 207 exits by 80 salmon (2.6 exits/fish) with closed orifice gates (Figure 5) and these values were not significantly different (ANOVA P = 0.1870). With orifice gates open, there were 71 (31%) exits at Lew2, 2 (1%) at Lew3, 53 (23%) at orifice gates, 69 (31%) at Lew4-5 and

31 exits (14%) at unknown locations. With orifice gates closed, 92 (44%) of exits occurred at Lew2, 113 (55%) at Lew4-5, and 2 exits (1%) occurred at unknown locations. The exit/entry ratio was 1.78 for Lew2, 0.44 for Lew4-5, and averaged 0.92 for orifice gates.

Time from first tailrace record until a fish first entered the transition pool in the east-shore fishway was analyzed for 123 chinook salmon during 10 replicate blocks of orifice gate treatments (Table 2). Mean times for chinook salmon to first enter the transition pool were 34.2 h with orifice gates open and 25.2 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.4438). Removing two salmon from analysis with times from the tailrace to the transition pool of 19.8 and 21.0 d when orifice gates were open resulted in a mean time of 15.6 h and lowered the P value to 0.061. Median times to enter to the transition pool were longer with orifices closed (10.5 h) than with orifice gates open (5.8 h; P = 0.0364). With the Mann-Whitney test for ranked data, times to first approach when orifice gates were closed ranked lower (longer passage times) than when orifice gates were open (P = 0.0235). Removing the two salmon with time to the transition pool of 19.8 and 21.0 d did not change results of the median or Mann-Whitney tests.

Analyses were run on times from first approach to first entrance into the transition pool by chinook salmon to separate time spent in tailrace prior to first approach from potential effects of orifice gate treatment on salmon passage. Time from first approach to first entrance into the transition pool was analyzed for 134 fish during 10 replicate blocks of orifice gate treatment (Table 2). Times from first approach to first entrance into the transition pool were not significantly different with respect to orifice gate pattern based on results from ANOVA (P = 0.1742), median (P = 0.6014) and Mann-Whitney (P = 0.9057) tests. Mean times from first approach to first entrance into the transition pool with orifice gates open and closed were 7.3 h and 11.7 h. Median times from first approach to first entrance into the transition pool with orifice gates open and closed were 1.8 h and 2.0 h.

Times from first record in the tailrace to last record at tops of ladders were available for 56 chinook salmon in five blocks of replicates. Times from first approach to last record at tops of ladders were available for 58 fish in five replicate blocks. These numbers were insufficient to produce reliable results from analysis. Data lost when the receiver monitoring top of the east-shore ladder became memory-full several times, along with salmon that were eliminated from analysis because of exposure to more than one orifice gate treatment, combined to produce the low sample size for this variable.

Priest Rapids Dam Sockeye Salmon

From 1 May until 10 August 1997, orifice gates at the Priest Rapids Dam powerhouse collection channel were alternately opened and closed a total of 14 times and 440 sockeye salmon with transmitters were recorded at receiver sites at the dam (Table 3). Clumping time periods resulted in 12 or 13 complete replicate blocks of orifice gate treatment for ANOVA analysis, depending on variable analyzed (Table 4). We found that sockeye salmon passage times were not significantly increased by closing orifice gates at Priest Rapids Dam in 1997.

Times from first record in the tailrace to first approach at a fishway entrance were analyzed for 380 (out of total of 391) sockeye salmon during 13 replicate blocks (Table 4). Mean times to first approach were 5.5 h when orifice gates were open and 6.2 h when orifice gates were closed, and these values were not significantly different (ANOVA P = 0.9887). Median times to first approach were 1.7 h when orifice gates were open and 1.7 h when orifice gates were closed and these values did not differ significantly (P = 0.7089). Results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed did not rank different than when orifice gates were open (P = 0.7085).

A total of 419 sockeye salmon were coded with first approaches during the study; 187 when orifice gates were open and 232 with orifice gates closed. When orifice gates were open, 11% of first approaches occurred at Lew2, 48% at the nine orifice gates, 37% at Lew4-5, and 4% approached at unknown locations (Figure 6). When orifice gates were closed, 21% of first approaches were at Lew2, 32% at orifice gates, 45% at Lew4-5, and 2% first approached at unknown locations (Figure 6).

Table 3. Date ranges for orifice gate treatment periods, orifice gate treatment, number of sockeye salmon first recorded at dam (at any location), number used in analysis for the five passage-time variables, and periods used in each replicate at Priest Rapids Dam, 1997.

Period	Orifice gate treatment	Fish recorded at dam	Tailrace to first approach		Tailrace to first entrance		Tailrace to transition pool		First approach to first entrance		Tailrace to top of ladder	
			Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate
13-18 June	Open	1	1	1	1	1	0	1	1	1	1	1
19-29 June	Closed	6	6	1	6	1	6	1	6	1	5	1
30 June-1 July	Open	9	7	1	7	1	7	1	8	1	3	1
2-3 July	Closed	14	14	2	13	2	11	2	13	2	9	2
4 July	Open	13	12	2	10	2	10	2	10	2	3	2
5 July	Closed	19	17	3	15	3	16	3	15	3	1	3
6 July	Open	16	16	3	13	3	13	3	14	3	0	2
7-8 July	Closed	60	47	4	42	4	45	4	45	4	9	3
9 July	Open	32	26	4	23	4	26	4	23	4	5	2
10 July	Closed	22	17	5	11	5	16	5	13	5	0	4
11 July	Open	33	20	5	13	5	17	5	17	5	7	3
12 July	Closed	28	25	6	19	6	23	6	21	6	11	4
13 July	Open	25	22	6	16	6	19	6	19	6	1	4
14 July	Closed	22	19	7	11	7	11	7	12	7	2	5
15 July	Open	22	21	7	18	7	19	7	19	7	2	4
16 July	Closed	17	16	8	9	8	11	8	11	8	4	5
17 July	Open	8	8	8	8	8	8	8	8	8	1	4
18 July	Closed	13	12	9	10	9	11	9	10	9	0	6
19 July	Open	15	13	9	12	9	10	9	13	9	1	5
20 July	Closed	11	9	10	9	10	9	10	9	10	1	6
21 July	Open	8	8	10	5	10	5	10	6	10	3	5
22 July	Closed	9	9	11	7	11	8	11	10	11	5	6
23 July	Open	7	6	11	6	11	6	11	6	11	5	6
24 July	Closed	6	4	12	3	12	3	11	3	12	2	7
25 July	Open	6	5	12	5	12	5	12	6	12	1	7
26-27 July	Closed	8	8	13	8	12	8	12	8	12	4	7
26 29 July	Open	5	5	13	5	13	5	13	5	13	4	7
30 July-10 August	Closed	12	7	14	4	13	3	12	8	13	8	8

Table 4. Number of fish and mean and median times (h) for five passage variables from each replicate block of orifice gates treatment for sockeye salmon at Priest Rapids Dam, 1997.

Replicate	Orifice gate treatment	Tailrace to first approach			Tailrace to first entrance			Tailrace to transition pool			First approach to first entrance			Tailrace to top of ladder		
		n	mean	median	n	mean	median	n	mean	median	n	mean	median	n	mean	median
1	Open	8	4.6	1.9	8	4.7	2.1	7	5.3	2.2	9	0.1	0.1	4	33.1	26.0
1	Closed	6	3.7	2.9	6	13.5	6.2	6	13.8	6.9	6	9.7	0.6	5	36.3	38.8
2	Open	12	3.1	1.6	10	4.4	3.0	10	5.0	3.4	10	1.2	0.4	9	19.4	9.5
2	Closed	14	22.7	1.5	13	25.8	2.8	11	5.5	4.0	13	1.5	0.2	9	22.0	18.6
3	Open	16	2.8	1.3	13	4.8	1.4	13	4.2	3.4	13	1.7	0.3	7	32.8	34.2
3	Closed	17	2.9	1.2	15	4.2	2.8	16	4.4	3.1	15	1.0	0.9	10	7.9	5.1
4	Open	26	6.1	2.1	23	7.0	2.7	26	7.0	3.3	23	0.5	0.1	4	25.8	25.7
4	Closed	47	3.1	1.6	42	4.5	3.1	45	5.4	3.9	45	1.7	0.5	11	20.1	20.8
5	Open	20	4.6	1.5	13	6.8	3.3	17	6.2	2.9	15	0.5	0.05	4	28.0	17.8
5	Closed	17	9.9	5.6	11	11.8	6.6	16	10.5	4.8	11	0.6	0.1	6	27.2	9.8
6	Open	22	3.2	1.4	16	4.1	2.0	19	4.6	3.0	16	0.2	0.1	5	20.4	17.8
6	Closed	25	6.2	2.0	19	5.9	2.9	23	6.2	3.4	19	0.7	0.1	6	25.6	21.8
7	Open	21	6.1	1.4	18	6.6	1.6	19	6.8	2.3	18	0.7	0.1	5	45.5	47.3
7	Closed	19	6.1	2.0	11	10.6	4.8	11	9.2	4.8	11	1.4	0.02	6	64.3	28.9
8	Open	8	3.7	1.4	8	5.4	2.6	8	7.6	4.2	8	1.7	0.5	0		
8	Closed	16	2.3	1.4	9	4.8	3.6	11	4.4	3.4	9	1.7	0.1	8	43.9	24.3
9	Open	13	17.6	8.6	12	18.9	7.7	10	10.8	7.7	13	0.6	0.1			
9	Closed	12	2.3	1.2	10	3.6	1.9	11	3.8	2.7	10	1.1	0.4			
10	Open	8	3.7	1.8	5	4.2	1.9	5	5.5	3.0	5	0.1	0.1			
10	Closed	9	7.7	2.2	9	10.0	7.2	9	10.1	7.2	9	2.3	1.3			
11	Open	6	4.1	1.5	6	5.9	5.3	6	8.0	5.8	6	1.8	1.5			
11	Closed	9	4.3	1.5	7	6.1	1.7	11	6.4	3.8	9	6.9	1.9			
12	Open	5	1.8	1.2	5	2.9	3.3	5	5.3	4.6	6	1.0	0.6			
12	Closed	4	5.6	4.5	11	5.3	2.3	11	6.9	2.6	11	0.6	0.1			
13	Open	5	10.6	10.0	5	10.6	10.1	5	11.2	10.1	5	0.1	0.1			
13	Closed	8	5.2	2.0	4	10.8	11.5				5	3.6	2.0			
14	Closed	7	4.8	2.7												
Overall	Open	170	5.5	1.7	142	6.6	2.6	149	6.7	3.0	146	0.8	0.1	37	29.5	26.0
Overall	Closed	210	6.2	1.7	165	9.0	3.2	177	7.2	3.6	171	2.5	0.3	61	30.9	22.8

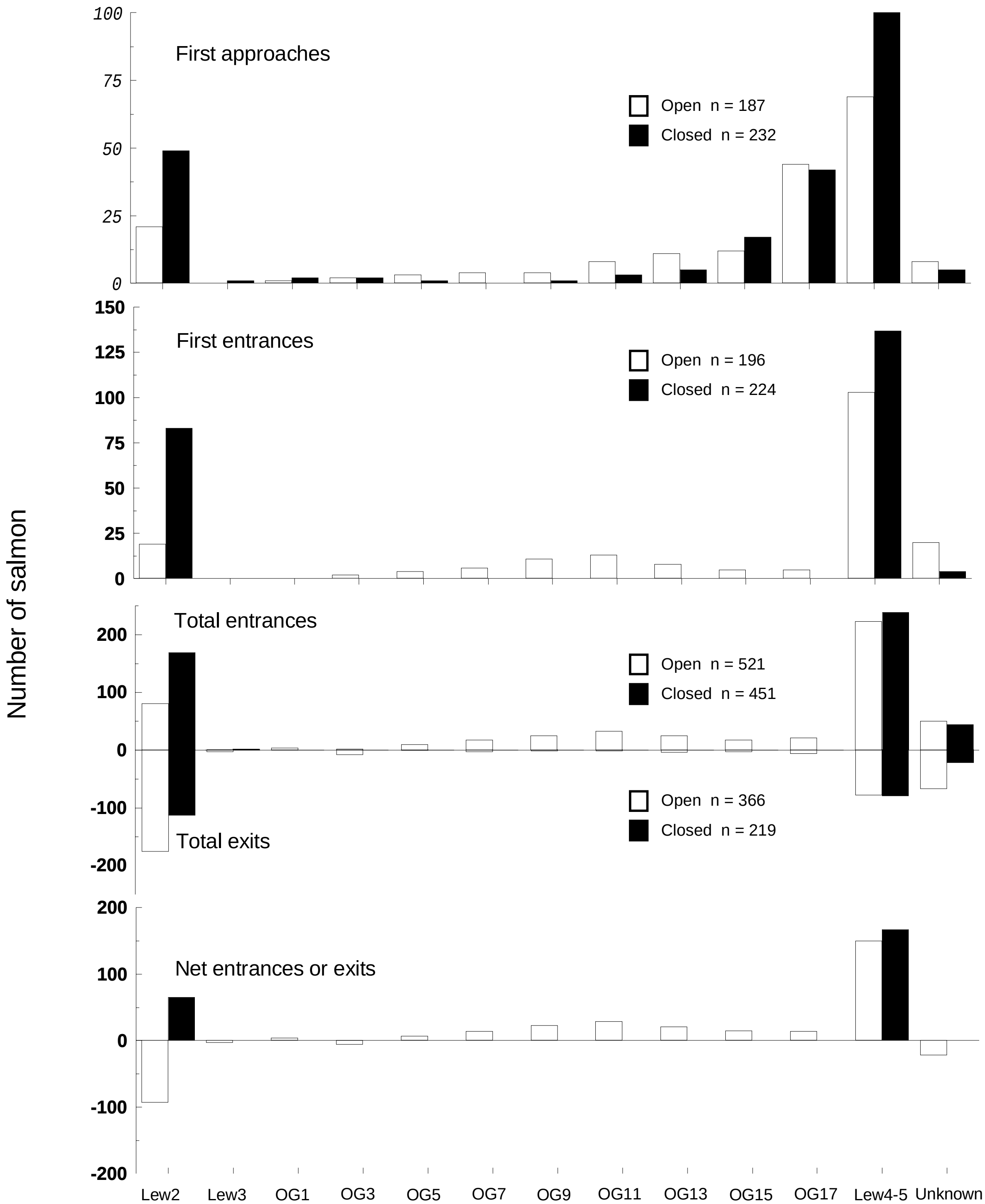

Figure 6. Number of first approaches, first entrances, total entries and exits, and net entrances or exits for radio-tagged sockeye salmon at Priest Rapids Dam with orifice gates open and closed, 1997. Lew2 is the west-powerhouse entrance, Lew4-5 is the east-shore fishway entrance and OG's are orifice gates.

Time and location of first entrances into the fishway are the primary variables of interest for this study. Times from first tailrace record until a fish first passed through a fishway entrance were analyzed for 307 (out of a total of 352) sockeye salmon from 13 replicate blocks of orifice gate treatment (Table 4). Mean times for sockeye salmon to first enter fishways were 6.6 h with orifice gates open and 9.0 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.2909). Median times for first entrances were 2.6 h with orifice gates open and 3.2 h with orifice gates closed, and these values were not significantly different (P = 0.2757). Results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed did not rank lower than when orifice gates were open (P = 0.2859).

Times from first approach to first entrance to the fishway were analyzed for 317 fish during 13 replicate blocks of orifice gate treatment (Table 4). Times from first approach to first entrance were significantly different with respect to orifice gate pattern, based on results from ANOVA (P = 0.0346) and median (P = 0.0418) and Mann-Whitney (P = 0.0402) tests. Mean times from first approach to first entrance with orifice gates open and closed were 0.8 h and 2.5 h. Median times from first approach to first entrance with orifice gates open and closed were 0.1 h and 0.3 h.

Of 196 sockeye salmon that first entered the fishway when orifice gates were open, 10% first entered at Lew2, 27% at orifice gates, 53% at Lew4-5, and 10% first entered at unknown locations (Figure 6). When orifice gates were closed, 37% of the salmon first entered at Lew2, 61% first entered at Lew4-5, and 2% entered at unknown locations (total of 224 salmon). There were 972 entries into the fishway by 404 sockeye salmon; 521 entries by 245 fish (mean of 2.1 entries/fish) with orifice gates open and 451 entries by 269 fish (1.7 entries/fish) with orifice gates closed. For total entries when orifice gates were open, 229 (44%) occurred at Lew4-5, 163 (31%) at orifice gates, 84 (16%) at Lew2 (plus one entry at Lew3) and 46 (9%) entries at unknown locations (Figure 6). When gates were closed, 248 (55%) of total entries occurred at Lew4-5, 179 (40%) at Lew2 (plus one at Lew3), and 23 entries (5%) occurred at unknown locations. The number of times sockeye salmon exited the fishway and returned to the tailrace totaled 585; 366 times by 160 salmon (2.3 exits/fish) when orifice gates were open, and 219 exits by 124 salmon (1.8 exits/fish) with closed orifice gates (Figure 6) and these values were significantly different (ANOVA P = 0.0128). With orifice gates open, the distribution of exits was 177 (48%) at Lew2, 4 (1%) at Lew3, 38 (10%) at orifice gates, 79 (22%) at Lew4-5 and 68 exits (19%) at unknown locations. With orifice gates closed, 114 (52%) exits occurred at Lew2, one at Lew3, 81 (37%) at Lew4-5, and 23 exits (11%) occurred at unknown locations. The exit/entry ratio was 1.11 for Lew2, 0.34 for Lew4-5, and averaged 0.70 for orifice gates.

Time from first tailrace record until a fish first entered the transition pool in the east-shore fishway was analyzed for 326 sockeye salmon during 12 replicate blocks of office gate treatments (Table 4). Mean times for sockeye salmon to first enter the transition pool were 6.7 h with orifice gates open and 7.2 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.8108). Median times to enter to the transition pool were 3.0 h with orifices open and 3.6 h with orifice gates closed and these values were not significantly different (P = 0.4040). With the Mann-Whitney test for ranked data, times to first approach when orifice gates were closed did not rank lower than when orifice gates were open (P = 0.7699).

Time from first approach to first entrance into the transition pool was analyzed for 314 fish during 12 replicate blocks of orifice gate treatment (Table 4). Times from first approach to first entrance into the transition pool were not significantly different with respect to orifice gate pattern based on results from ANOVA (P = 0.4117), median (P = 0.2647) and Mann-Whitney (P = 0.2792) tests. Mean times from first approach to first entrance into the transition pool with orifice gates open and closed were 1.6 h and 2.4 h. Median times from first approach to first entrance into the transition pool with orifice gates open and closed were 0.5 h and 0.7 h.

Times from first record in the tailrace to last record at tops of ladders were analyzed for 98 sockeye salmon in seven blocks of replicates and were not significantly different with respect to orifice gate pattern based on results from ANOVA (P = 0.6569), median (P = 0.7396) and Mann-Whitney (P = 0.4329) tests. Mean times to cross the dam with orifice gates open and closed were 29.5 h and 30.9 h. Median times to cross the dam with orifice gates open and closed were 26.0 h and 22.8 h.

Wanapum Dam Chinook Salmon

From 4 May until 20 August 1997, orifice gates at the Wanapum Dam powerhouse collection channel were alternately opened and closed a total of 18 times and 199 chinook salmon with transmitters were recorded at receiver sites at the dam (Table 5). Clumping time periods resulted in 7 to 13 complete replicate blocks of orifice gate treatment for ANOVA analysis, depending on variable analyzed (Table 6). We found that chinook salmon passage times were not significantly increased by closing orifice gates at Wanapum Dam in 1997.

Times from first record in the tailrace to first approach at a fishway entrance were analyzed for 186 (out of total of 204 first approaches with fallback fish) chinook salmon during 12 replicate blocks (Table 6). Mean times to first approach were 4.8 h when orifice gates were open and 3.5 h when orifice gates were closed, and these values were not significantly different (ANOVA P = 0.4452). Median times to first approach were 1.3 h when orifice gates were open and 1.4 h when orifice gates were closed and these values did not differ significantly (P = 0.6597). Results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed did not rank different than when orifice gates were open (P = 0.4136).

There were a total of 206 first approaches to the dam by 198 chinook salmon (eight fish were coded with first approaches a second time after they fell back at the dam) during the study; 94 when orifice gates were open and 112 with orifice gates closed. When orifice gates were open, 5% of first approaches occurred at the west-shore entrance (Rew2), 9% at the south-powerhouse entrance (Se3), 14% at the ten orifice gates, and 72% at the east-shore ladder entrance (Se2) (Figure 7). When orifice gates were closed, 7% of first approaches were at Rew2, 5% of first approaches were at Se3, 11% at orifice gates, and 77% were at Se2 (Figure 7).

Table 5. Date ranges for orifice gate treatment periods, orifice gate treatment, number of chinook salmon first recorded at dam (at any location), number used in analysis for the five passage-time variables, and periods used in each replicate at Wanapum Dam, 1997.

Period	Orifice gate treatment	Fish recorded at dam	Tailrace to first approach		Tailrace to first entrance		Tailrace to transition pool		First approach to first entrance		Tailrace to top of ladder	
			Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate
4-6 May	Open	6	6	1	5	1	5	1	5	1	3	1
17-22 May	Closed	5	5	1	5	1	5	1	5	1	5	1
23-26 May	Open	10	10	2	10	2	10	2	10	2	10	1
27 May-7 June	Closed	9	9	2	9	2	8	2	9	2	9	2
8-12 June	Open	6	4	3	4	3	4	3	6	3	3	2
13-21 June	Closed	5	5	3	5	3	5	3	5	3	5	3
22 June-1 July	Open	7	6	3	5	4	4	4	5	4	6	3
2-3 July	Closed	3	3	3	2	3	2	3	2	3	2	3
4 July	Open	1	1	4	0	4	0	4	0	5	0	3
5 July	Closed	1	1	3	2	4	1	4	2	4	2	4
6 July	Open	2	1	4	1	4	1	4	2	5	1	3
7 July	Closed	5	1	4	1	4	1	4	5	4	1	4
8 July	Open	0	0	4	0	5	0	5	0	5	0	4
9 July	Closed	11	10	4	8	4	5	4	8	5	4	4
10 July	Open	3	2	4	1	5	0	5	2	5	1	4
11 July	Closed	8	7	5	7	5	7	5	7	6	5	5
12 July	Open	13	11	5	7	5	7	5	9	6	3	4
13 July	Closed	6	6	6	6	6	5	6	6	7	2	6
14 July	Open	5	5	6	4	6	3	6	4	7	0	4
15 July	Closed	5	4	7	4	7	2	7	5	8	2	6
16 July	Open	7	7	7	5	7	4	6	5	8	1	4
17 July	Closed	11	10	7	9	7	5	7	10	9	7	6
18 July	Open	10	10	8	9	8	8	7	9	9	7	5
19 July	Closed	11	11	8	8	8	4	8	8	10	4	7
20 July	Open	7	7	9	6	9	6	8	6	10	3	6
21 July	Closed	5	4	9	4	9	3	8	5	11	2	7
22 July	Open	2	2	10	1	10	1	9	1	11	1	6
23 July	Closed	7	7	9	6	9	6	9	6	12	5	8

Table 5. Continued.

Period	Orifice gate treatment	Fish recorded at dam	Tailrace to first approach		Tailrace to first entrance		Tailrace to transition pool		First approach to first entrance		Tailrace to top of ladder	
			Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate
24 July	Open	6	6	10	6	10	5	9	6	11	2	6
25 July	Closed	6	6	10	5	10	3	10	5	13	1	8
26 July	Open	1	1	11	1	11	0	10	1	12	1	7
27 July	Closed	6	6	11	6	11	4	10	6	14	5	9
28 -29 July	Open	3	3	11	3	11	2	10	3	12	0	7
30-31 July	Closed	6	6	12	5	12	3	10	5	15	5	9
1-10 August	Open	5	5	12	5	12	4	10	5	13	3	7
11-20 August	Closed	1	1	12	1	12	1	10	1	15	1	9

Table 6. Number of fish and mean and median times (h) for five passage variables from each replicate block of orifice gates treatment for chinook salmon at Wanapum Dam, 1997.

Replicate	Orifice gate treatment	Tailrace to first approach			Tailrace to first entrance			Tailrace to transition pool			First approach to first entrance			Tailrace to top of ladder		
		n	mean	median	n	mean	median	n	mean	median	n	mean	median	n	mean	median
1	Open	6	3.3	1.8	5	4.6	3.7	4	4.9	3.8	5	0.8	1.0	13	13.0	8.8
1	Closed	5	1.0	1.0	5	18.2	1.7	5	20.8	13.5	5	17.2	0.6	5	27.2	18.1
2	Open	10	1.9	2.0	10	4.6	3.5	7	5.1	4.7	10	2.8	1.7	3	18.1	18.1
2	Closed	9	3.0	1.4	9	40.4	13.6	7	40.	13.8	9	37.4	5.6	9	42.6	15.8
3	Open	10	9.2	1.7	4	10.9	10.0	4	11.0	10.1	6	11.5	9.7	7	22.4	13.5
3	Closed	9	7.1	6.9	7	13.2	11.2	6	17.2	11.3	7	5.3	3.3	7	22.5	14.7
4	Open	4	7.7	3.8	6	16.1	4.9	4	18.4	2.2	5	0.8	0.1	5	13.8	10.1
4	Closed	11	6.9	5.1	11	8.8	7.6	6	7.2	6.8	7	2.1	0.3	7	14.9	15.4
5	Open	11	1.0	0.9	8	4.8	2.6	5	3.4	3.1	4	1.6	0.6	7	13.9	14.1
5	Closed	7	2.1	1.5	7	5.7	5.3	7	7.5	7.5	8	4.0	3.7	5	15.1	14.1
6	Open	5	3.5	1.6	4	9.0	8.9	6	8.4	7.8	9	1.7	1.9	6	12.2	12.6
6	Closed	6	1.8	1.2	6	4.6	4.2	5	5.5	5.2	7	3.5	3.1	11	15.7	17.3
7	Open	7	1.0	1.1	5	2.5	2.4	8	8.5	7.8	4	5.5	6.5	5	44.3	21.9
7	Closed	14	13.9	2.3	13	19.0	10.5	7	9.8	11.4	6	2.8	3.3	6	11.0	8.6
8	Open	10	2.8	1.0	9	6.0	4.0	6	7.2	8.2	5	1.3	0.7			
8	Closed	11	1.8	1.2	8	4.6	2.8	7	4.0	1.9	5	5.7	5.6	6	13.4	14.2
9	Open	7	2.4	1.5	6	5.6	3.7	6	7.1	5.4	9	3.0	2.6			
9	Closed	11	2.9	2.3	10	6.3	3.6	5	5.8	3.7	10	1.4	1.4	11	26.7	15.6
10	Open	8	1.7	1.0	7	4.2	2.9	6	14.0	11.3	6	3.0	2.0			
10	Closed	6	2.0	1.2	5	3.9	4.4	10	6.5	3.9	8	2.5	1.3			
11	Open	4	1.5	1.0	4	4.9	5.2				7	2.7	1.6			
11	Closed	6	2.6	1.5	6	3.3	2.6				5	3.5	1.5			
12	Open	5	5.6	1.9	5	7.0	4.6				4	3.5	4.0			
12	Closed	7	2.1	0.8	6	8.5	7.1				6	2.6	2.5			
13	Open										5	1.4	0.3			
13	Closed										5	1.9	1.2			
14	Closed										6	0.7	0.6			
15	Closed										6	6.1	2.3			
Overall	Open	85	4.8	1.3	71	6.7	3.7	63	8.8	5.5	79	3.0	1.6	44	19.7	13.1
Overall	Closed	101	3.5	1.4	92	12.8	5.5	70	15.1	6.6	100	6.7	2.2	66	23.6	15.6

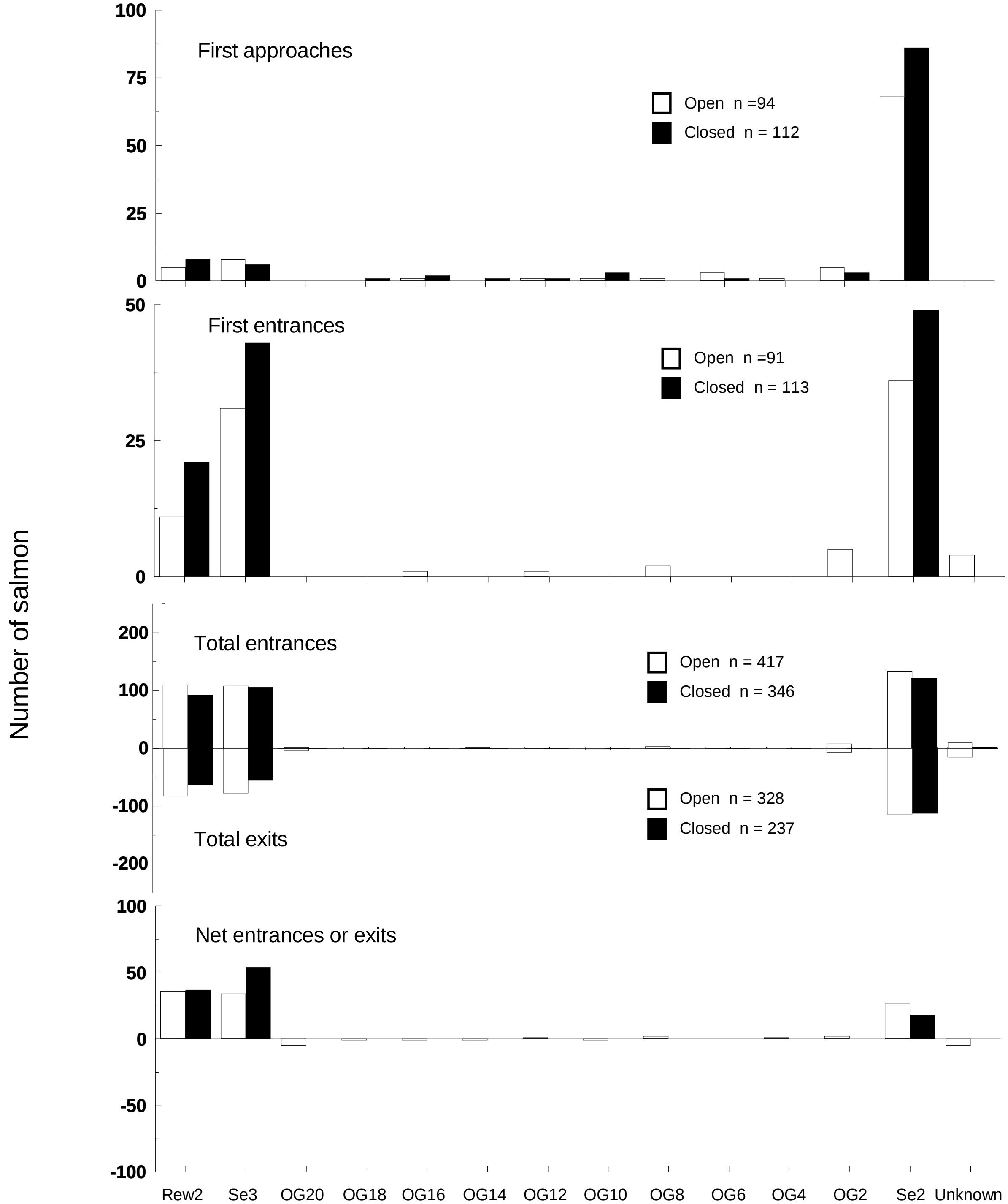

Figure 7. Number of first approaches, first entrances, total entries and exits, and net entrances or exits for radio-tagged chinook salmon at Wanapum Dam with orifice gates open and closed, 1997. Rew2 is the west-shore entrance. Se3 is the south-powerhouse entrance, Se2 is the east-shore fishway entrance and OG's are orifice gates.

Time and location of first entrances into the fishway are the primary variables of interest for this study. Time from first tailrace record until a fish first passed through a fishway entrance were analyzed for 163 (out of a total of 93 salmon with fallback fish) chinook salmon from 12 replicate blocks of orifice gate treatment (Table 6). Mean times for chinook salmon to first enter fishways were 6.7 h with orifice gates open and 12.8 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.1353). Median times to first entrances were 3.7 h with orifices open and 5.5 h with orifice gates closed, and these values were significantly different (P = 0.0478). Results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed ranked lower than when orifice gates were open (P = 0.0253).

Times from first approach to first entrance to the fishway were analyzed for 179 fish during 13 replicate blocks of orifice gate treatment (Table 6). Times from first approach to first entrance were not significantly different with respect to orifice gate pattern, based on results from ANOVA (P = 0.2389), median (P = 0.3249), and Mann-Whitney (P = 0.1376) tests. Mean times from first approach to first entrance with orifice gates open and closed were 3.0 h and 6.7 h. Median times from first approach to first entrance with orifice gates open and closed were 1.6 h and 2.2 h.

Of 91 chinook salmon that first entered the fishway when orifice gates were open, 12% first entered at Rew2, 34% at Se3, 10% at orifice gates, 40% at Se2, and 4% that first entered at unknown locations (Figure 7). When orifice gates were closed, 19% of the salmon first entered at Rew2, 38% at Se3, and 43% entered at Se2 (total of 113 entries). There were 763 entries into the fishway by 202 chinook salmon; 417 entries by 126 fish (mean of 3.3 entries/fish) with orifice gates open and 346 entries by 134 fish (2.6 entries/fish) with orifice gates closed. For total entries when orifice gates were open, 120 (29%) occurred at Rew2, 113 (27%) at Se3, 30 (7%) at orifice gates, 142 (34%) at Se2, and 12 (3%) entries at unknown locations (Figure 7). When gates were closed, 101 (29%) entries occurred at Rew2, 111 (32%) at Se3, 132 (38%) at Se2, and 2 (0.6%) entries at unknown locations. The number of times chinook salmon exited the fishway and returned to the tailrace totaled 565; 328 times by 106 salmon (3.1 exits/fish) when orifice gates were open, and 237 exits by 90 salmon (2.6 exits/fish) with closed orifice gates (Figure 7), and these values were not significantly different (ANOVA P = 0.2520). With orifice gates open, there were 84 (26%) exits at Rew2, 79 (24%) at Se3, 33 (10%) at orifice gates, 115 (35%) at Se2 and 17 exits (5%) at unknown locations. With orifice gates closed, 64 (27%) of the exits occurred at Rew2, 57 (24%) at Se3, 114 (48%) at Se2, and two exits occurred at unknown locations. The exit/entry ratio was 0.67 for Rew2, 0.61 for Se3, 0.84 for Se2, and averaged 1.58 for orifice gates.

Time from first tailrace record until a fish first entered the transition pool in the east-shore fishway was analyzed for 133 chinook salmon with 10 replicate blocks of office gate treatments (Table 6). Mean times for chinook salmon to first enter the transition pool were 8.8 h with orifice gates open and 15.1 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.2819). Median times to enter to the transition pool were 5.5 h with orifices open and 6.6 h with orifice gates closed and these values were not significantly different (P = 0.9274). With the Mann-Whitney test for ranked data, times to first approach when orifice gates were closed did not rank lower than when orifice gates were open (P = 0.3215).

Time from first approach to first entrance into the transition pool was analyzed for 143 fish during 10 replicate blocks of orifice gate treatment (Table 6). Times from first approach to first entrance into the transition pool were not significantly different with respect to orifice gate pattern based on results from ANOVA (P = 0.3861), median (P = 0.2265) and Mann-Whitney (P = 0.5246) tests. Mean times from first approach to first entrance into the transition pool with orifice gates open and closed were 4.9 h and 10.0 h. Median times from first approach to first entrance into the transition pool with orifice gates open and closed were 2.6 h and 3.4 h.

Times from first record in the tailrace to last record at tops of ladders were analyzed for 110 chinook salmon with seven blocks of replicates and were not significantly different with respect to orifice gate pattern based on results from ANOVA (P = 0.6423), median (P = 0.1212) and Mann-Whitney (P = 0.3185) tests. Mean times to cross the dam with orifice gates open and closed were 19.7 h and 23.6 h. Median times to cross the dam with orifice gates open and closed were 13.1 h and 15.6 h.

Wanapum Dam Sockeye Salmon

From 22 June until 20 August 1997, orifice gates at the Wanapum Dam powerhouse collection channel were alternately opened and closed a total of 15 times and 429 sockeye salmon with transmitters were recorded at receiver sites at the dam (Table 7). Clumping time periods resulted in 11 to 14 complete replicate blocks of orifice gate treatment for ANOVA analysis, depending on variable analyzed (Table 8). We found that sockeye salmon passage times were not significantly increased by closing orifice gates at Wanapum Dam in 1997.

Times from first record in the tailrace to first approach at a fishway entrance were analyzed for 391 (out of total of 442 salmon with fallback fish) sockeye salmon during 14 replicate blocks (Table 8). Mean times to first approach were 9.4 h when orifice gates were open and 11.0 h when orifice gates were closed, and these values were not significantly different (ANOVA P = 0.2802). Median times to first approach were 2.1 h when orifice gates were open and 2.3 h when orifice gates were closed and these values did not differ significantly (P = 0.4682). Results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed did not rank different than when orifice gates were open (P = 0.2635).

There were a total of 442 first approaches to the dam by 429 sockeye salmon (13 fish were coded with first approaches a second time after they fell back at the dam) during the study; 214 when orifice gates were open and 228 with orifice gates closed. When orifice gates were open, 13% of first approaches occurred at Rew2, 6% at Se3, 14% at the ten orifice gates, 65% at Se2, and 2% approached at unknown locations (Figure 8). When orifice gates were closed, 9% of first approaches were at Rew2, 4% of first approaches were at Se3, 10% at orifice gates, 76% at Se2 and 1% were at unknown locations (Figure 8).

Time and location of first entrances into the fishway are the primary variables of interest for this study. Time from first tailrace record until a fish first passed through a fishway entrance

Table 7. Date ranges for orifice gate treatment periods, orifice gate treatment, number of sockeye salmon first recorded at dam (at any location), number used in analysis for the five passage-time variables, and periods used in each replicate at Wanapum Dam.

Period	Orifice gate treatment	Fish recorded at dam	Tailrace to first approach		Tailrace to first entrance		Tailrace to transition pool		First approach to first entrance		Tailrace to top of ladder	
			Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate	Fish	Replicate
22 June-1 July	Open	7	7	1	6	1	5	1	6	1	6	1
2-3 July	Closed	8	8	1	8	1	8	1	8	1	4	1
4 July	Open	5	5	2	2	1	1	1	2	1	0	1
5 July	Closed	11	11	2	11	2	11	2	11	2	4	1
6 July	Open	15	15	3	14	2	12	2	14	2	6	2
7 July	Closed	18	14	3	8	3	7	3	12	3	3	1
8 July	Open	10	8	4	4	3	2	2	6	3	2	2
9 July	Closed	28	25	4	20	4	19	4	21	4	16	2
10 July	Open	34	23	5	21	4	20	3	30	4	11	3
11 July	Closed	28	21	5	19	5	17	5	21	5	9	3
12 July	Open	19	16	6	12	5	11	4	15	5	8	4
13 July	Closed	26	26	6	20	6	19	6	20	6	9	4
14 July	Open	26	24	7	22	6	21	5	24	6	12	5
15 July	Closed	17	17	7	7	7	13	7	7	7	7	5
16 July	Open	17	16	8	15	7	11	6	16	7	6	6
17 July	Closed	21	20	8	18	8	14	8	18	8	10	6
18 July	Open	20	20	9	17	8	19	7	17	8	10	7
19 July	Closed	16	16	9	13	9	11	9	13	9	5	7
20 July	Open	13	13	10	11	9	8	8	11	9	6	8
21 July	Closed	13	13	10	11	10	9	10	11	10	8	8
22 July	Open	12	11	11	10	10	11	9	11	10	5	9
23 July	Closed	11	11	11	10	11	9	11	10	11	7	9
24 July	Open	11	10	12	10	11	10	10	11	11	2	10
25 July	Closed	7	6	12	5	12	3	11	6	12	1	10
26 July	Open	8	7	13	6	12	3	11	7	12	2	10
27 July	Closed	2	2	12	0	12	2	11	0	12	4	10
28 -29 July	Open	3	2	14	1	12	2	11	2	13	3	11
30-31 July	Closed	13	13	13	13	13	13	12	13	13	7	11
1-10 August	Open	7	7	14	7	13	6	12	7	13	4	10
11-20 August	Closed	4	4	14	4	13	4	12	4	13	3	11

Table 8. Number of fish and mean and median times (h) for five passage variables from each replicate block of orifice gates treatment for sockeye salmon at Wanapum Dam, 1997.

Replicate	Orifice gate treatment	Tailrace to first approach			Tailrace to first entrance			Tailrace to transition pool			First approach to first entrance			Tailrace to top of ladder		
		n	mean	median	n	mean	median	n	mean	median	n	mean	median	n	mean	median
1	Open	7	3.3	1.7	8	4.2	3.2	6	5.6	3.7	8	1.1	0.1	6	20.9	21.2
1	Closed	8	51.2	2.8	8	56.8	6.2	8	58.4	6.4	8	5.6	1.4	11	51.6	12.2
2	Open	5	3.4	3.4	14	2.0	1.7	14	2.6	2.0	14	0.8	0.2	8	11.8	9.6
2	Closed	11	2.0	1.4	11	5.2	4.3	11	7.0	7.2	11	3.1	2.6	16	18.0	20.4
3	Open	15	1.3	1.2	4	4.9	3.6	20	7.2	5.4	6	0.8	0.4	11	17.2	10.1
3	Closed	14	5.1	1.8	8	3.5	2.6	7	3.8	2.2	12	1.5	0.4	7	28.6	30.0
4	Open	8	3.0	1.7	21	6.8	2.9	11	24.4	2.4	30	1.4	0.2	8	50.5	21.7
4	Closed	25	9.4	1.7	20	5.6	3.7	19	6.0	3.8	21	2.5	1.0	9	19.3	21.8
5	Open	23	5.4	2.2	12	22.2	1.9	21	7.2	5.5	15	0.4	0.2	11	21.0	23.8
5	Closed	21	19.8	5.8	19	22.1	7.9	17	25.3	8.2	21	1.7	1.0	7	24.5	25.2
6	Open	16	16.9	1.6	22	5.8	4.6	11	9.5	3.6	24	1.4	0.1	6	23.4	25.7
6	Closed	26	3.8	2.0	20	6.9	6.2	19	7.9	7.7	20	2.8	1.8	10	14.8	10.6
7	Open	24	4.8	2.6	15	6.6	2.2	19	6.8	6.2	16	1.0	0.01	10	16.7	13.1
7	Closed	17	17.1	2.9	7	7.6	5.0	13	24.7	5.3	7	1.3	0.01	5	11.7	10.1
8	Open	16	5.7	2.0	17	6.8	6.0	8	7.6	7.0	17	2.5	1.7	6	22.9	22.8
8	Closed	20	18.5	2.8	18	22.2	5.0	14	30.3	5.9	18	1.8	0.4	8	20.3	18.5
9	Open	20	4.2	3.0	11	6.0	5.0	11	9.5	5.8	11	1.7	0.2	5	12.6	11.5
9	Closed	16	2.9	2.4	13	4.7	3.4	11	5.1	5.3	13	1.5	1.0	7	14.0	12.2
10	Open	13	4.0	2.9	10	7.2	4.6	10	67.5	3.1	11	0.9	0.01	4	9.2	9.1
10	Closed	13	4.2	2.2	11	6.4	6.5	9	6.9	6.7	11	2.3	1.2	5	14.9	10.8
11	Open	11	7.2	4.3	10	68.3	3.5	5	3.1	2.6	11	1.4	0.7	7	30.2	26.4
11	Closed	11	4.8	2.6	10	7.7	7.6	14	9.8	8.0	10	2.8	1.4	10	18.8	11.6
12	Open	10	66.8	2.6	7	2.7	2.6	6	5.0	5.3	7	0.1	0.01			
12	Closed	8	8.9	6.8	5	12.3	14.2	17	9.6	7.9	6	1.0	0.01			
13	Open	7	2.5	2.4	7	5.8	2.6				9	2.7	0.7			
13	Closed	13	5.2	2.4	17	8.7	5.8				17	4.3	2.6			
14	Open	9	3.3	1.9												
14	Closed	4	1.7	1.8												
Overall	Open	184	9.4	2.1	158	11.5	3.3	142	13.0	4.5	179	1.3	0.2	82	21.5	15.6
Overall	Closed	207	11.0	2.3	167	13.1	5.4	159	16.2	6.2	175	2.5	1.0	95	21.5	16.4

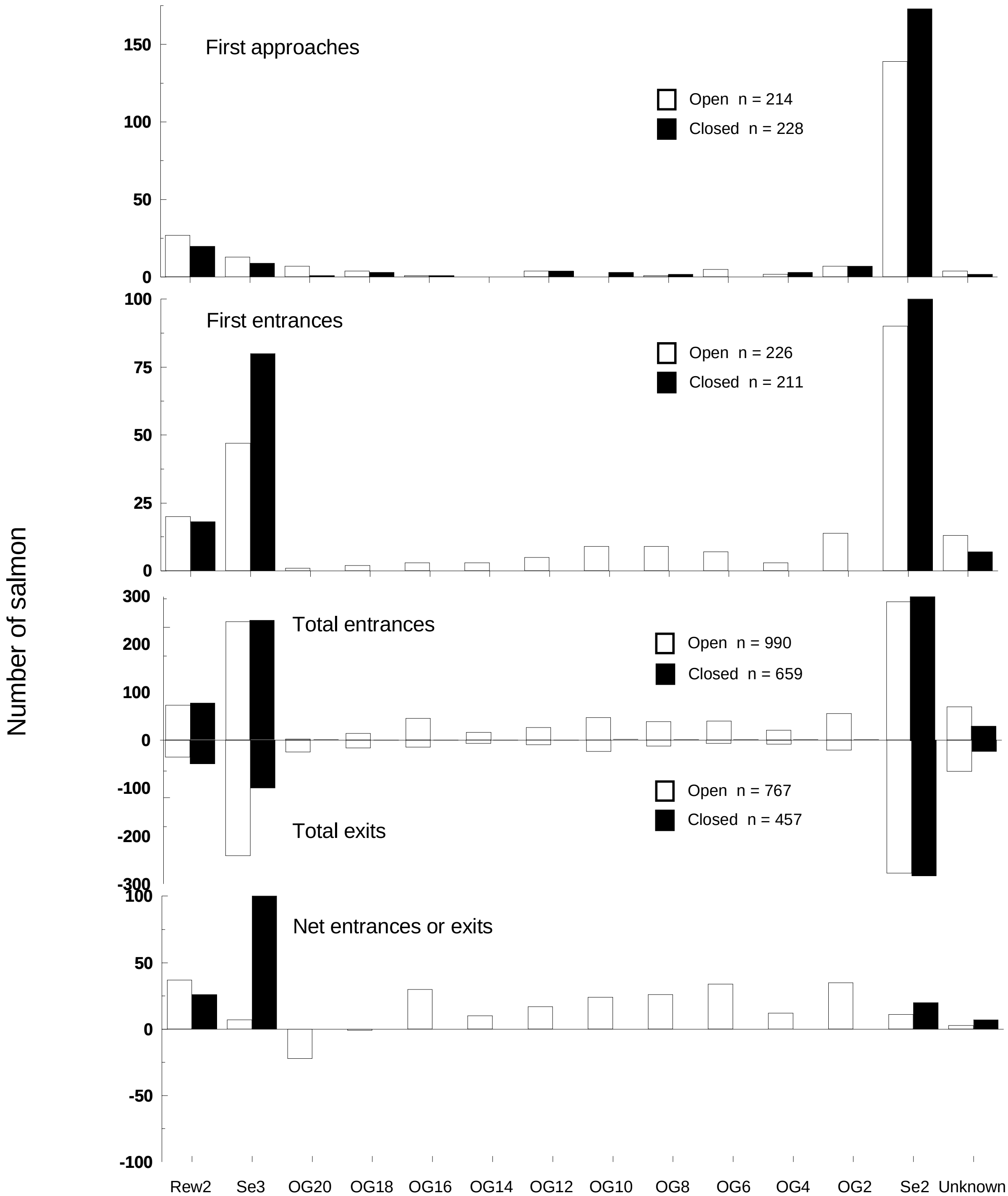

Figure 8. Number of first approaches, first entrances, total entries and exits, and net entrances or exits for radio-tagged sockeye salmon at Wanapum Dam with orifice gates open and closed, 1997. Rew2 is the west-shore entrance. Se3 is the south-powerhouse entrance, Se2 is the east-shore fishway entrance and OG's are orifice gates.

were analyzed for 325 (out of a total of 403 first entries with fallback fish) sockeye salmon from 13 replicate blocks of orifice gate treatment (Table 8). Mean times for sockeye salmon to first enter fishways were 11.5 h with orifice gates open and 13.1 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.1532). Median times for first entrances were 3.3 h with orifices open and 5.4 h with orifice gates closed, and these values were significantly different (P = 0.0015). Results of the Mann-Whitney test for ranked data were that times to first approach when orifice gates were closed ranked lower (passage times were longer) than when orifice gates were open (P = 0.0002).

Times from first approach to first entrance to the fishway were analyzed for 354 fish during 13 replicate blocks of orifice gate treatment (Table 8). Times from first approach to first entrance were significantly different with respect to orifice gate pattern, based on results from ANOVA (P = 0.0029), median (P = 0.0001), and Mann-Whitney (P = 0.0001) tests. Mean times from first approach to first entrance with orifice gates open and closed were 1.3 h and 2.5 h. Median times from first approach to first entrance with orifice gates open and closed were 0.2 h and 1.0 h.

Of 226 sockeye salmon that first entered the fishway when orifice gates were open, 9% first entered at Rew2, 21% at Se3, 25% at orifice gates, 39% at Se2, and 6% first entered at unknown locations (Figure 8). When orifice gates were closed, 9% of the salmon first entered at Rew2, 38% at Se3, 50% entered at Se2 and 3% entered at unknown locations (total of 211 entries). There were 1,649 entries into the fishway by 429 sockeye salmon; 990 entries by 313 fish (mean of 3.2 entries/fish) with orifice gates open and 659 entries by 294 fish (2.2 entries/fish) with orifice gates closed. For total entries when orifice gates were open, 73 (7%) occurred at Rew2, 248 (25%) at Se3, 312 (32%) at orifice gates, 288 (29%) at Se2, and 69 (7%) entries occurred at unknown locations (Figure 8). When gates were closed, 76 (12%) occurred at Rew2, 249 (38%) at Se3, 303 (46%) at Se2, and 31 (5%) entries occurred at unknown locations. The number of times chinook salmon exited the fishway and returned to the tailrace totaled 1,224; 767 times by 216 salmon (3.6 exits/fish) when orifice gates were open, and 457 exits by 189 salmon (2.4 exits/fish) with closed orifice gates (Figure 8) and these values were significantly different

(ANOVA P = 0.0001). With orifice gates open, there were 36 (5%) exits at Rew2, 241 (31%) at Se3, 147 (19%) at orifice gates, 277 (36%) at Se2 and 66 exits (9%) at unknown locations. With orifice gates closed, 50 (11%) of the exits occurred at Rew2, 100 (22%) at Se3, 283 (62%) at Se2, and 24 (5%) exits occurred at unknown locations. The exit/entry ratio was 0.6 for Rew2, 0.7 for Se3, 0.9 for Se2, and averaged 1.2 for orifice gates.

Time from first tailrace record until a fish first entered the transition pool in the east-shore fishway was analyzed for 443 sockeye salmon during 12 replicate blocks of office gate treatments (Table 8). Mean times for sockeye salmon to first enter the transition pool were 13.0 h with orifice gates open and 16.2 h with orifice gates closed, and these values were not significantly different (ANOVA P = 0.1688). Median times to enter to the transition pool were 4.5 h with orifices open and 6.2 h with orifice gates closed and these values were significantly different (P = 0.0164). With the Mann-Whitney test for ranked data, times to first approach when orifice gates were closed ranked lower than when orifice gates were open (P = 0.0014).

Time from first approach to first entrance into the transition pool was analyzed for 323 fish during 13 replicate blocks of orifice gate treatment (Table 8). Times from first approach to first entrance into the transition pool were significantly different with respect to orifice gate pattern based on results from ANOVA (P = 0.0033), median (P = 0.0005) and Mann-Whitney (P = 0.0016) tests. Mean times from first approach to first entrance into the transition pool with orifice gates open and closed were 2.2 h and 3.6 h. Median times from first approach to first entrance into the transition pool with orifice gates open and closed were 0.9 h and 1.8 h.

Times from first record in the tailrace to last record at tops of ladders were analyzed for 177 sockeye salmon in 11 blocks of replicates and were not significantly different with respect to orifice gate pattern based on results from ANOVA (P = 0.9336), median (P = 0.8249) and Mann-Whitney (P = 0.8185) tests. Mean times to cross the dam with orifice gates open and closed were the same at 21.5 h. Median times to cross the dam with orifice gates open and closed were 16.4 h and 15.6 h.

Hanford Reach Passage

A total of 229 chinook salmon with transmitters were recorded on receivers situated near the downstream end of the Hanford Reach (approximately rkm 553), 159 of which were later recorded at Priest Rapids Dam (rkm 638.9). Passage times from the last record at the Hanford Reach sites until the first record at Priest Rapids Dam ranged from 1.4 d (2.6 km/h) to 34.2 d (0.1 km/h), and had median and mean times of 2.2 d (1.6 km/h) and 2.7 d (1.3 km/h). Chinook salmon that reached the Hanford Reach early (1 May-17 June, 39 fish) had a median passage time of 2.1 d versus a median passage time of 2.3 d for later (2 July-9 August, 114 fish) chinook salmon. Twenty-five chinook salmon returned to the Hanford Reach sites after reaching Priest Rapids Dam, including six salmon that were missed the first time they passed the Hanford Reach sites. Of the 217 chinook salmon recorded at Priest Rapids Dam, 159 (73%) were recorded while passing the Hanford Reach sites. Of the 70 chinook salmon that did not reach Priest Rapids Dam, three were captured in fisheries in the Columbia River, five entered Ringold Hatchery, 56 entered the Snake River and six were last heard in the Columbia River.

A total of 361 sockeye salmon with transmitters were recorded at the Hanford Reach sites, 351 of which were later recorded at Priest Rapids Dam. Passage times from the last record at the Hanford Reach sites until the first record at Priest Rapids Dam ranged from 1.4 d (2.6 km/h) to 27.2 d (0.1 km/h), and had median and mean times of 3.0 d (1.2 km/h) and 3.2 d (1.1 km). There were 123 sockeye salmon that returned to the Hanford Reach sites after reaching Priest Rapids Dam, including 22 salmon that were missed the first time they passed the Hanford Reach sites. Of the 440 sockeye salmon recorded at Priest Rapids Dam, 351 (84%) were recorded while passing the Hanford Reach sites. It is unknown at this time the fate of the 10 sockeye salmon that did not reach Priest Rapids Dam.

Run Timing

A total of 217 chinook salmon with transmitters were recorded at Priest Rapids Dam between 20 April and 23 September 1997 (Figure 9), of which 110 were tagged at Bonneville Dam during the spring (before 1 June) and 107 were tagged during the summer (1 June - 31

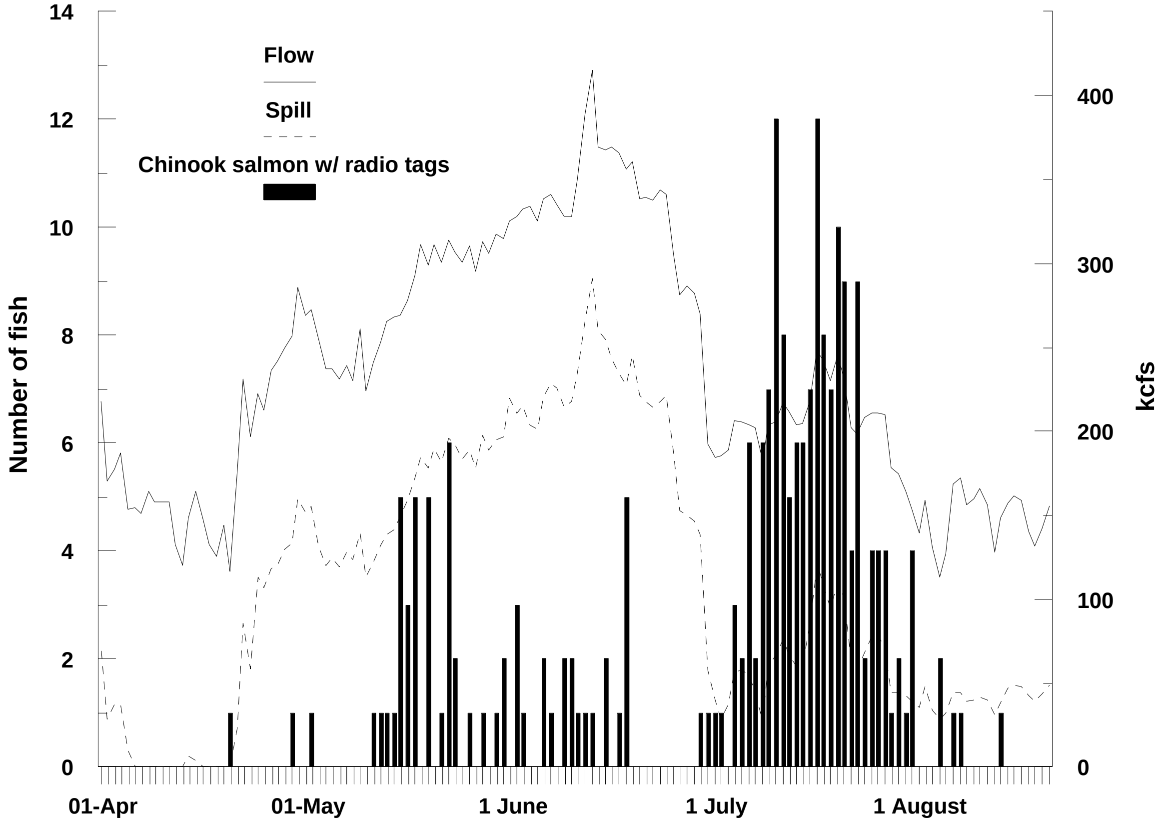

Figure 9. Time of first arrival to tailrace of Priest Rapids Dam for chinook salmon with radio transmitters, 1997.

July). These same fish would have been classified as 53 spring (before 14 June), 163 summer (14 June - 13 August), and one fall (after 13 August) chinook salmon, based on date of arrival in the tailrace at Priest Rapids Dam.

Priest Rapids Dam

The following is a summary of passage for all chinook and sockeye salmon at Priest Rapids Dams, including those that were not used in analysis for the orifice gate tests.

Chinook Salmon Passage

Passage from the first record in the tailrace until first approach at the dam for 203 chinook salmon occurred in a median of 2.1 h and mean of 17.4 h, with a range of 0.6 h to 19.6 d. Most first approaches occurred at Lew4-5 (41%), in the area of orifice gates 17-18 (23%), and at Lew2 (16%) (Figure 10). Passage from the tailrace to first entrance to the fishway for 129 fish occurred in a median of 8.8 h, mean of 29.1 h, and ranged from 0.7 h to 21.0 d (Figure 11). Most first entrances occurred at Lew4-5 (79%) and at Lew2 (13%), but few first entrances occurred at orifice gates (8%) (Figure 10). Median time from the tailrace to first entrance to the transition pool for 123 fish was 8.7 h, averaged 29.4 h, and ranged from 0.7 h to 21.0 d. We had few records of fish exiting from the tops of ladders because of data lost when receivers became repeatedly memory-full and could no longer record information. Median time from the tailrace to exit from top of ladders for 56 fish was 37.6 h, averaged 88.6 h and ranged from 4.5 h to 28.8 d (Figure 11). Of the 130 fish with records at tops of ladders, 66% crossed the dam using the east-shore ladder.

Sockeye Salmon Passage

A total of 440 sockeye salmon with transmitters were recorded at Priest Rapids Dam between 11 June and 6 September 1997 (Figure 12). Passage from the first record in the tailrace until first approach at the dam for 380 sockeye salmon occurred in a median time of 1.7 h, mean of 5.7 h, and ranged from 0.7 h to 11.9 d. Of 419 first approaches, 17% occurred at Lew2, one at Lew3, 39% at orifice gates, 41% at Lew4-5, and 3% first approached at unknown locations (Figure 13). Passage from the tailrace to first entrance to the fishway for 309 salmon occurred in a median time of 2.9 h, mean of 7.5 h, and ranged from 0.8 h to 12.0 d (Figure 14). Of 420 first entrances, 24% occurred at Lew2, 13% occurred at orifice gates (orifice gates were open approximately half of the time the study was conducted), 57% at Lew4-5, and 6% of first entrances occurred at unknown locations (Figure 14). Median time from the tailrace to first entrance to the transition pool for 331 fish was 3.4 h, averaged 6.1 h, and ranged from 0.9 h to 2.0 d. We had relatively few records of fish exiting from the tops of ladders because of data lost when receivers became repeatedly memory-full and could no longer record information. Time from the tailrace to exit from top of ladders for 99 sockeye salmon was a median of 18.6 h, mean

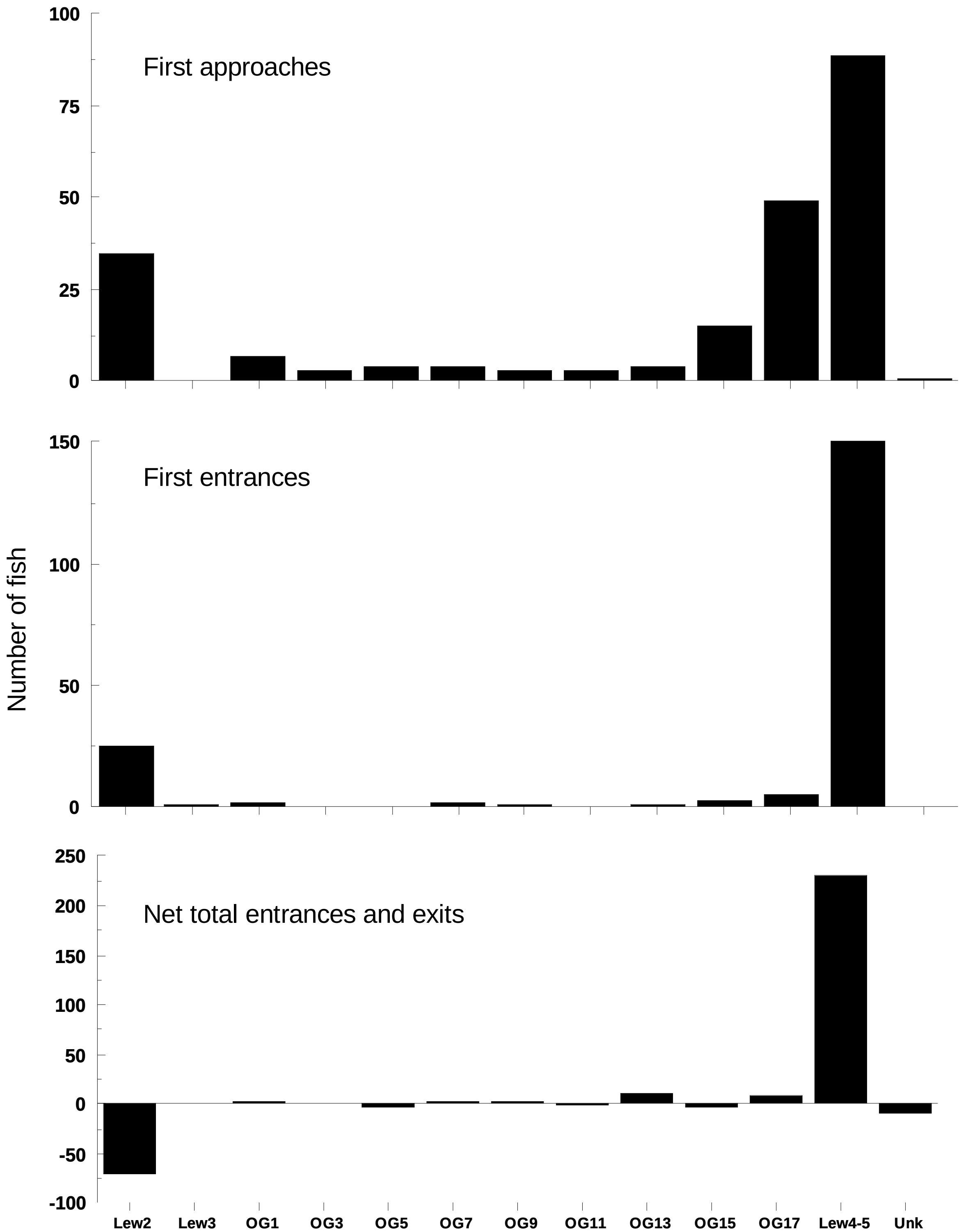

Figure 10. Location of first approaches (top), first entries (middle) and net entries (bottom) for all chinook salmon with transmitters at Priest Rapids dam in 1997. Lew2 is the west-powerhouse entrance, Lew4-5 is the east-shore fishway entrance, and OG's are orifice

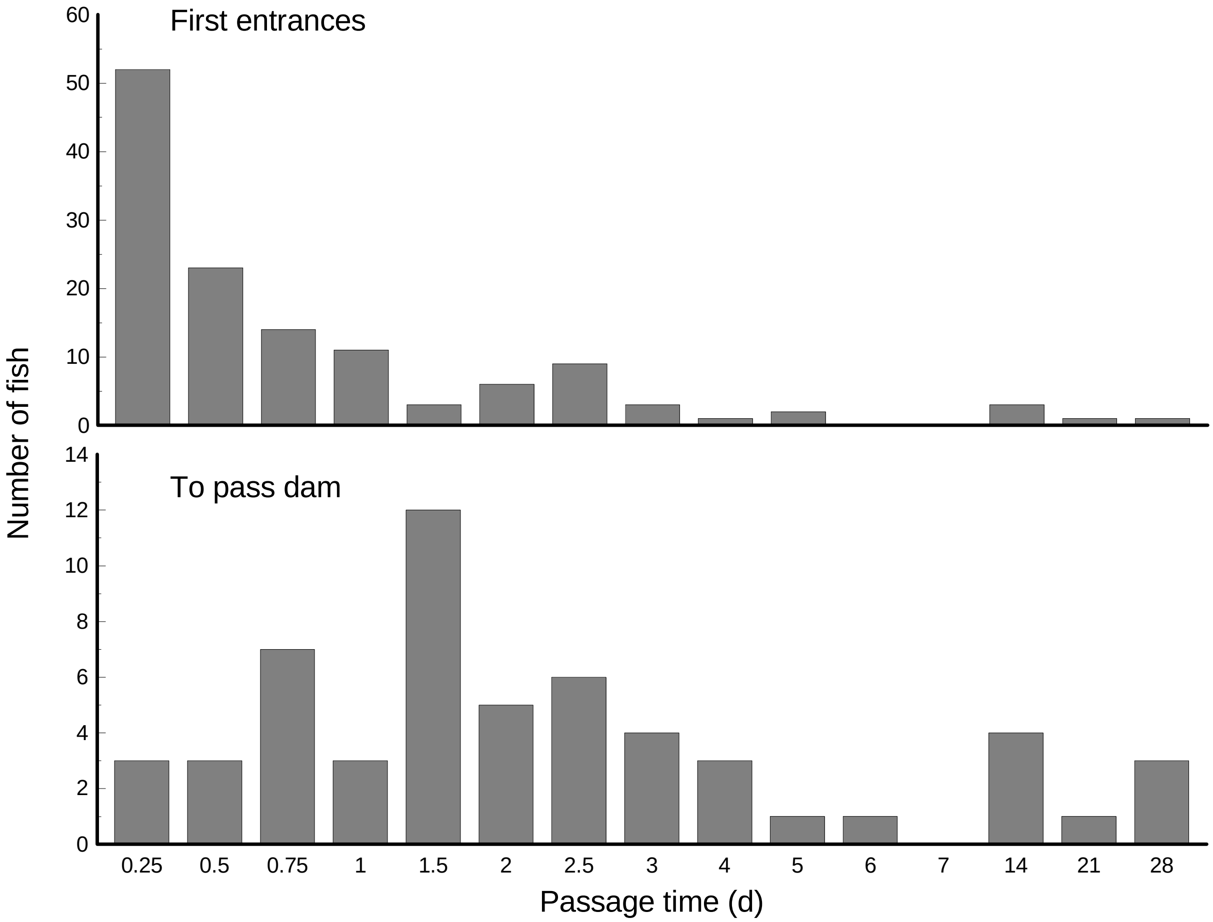

Figure 11. Passage times from first record in the tailrace until first entrance to the fishway (top) and from first record in tailrace until exit from top of ladders (bottom) for chinook salmon at Priest Rapids Dam, 1997.

of 28.4, h and ranged from 3.6 h to 10.0 d (Figure 14). Of the 182 salmon with records at tops of ladders, 64% crossed the dam using the east-shore ladder.

Passage Past the Counting Station

Time to pass the fish counting station in the east-shore ladder was calculated from the first record by a fish on an antenna placed two weirs downstream from the station, until the last record at the antenna placed one weir upstream from the station. Fifty-eight chinook salmon moved past the counting station in median and mean times of 0.3 h, and a range of 0.07 to 1.25 h.

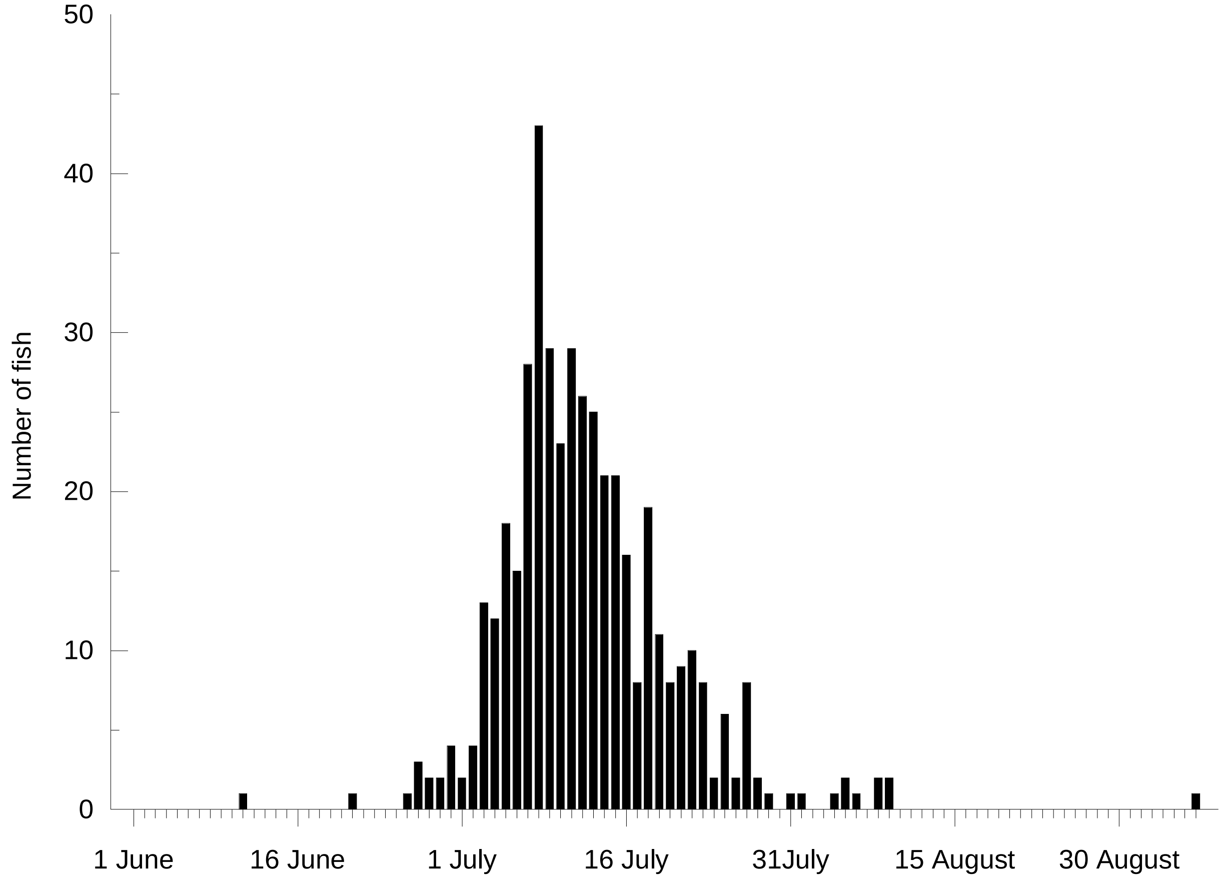

Figure 12. Time of first arrival to tailrace of Priest Rapids Dam for sockeye salmon with radio transmitters, 1997.

Eighty-nine sockeye salmon moved past the counting station in a median of 0.2 h, mean of 2.1 h, and a range of 0.04 h to 50.2 h.

Passage Past the Coded-Wire-Tag Trap

Time to pass the coded-wire-tag (CWT) trap, near the top of the east-shore ladder, was calculated for salmon from the first record on an antenna placed two weirs downstream from the trap until the first record at the antenna at the ladder exit. The CWT trap was operated by personnel from the Washington Department of Fisheries to monitor steelhead. In 1997, the CWT trap was operated a total of 20 d between 15 July and 14 October.

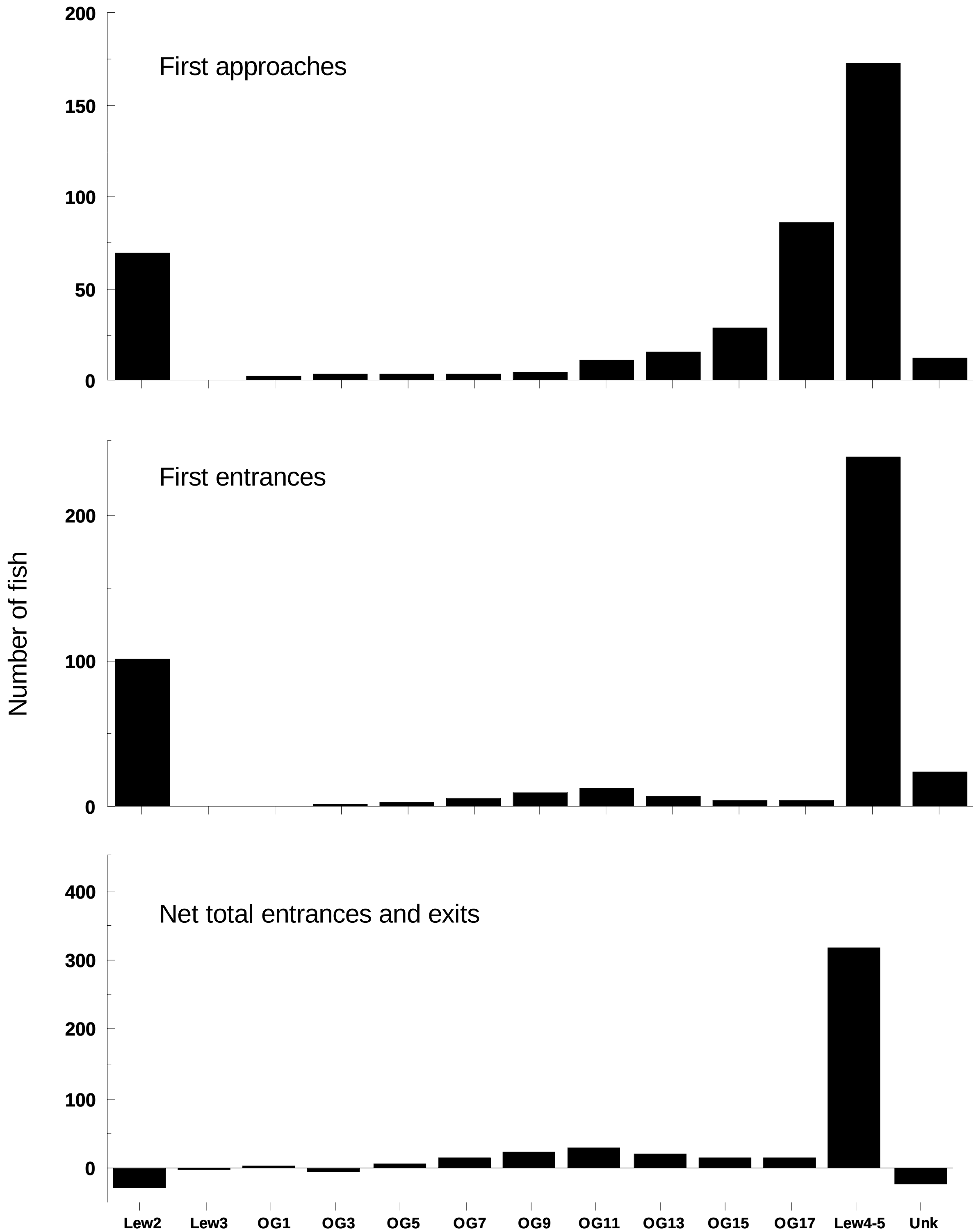

Figure 13. Location of first approaches (top), first entries (middle) and net entries (bottom) for all sockeye salmon with transmitters at Priest Rapids dam in 1997. Lew2 is the west-powerhouse entrance, Lew4-5 is the east-shore fishway entrance, and OG's are orifice

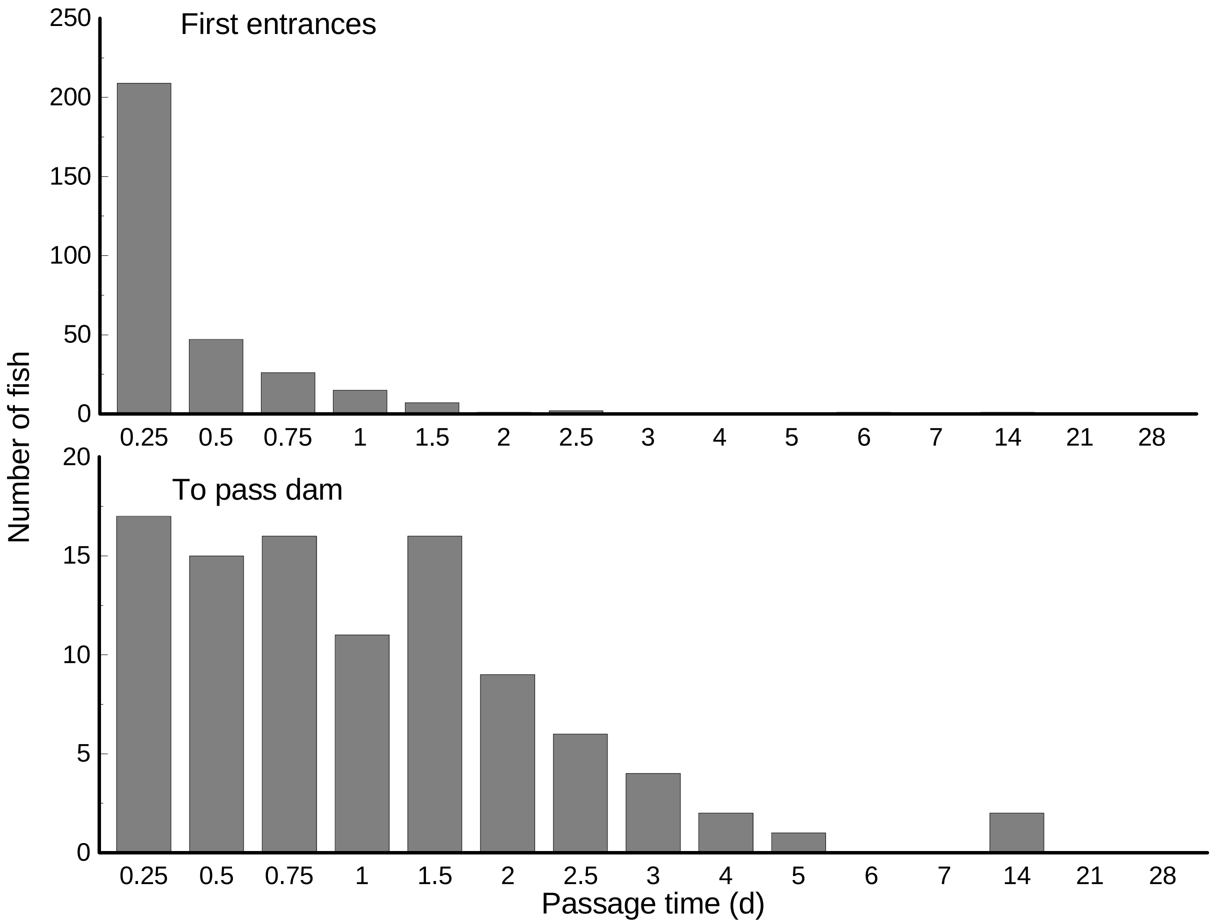

Figure 14. Passage times from first record in the tailrace until first entrance to the fishway (top) and from first record in tailrace until exit from top of ladders (bottom) for sockeye salmon at Priest Rapids Dam, 1997.

Eighty-one chinook salmon moved past the CWT trap during 1997 in a median of 0.4 h and mean of 1.0 h. Thirty-one chinook salmon moved past the CWT trap after 15 July, eight while the trap was in operation and 23 when the trap was not operated. Median times for these 31 chinook salmon to pass that section of the fish ladder with and without the trap in operation were 1.0 h and 0.3 h (P = 0.0115, test of medians). For comparison, times for 52 chinook salmon to ascend the entire east-shore ladder (from exiting the top of the transition pool until exiting top of ladder) had a median of 2.3 h, mean of 2.8 h, and ranged 1.5 to 10.3 h.

One hundred and five sockeye salmon moved past the CWT trap during 1997 in a median of 1.3 h and mean of 2.1 h. Sixty-seven sockeye salmon moved past the CWT trap after 15 July, 19 while the trap was in operation and 48 when the trap was not operated. Median times for these 67 sockeye salmon to pass the CWT trap with and without the trap in operation were 3.4 h and 1.3 h ($P = 0.0125$, test of medians). Times for 36 sockeye salmon to ascend the entire east-shore ladder (from exiting the top of the transition pool until exiting top of ladder) had a median of 4.1 h, mean of 7.1 h, and ranged 1.8 to 24.9 h.

Wanapum Dam

The following is a summary of passage for all chinook and sockeye salmon at Wanapum Dams, including those that were not used in analysis for the orifice gate tests.

Chinook Salmon Passage

A total of 199 chinook salmon with transmitters were recorded at Wanapum Dam between 2 May and 4 September 1997 (Figure 15). Median and mean times for 100 chinook salmon to move between Priest Rapids and Wanapum dams were 12.5 h (2.4 km/h) and 14.2 h (2.1 km/h). Passage from the first record in the tailrace until first approach at the dam for 186 chinook salmon occurred in a median of 1.3 h, mean of 4.6 h, and ranged from 0.1 h to 5.0 d. Of 206 first approaches (includes seven fish that fell back and approached the dam a second time), 6% occurred at Rew2, 7% at Se3, 12% at orifice gates, and 75% at Se2 (Figure 16). Passage from the tailrace to first entrance to the fishway for 183 salmon occurred in a median of 5.5 h, mean of 11.5 h, and ranged from 0.4 h to 8.0 d (Figure 17). Of 204 first entrances, 16% occurred at Rew2, 36% at Se3, 5% at orifice gates (orifice gates were open approximately half of the time study was conducted), 42% at Se2, and 1% of first entrances occurred at unknown locations (Figure 16). Median time from tailrace to first entrance to the transition pool for 160 fish was 8.0 h, averaged 14.4 h, and ranged from 0.8 h to 8.0 d. Time from the tailrace to exit from top of ladders for 175 chinook salmon was a median of 20.1 h, mean of 32.5 h, and ranged from 2.3 h to 17.0 d (Figure 17). Of the 197 salmon with records at tops of ladders, 63% crossed the dam using the east-shore ladder.

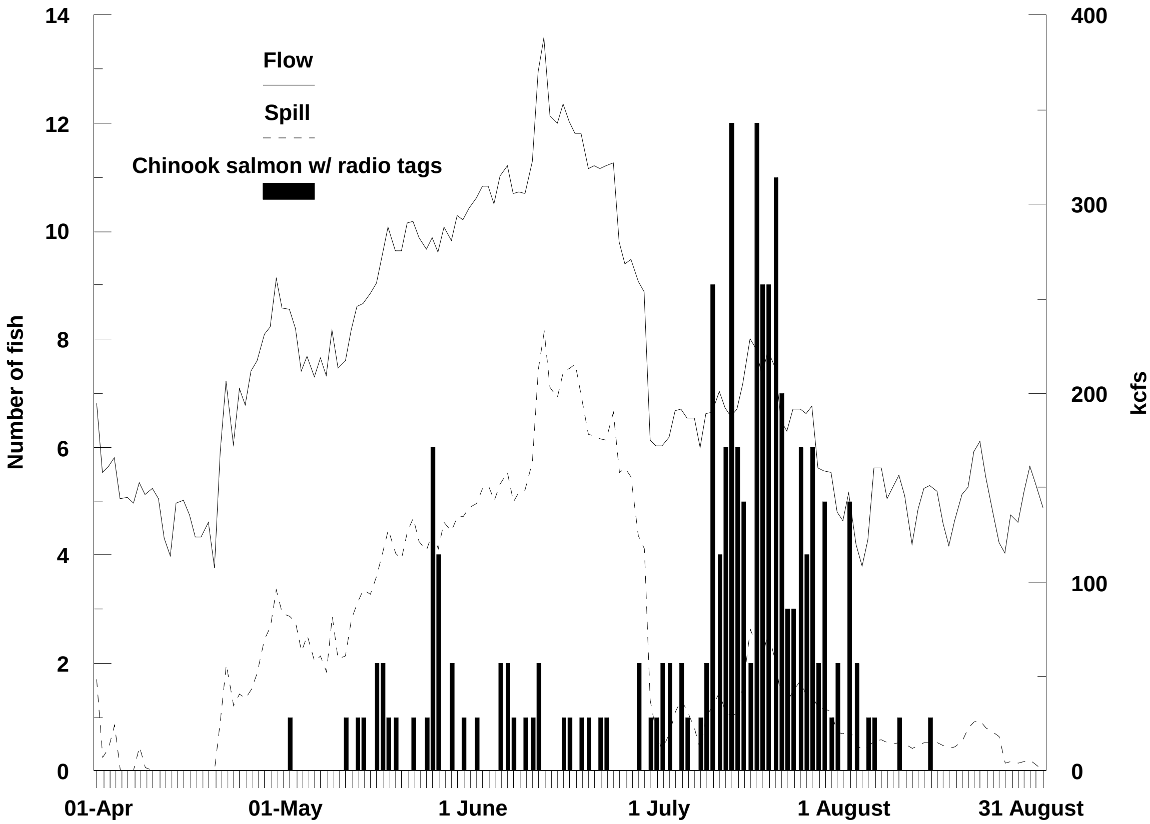

Figure 15. Time of first arrival to tailrace of Wanapum Dam for chinook salmon with radio transmitters, 1997.

Sockeye Salmon Passage

A total of 429 sockeye salmon with transmitters were recorded at Wanapum Dam between 19 June and 26 August 1997 (Figure 18). Median and mean times for 170 sockeye salmon to move between Priest Rapids and Wanapum dams were 18.7 h (1.6 km/h) and 20.6 h (1.5 km/h). Passage from the first record in the tailrace until first approach at the dam for 391 sockeye salmon occurred in a median of 2.2 h, mean of 9.8 h, and ranged from 0.4 h to 26.8 d. Of 442 first approaches (includes 15 fish that fell back and approached the dam a second time), 11% occurred at Rew2, 5% at Se3, 12% at orifice gates, 71% at Se2, and 1% were at unknown locations (Figure 19). Passage from the tailrace to first entrance to the fishway for 363 salmon occurred in a median of 5.1 h, mean of 13.7 h, and ranged from 0.4 h to 26.8 d (Figure 20). Of 437 first entrances, 9% occurred at Rew2, 29% at Se3, 13% at orifice gates (orifice gates were

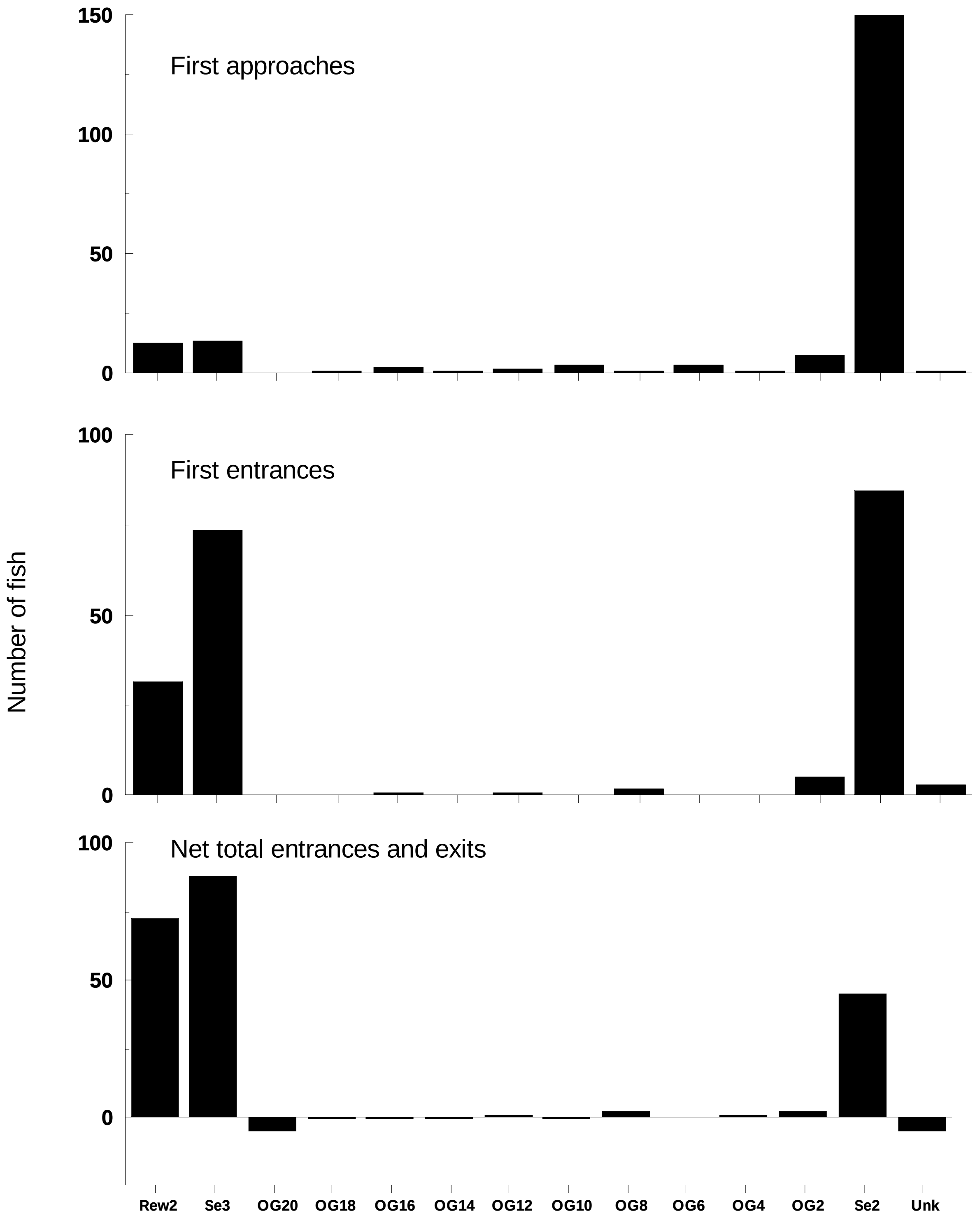

Figure 16. Location of first approaches (top), first entries (middle) and net entries (bottom) for all chinook salmon with transmitters at Wanapum dam in 1997. Rew2 is the west-shore entrance, Se3 is the south-powerhouse entrance, Se2 is the east-shore fishway entrance, and OG's are orifice gates.

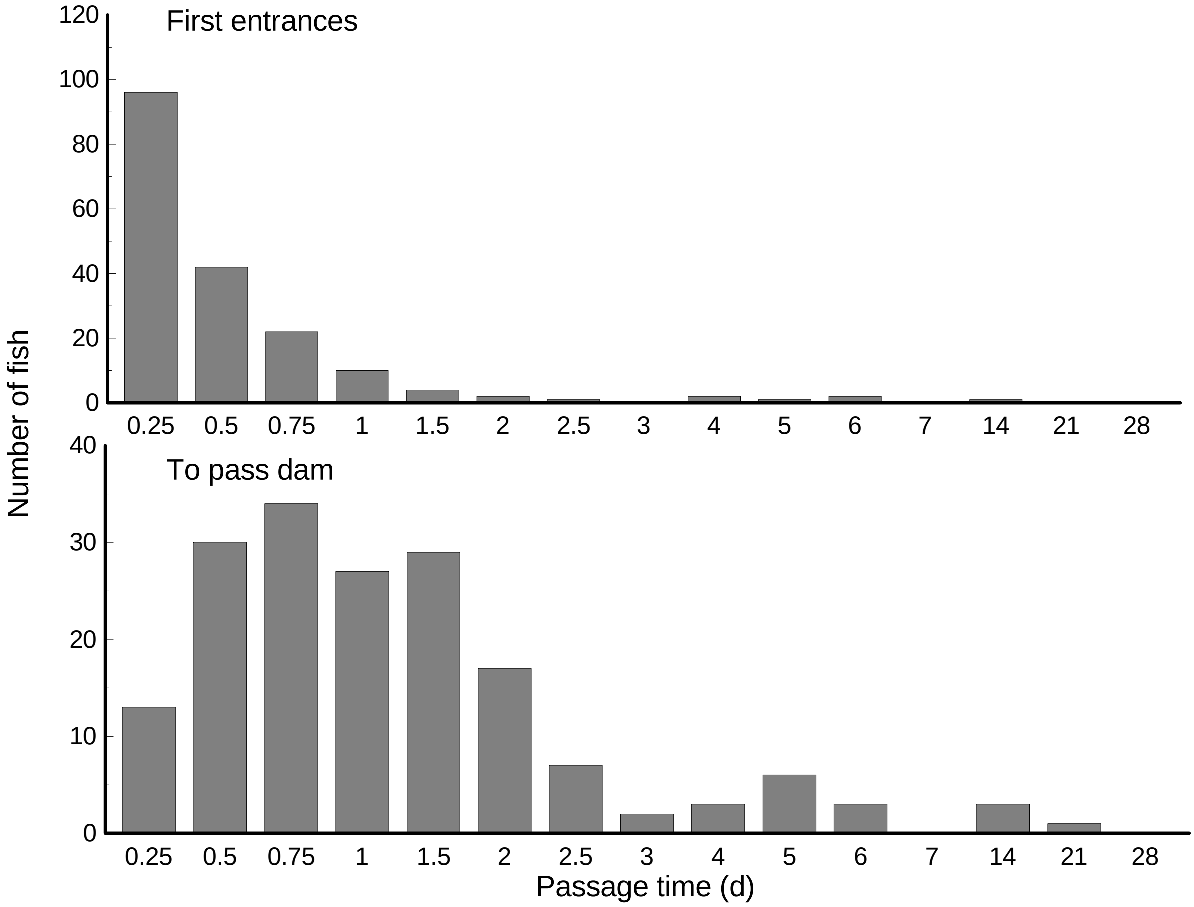

Figure 17. Passage times from first record in the tailrace until first entrance to the fishway (top) and from first record in tailrace until exit from top of ladders (bottom) for chinook salmon at Wanapum Dam, 1997.

open approximately half of the time study was conducted), 45% at Se2, and 4% of first entrances occurred at unknown locations (Figure 19). Median time from tailrace to first entrance to the transition pool for 369 fish was 7.0 h, averaged 17.1 h, and ranged from 1.2 h to 26.8 d. Time from the tailrace to exit from top of ladders for 382 sockeye salmon was a median of 29.7 h, mean of 44.1 h and ranged from 3.8 h to 28.0 d (Figure 20). Of the 421 salmon with records at tops of ladders, 87% crossed the dam using the east-shore fish ladder.

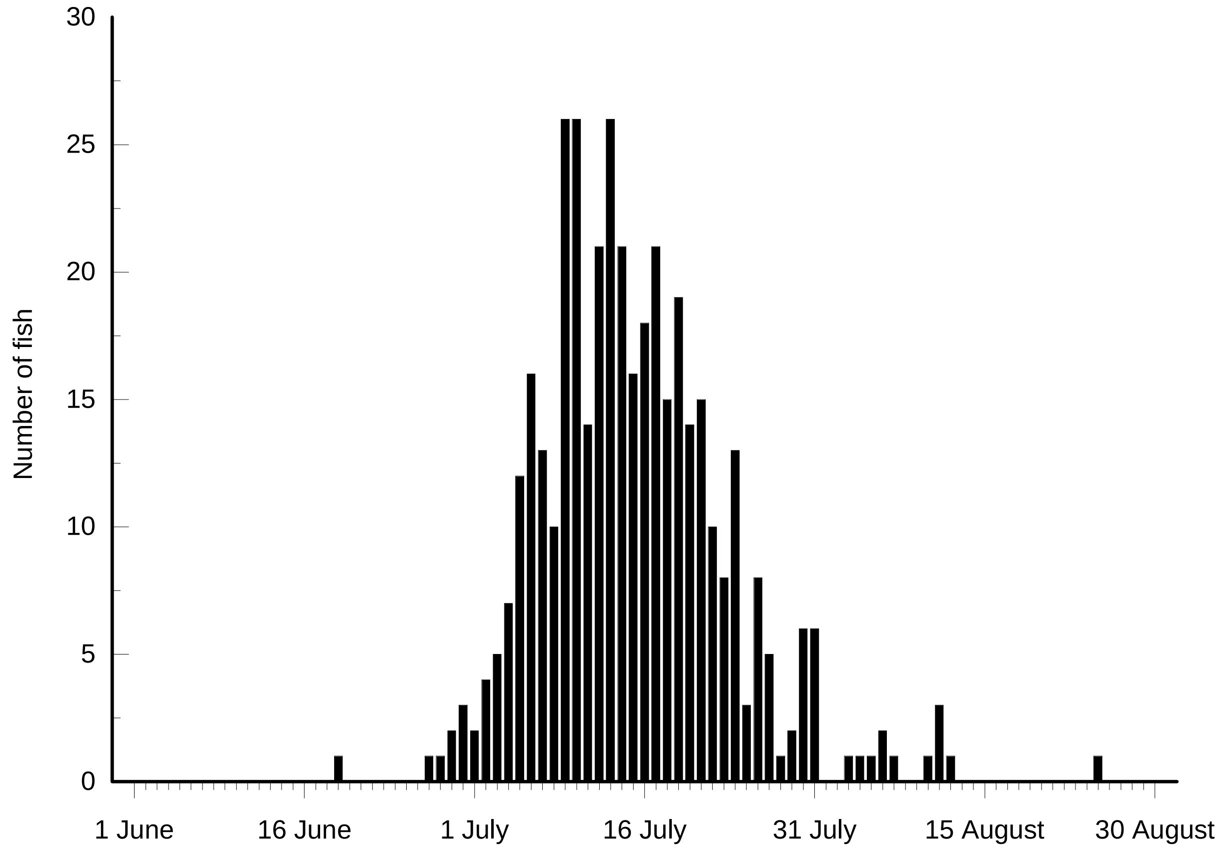

Figure 18. Time of first arrival to tailrace of Wanapum Dam for sockeye salmon with radio transmitters, 1997.

Use of the West-Shore Slotted Entrance

There was a total of 250 approaches by chinook salmon at the new Rew2 slotted entrance at Wanapum Dam in 1997, resulting in 224 entrances, or one entry for every 1.1 approaches by chinook salmon. At the Se2 (slotted entrance), there were 1,590 approaches by chinook salmon, resulting in 273 entries, or one entry for every 5.8 approaches, and at Se3 (slotted entrance), there were 756 approaches and 224 entries, for 3.3 approaches per entry.

There was a total of 245 approaches by sockeye salmon to Rew2 at Wanapum Dam in 1997, resulting in 149 entrances, or one entry for every 1.6 approaches. At Se2, there were 1,799 approaches by sockeye salmon, resulting in 589 entries, or one entry for every 3.1 approaches, and at Se3, there were 820 approaches and 497 entries, or 1.6 approaches per entry.

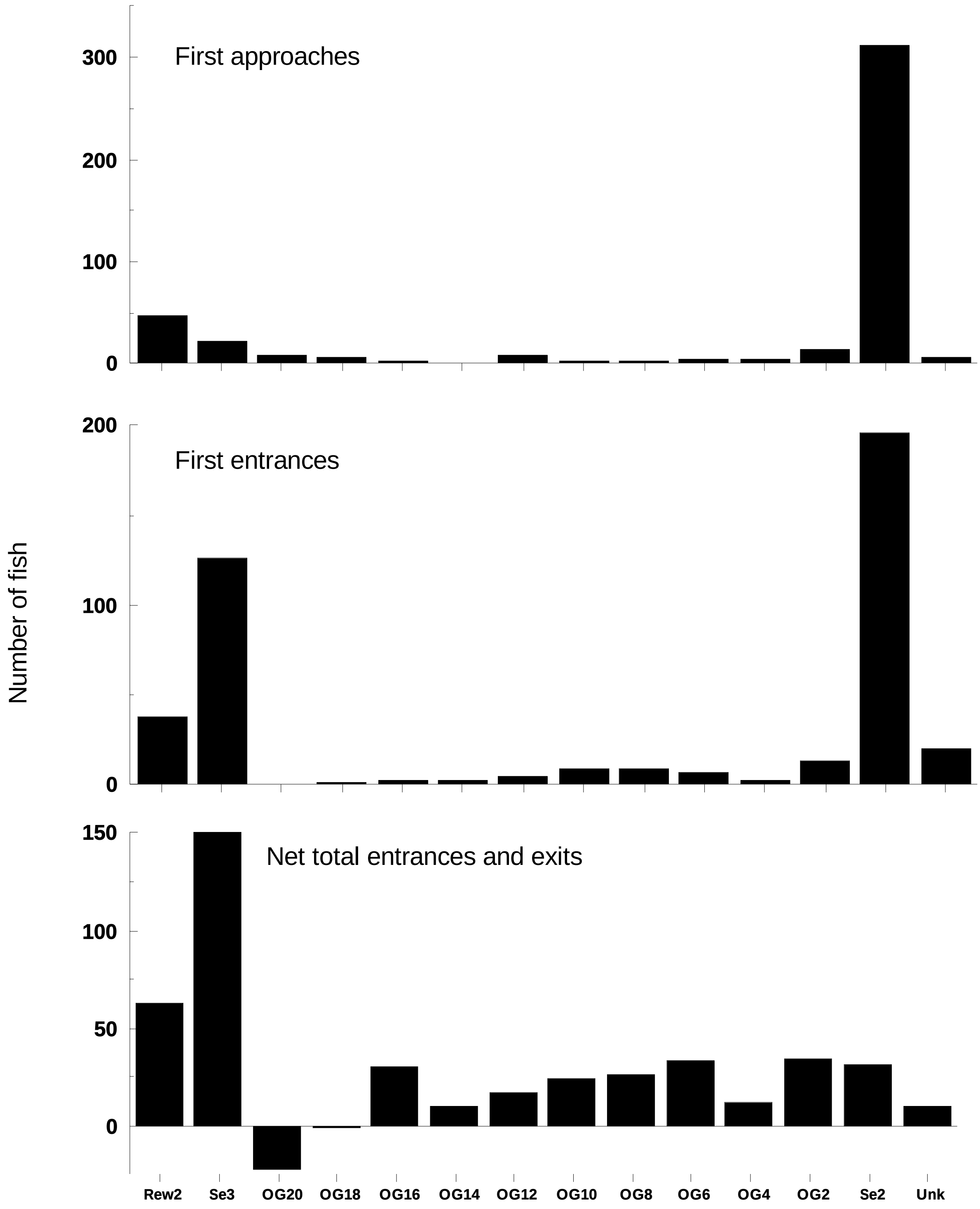

Figure 19. Location of first approaches (top), first entries (middle) and net entries (bottom) for all sockeye salmon with transmitters at Wanapum dam in 1997. Rew2 is the west-shore entrance, Se3 is the south-powerhouse entrance, Se2 is the east-shore fishway entrance, and OG's are orifice gates.

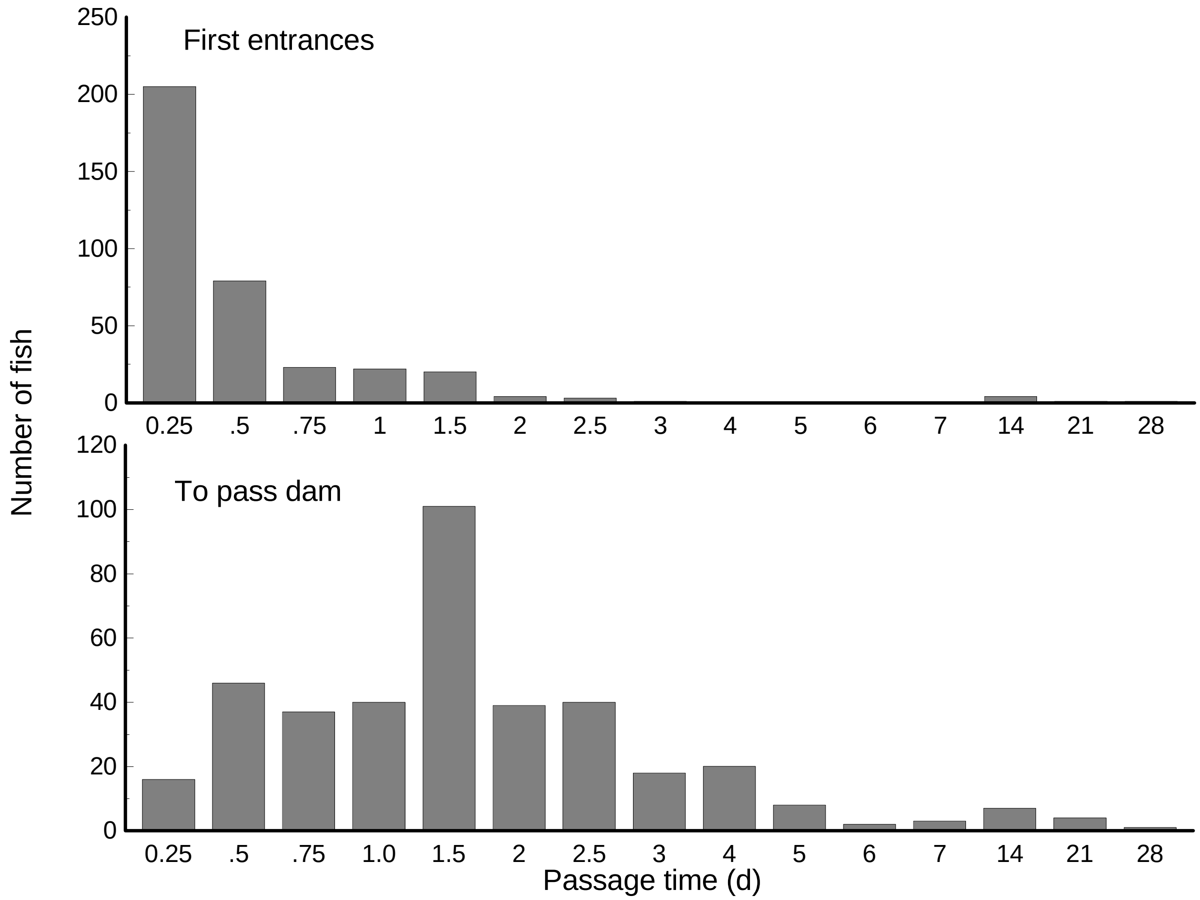

Figure 20. Passage times from first record in the tailrace until first entrance to the fishway (top) and from first record in tailrace until exit from top of ladders (bottom) for sockeye salmon at Wanapum Dam, 1997.

Passage Through Transition Pools

Median time for 62 chinook salmon to pass through the transition pool (from first record at base of the transition pool until last record at the upstream end of the transition pool) at Priest Rapids Dam was 1.1 h. Twenty-two (35%) chinook salmon passed through the transition pool without exiting in a median time of 0.2 h. The 20 (32%) salmon that exited the transition pool and moved downstream to the collection channel before returning and passing over the dam, took 1.2 h (median time) to traverse the transition pool. The 20 (32%) salmon that exited the transition pool and then exited dam and returned to the tailrace before eventually returning and passing over the dam took a median of 31.8 h to pass through the transition pool.

Median time for 88 sockeye salmon to pass through the transition pool at Priest Rapids Dam was 7.2 h. Thirteen (15%) sockeye salmon passed through the transition pool without exiting in a median time of 0.4 h. The 28 (32%) salmon that exited the transition pool and moved downstream to the collection channel before returning and passing over the dam, took 3.3 h (median time) to traverse the transition pool. The 47 (53%) salmon that exited the transition pool and then exited dam and returned to the tailrace before eventually returning and passing over the dam took a median of 14.5 h to pass through the transition pool.

Median time for 121 chinook salmon to pass through the transition pool at Wanapum Dam was 1.4 h. Forty-four (36%) chinook salmon passed through the transition pool without exiting in a median time of 0.1 h. The 17 (14%) salmon that exited the transition pool and moved downstream to the collection channel before returning and passing over the dam, took 0.5 h (median time) to traverse the transition pool. The 60 (50%) salmon that exited the transition pool and then exited dam and returned to the tailrace before eventually returning and passing over the dam took a median of 17.0 h to pass through the transition pool.

Median time for 341 sockeye salmon to pass through the transition pool at Wanapum Dam was 8.2 h. Eighty-six (25%) sockeye salmon passed through the transition pool without exiting in a median time of 0.2 h. The 46 (13%) salmon that exited the transition pool and moved downstream to the collection channel before returning and passing over the dam, took 1.5 h (median time) to traverse the transition pool. The 209 (61%) salmon that exited the transition pool and then exited dam and returned to the tailrace before eventually returning and passing over the dam, took a median of 21.5 h to pass through the transition pool.

Fallback

Six chinook salmon fell back at Priest Rapids Dam in 1997, which was 3.0% of the salmon with transmitters known to have crossed Priest Rapids Dam and reach Wanapum Dam. Five salmon fell back after exiting the east-shore ladder, the sixth fish fell back after exiting the west-shore ladder. Two salmon are known to have re-crossed Priest Rapids Dam after 8 d and 27 d. Five of the six fish that fell back at Priest Rapids Dam eventually reached Wanapum Dam and one salmon was caught in a sport fishery. Two of the five fish that reached Wanapum Dam subsequently returned to, and fell back over, Priest Rapids Dam (accounting for two of the six fallback fish) and nether fish returned to Wanapum Dam.

Sixteen sockeye salmon fell back at Priest Rapids Dam in 1997, which was 3.9% of the salmon known to have crossed Priest Rapids Dam and reach Wanapum Dam. Six salmon fell back after exiting the east-shore ladder and 10 fish fell back after exiting the west-shore ladder. Five salmon are known to have re-crossed Priest Rapids Dam after an average of 26.2 h. Fifteen of the 16 fish that fell back at Priest Rapids Dam eventually reached Wanapum Dam. Four of the 15 fish that reached Wanapum Dam subsequently returned to, and fell back over, Priest Rapids Dam, and one returned to Wanapum Dam.

Eight chinook salmon fell back at Wanapum Dam in 1997, which was 4.1% of the salmon known to have crossed Wanapum Dam. Seven of the eight salmon fell back after exiting the east-shore ladder, or 5.6% of the fish that used the east-ladder to cross the dam. The one salmon that fell from the west-shore ladder was 1.3% of the fish known to have passed the dam using that ladder. Seven salmon are known to have re-crossed Wanapum Dam after an average of 48.5 h.

Nineteen sockeye salmon fell back at Wanapum Dam in 1997, which was 4.5% of the salmon known to have crossed Wanapum Dam. Nine sockeye salmon fell back after exiting the east-shore ladder (2.5% of the fish that used the ladder), 10 salmon fell back after exiting the west-shore ladder (18.2% of the fish that used the ladder). Twelve salmon are known to have re-crossed Wanapum Dam after an average of 41.6 h.

Discussion

Orifice Gate Closure

In 1996, we found no difference in passage times for chinook salmon at Priest Rapids Dam with orifice gates open and closed, but the results were questionable because of low sample size (n = 4). By remotely downloading the receivers monitoring the transition pool at both dams, we were able to obtain 10 to 14 replicates of orifice gate treatments for analysis of passage times for first approaches to the dams, first entry to fishways, and first entry to transition pools, and 7-11 replicates for analysis of time to pass dams for sockeye salmon and for chinook salmon at Wanapum Dam. We believe sample sizes were sufficient to produce reliable results for those analyses. Sample size was insufficient to produce reliable results for analysis of total time to pass Priest Rapids Dam by chinook salmon because of data lost when the receiver monitoring top of the east-shore ladder was not downloaded often enough and became memory-full for periods of time.

A few statistically significant differences were found in the data but we believe these do not represent significant biological effects on the passage of salmon at the dams when orifice gates are closed. At Priest Rapids Dam, chinook salmon passage times from the tailrace to first entrance to the fishway, and from the tailrace to entry to the transition pool, were significantly longer (by about 5 h, median times) when orifice gates were closed, based on outcomes of median and Mann-Whitney tests, but were not significantly different based on ANOVA analysis. There were no significant differences in passage times from first approach to first entrance to the fishway or from first approach to first entry to the transition pool for these same fish. So, the longer passage times from the tailrace with orifice gates closed were probably due to time spent by fish in the tailrace prior to approaching the dam, and were unrelated to orifice gate closure. For sockeye salmon at Priest Rapids Dam, times to move between first approach and first entrance to the fishway were significantly longer when orifice gates were closed, based on outcomes of ANOVA, median, and Mann-Whitney tests. But the difference in median times were about 12 minutes (0.2 h) and we feel this does not represent a biologically significant effect on passage for salmon at the dam. For chinook salmon at Wanapum Dam in 1997, passage times were not significantly different with respect to orifice gate status in all tests performed.

Median times from the tailrace to first entries at Wanapum Dam were 1.8 h longer when orifice gates were closed, based on outcome of the median test, but mean times analyzed with ANOVA were not significantly different. No other significant difference was found for chinook salmon at Wanapum Dam. With sockeye salmon at Wanapum Dam, passage times from the tailrace to first entrance to the fishway, and from the tailrace to first entry to the transition pool were significantly longer when orifice gates were closed, based results of the median and Mann-Whitney tests, but passage times were not significantly different based on results of the ANOVA analysis. Differences in median passage time were about 2 h longer with orifice gates closed. When we analyzed from first approach to first entry to the fishway, and from first approach to first entry to the transition pool, passage times were again significantly longer with orifice gates closed with all three tests used. Differences were about 1 h for mean and median times, which we feel does not represent a biologically significant effect on passage of salmon at the dam. There was no difference for total time for sockeye salmon to pass the two dams, and for chinook salmon to pass Wanapum Dam with orifice gates open and closed. Fish were eliminated from analysis if they spent enough time in the tailrace to be exposed to more than one treatment, and this artificially shortened the median and mean times to pass the dams used in analysis. However, fish were removed from analysis about equally regardless of which orifice gate treatment they were initially exposed, and so this probably had little effect on outcome of analysis.

The number of exits made per fish was not significantly different with respect to orifice gate treatment for chinook salmon at the two dams, but was significantly fewer for sockeye salmon when orifice gates were closed at the two dams. But, making fewer exits did not translate to shorter passage times when orifice gates were closed for sockeye salmon.

Our conclusion is that closing orifice gates did not produce a negative or positive effect on passage of chinook and sockeye salmon at Priest Rapids and Wanapum dams. Use of orifice gates by salmon and steelhead at Columbia and Snake rivers dams is relatively low compared to use of the larger fishway entrances, so it is not surprising that closing orifice gates had little effect on passage at Priest Rapids and Wanapum dams. Since the greatest delay at both dams was for fish that exited fishways and returned to tailrace areas before eventually crossing the dams, passage times may be more noticeably improved if all collection channel entrances (including Lew2 and Priest Rapids Dam and Se2 at Wanapum Dam) were to be closed, as was recommended by Stuehrenberg et al. (1995). This may be more effective at Priest Rapids Dam than at Wanapum Dam because of the high exit rate at Lew2 observed in 1996 and 1997.

Hanford Reach

Chinook and sockeye salmon required 2 to 3 d (1.6 and 1.2 km/h) to pass through the Hanford Reach and enter the tailrace at Priest Rapids Dam and rates did not vary between spring and summer. Travel rates are not available for chinook salmon in the pre-impounded Columbia River, but chinook salmon migrated through free-flowing sections of the Snake River and lower Clearwater and Salmon rivers at about 20-30 km/d (Bjornn et al. 1998). Sockeye salmon travel rates through the Hanford Reach were comparable to those estimated for sockeye salmon in the pre-impounded Columbia River (28 km/d), based on 1938-50 fish counts at Bonneville and Rock Island dams (Bjornn and Peery 1992). Of the chinook salmon that entered the Hanford Reach, 69% eventually reached Priest Rapids Dam, as compared to 97% of the sockeye salmon. Many of the chinook salmon that did not reach Priest Rapids Dam were later found in the Snake River. Most of the radio-tagged chinook and sockeye salmon reached the two dams during July.

Run Timing

About half the chinook salmon that reached Priest Rapids Dam were tagged from the summer run at Bonneville Dam, but three-fourths of the fish would have been classified as summer chinook salmon based on their arrival date at Priest Rapids Dam. High and turbid spring flows may have slowed some spring chinook salmon migrating to the mid-Columbia River in 1997.

Passage at Wanapum and Priest Rapids Dams

Median times to pass Priest Rapids Dam in 1997 were 37.6 h for chinook salmon and 18.6 h for sockeye salmon, as compared to 37.6 h for chinook salmon in 1996. If chinook salmon that passed Priest Rapids Dam were divided into spring and summer runs based on the 14 June date, median passage times would have been 58.6 h during spring and 21.4 h during summer, as compared to passage times of 44.9 h and 29.4 h for spring and summer chinook salmon in 1993 (Stuehrenberg et al. 1995). Chinook and sockeye salmon passed Wanapum Dam in median times of 20.1 h and 29.7 h in 1997. Separating chinook salmon into spring and summer runs produced median passage times of 18.2 h and 24.0 h, as compared to passage times of 36.6 h and 22.9 h for spring and summer chinook salmon at Wanapum Dam in 1993 (Stuehrenberg et al. 1995).

For the sake of comparing passage conditions at Priest Rapids Dam with previous and ongoing adult salmon and steelhead telemetry studies, the most valid comparisons are probably with the two closest COE dams, McNary Dam on the Columbia River, and Ice Harbor Dam on the Snake River. These three dams have roughly the same configuration and design of the fishways. McNary and Priest Rapids dams will experience similar flow patterns in the Columbia River and all the fish that pass Priest Rapids Dam would have also passed McNary Dam. In addition, Ice Harbor and Priest Rapids Dams are both situated upstream from the confluence of two large rivers, and will potentially experience the same associated problems (i.e. straying and associated fallback at the dams). Median time for radio-tagged chinook salmon to pass Ice Harbor Dam in 1993 (average-flow year) was 20.6 h (Bjornn et al. 1995). In preliminary analysis, median times for chinook salmon to pass McNary and Ice Harbor dams in 1996 (high-flow year) were 25.3 h and 17.5 h. Data for COE dams from 1997 has not been processed at this time.

The majority of first approaches and first entries for both salmon species at Priest Rapids Dam occurred in the vicinity of the east-shore entrance, followed by Lew2 at the west end of the powerhouse collection channel. The west-shore entrance at Priest Rapids Dam was not monitored, so it is not known how many fish first approached and entered the dam along the west bank. Most first approaches at Wanapum Dam occurred at Se2, but first entries to the fishway were evenly divided between Se2 and Se3, the large openings at either end of the collection channel. Salmon may have moved upstream along the eastern shore, possibly to avoid turbulent flow from the spillway on the western shore, approached the dam at Se2 and either entered there, or moved along the powerhouse face and entered at Se3. Sockeye salmon used orifice gates more than chinook salmon at both dams, but for both species, use of orifice gates was low compared to use of the other larger entrances. This was partially due to the fact that orifice gates were closed for about half of the study period, but low use of orifice gates by chinook salmon has also been observed at lower Snake River (Bjornn et al. 1995) and mid-Columbia River (Stuehrenberg et al. 1995) dams. There was a negative entry rate (more exits that entrances) for both salmon species at Lew2 and a positive entry rate at Lew4-5 at Priest Rapids Dam, as was observed in 1996 (Bjornn et al. 1997). As in 1996, the general pattern for many fish was to enter at Lew4-5, enter and then exit the transition pool, move downstream the length of the collection channel, and then exit the dam at Lew2 (see discussion on fishway fence below). At Wanapum Dam, entry rates were highest at Rew2 and Se3, followed by Se2. The Se3 entrance faces downstream into an area of relatively calm water that forms between the spillway and the south end of the powerhouse. Once fish enter this area, it should be relatively easy for them to find and enter the Se3 opening. The net entrance rate for orifice gates at both dams were mostly near zero. The exception was for sockeye salmon at Wanapum Dam where entrance rates at orifice gates, except at OG-18 and OG-20, were similar to that at the Se2 entrance. About two-thirds or more of the salmon passed both dams using the east-shore ladder.

Chinook and sockeye salmon moved through the Priest Rapids reservoir at median rates of 2.4 and 1.6 km/h. Chinook salmon migration rates are comparable to those observed through the Ice Harbor Reservoir (2.4-2.6 km/h) during 1991-93 (Bjornn et al. 1998)

Fishway Fence Evaluation

With the prototype fishway fence installed inside the west end of the collection channel at Priest Rapids Dam, we found that the exit/entry ratio at Lew2 was 1.78 for chinook salmon and

1.12 for sockeye salmon. The exit/entrance ratio for chinook salmon in 1996, prior to installation of the fishway fence, was 1.73 (Bjornn et al. 1997). Our conclusion is that the fishway fence was not effective at reducing the number of salmon that exited the collection channel through Lew2. This in contrast to results from tests of similar devices at lower Snake River dams where fishway fences have been effective at reducing exits from north powerhouse entrances (Ted Bjornn, unpublished data).

A number of factors may have contributed to the ineffectiveness of the fishway fence. At high flows the fence was submerged and fish would have been able to exit at Lew2 by swimming over the fence. There were a total 49 days between 30 April and 27 June during which the maximum daily tailwater elevation exceeded the height of the fishway fence (elevation 420'), however only eight exits by chinook salmon and two exits by sockeye salmon occurred at Lew2 on these same days. The occurrence of high water did not seem to significantly increase the number of exits at Lew2. When the collection channel was de-watered in the fall of 1997, it was discovered that the upstream edge of the triangle-shaped portion of the fence (see Figure 2) had detached from the floor of the collection channel. This may have decreased the effectiveness of the fence to deflect fish away from the opening, but would not have increased access to Lew2 from inside the collection channel. The third possibility why the fishway fence did not work is related to the dimensions of the collection channel and fence at Priest Rapids Dam. The Priest Rapids fishway fence was 3.2 m at the widest point (tip of the triangle) and the collection channel was 4.6 m wide and ends 3.0 m downstream from the fence (Figure 21). Fish moving downstream in the collection channel would have been diverted around Lew2 by the fence, then would have reached the end of the channel and either stopped and milled around in this area or turned and moved upstream. The relatively narrow gap between the tip of the triangle and the opposite wall of the collection channel (1.4 m) formed a constriction which may have caused fish to turn and, finding the opening to the fence, pass out Lew2. Collection channels at the two Snake River dams are 5.5 m wide and continue past the fishway fences, across the spillway to the opposite-shore entrance, so fish are not confined to as small an area as existed at Priest Rapids Dam.

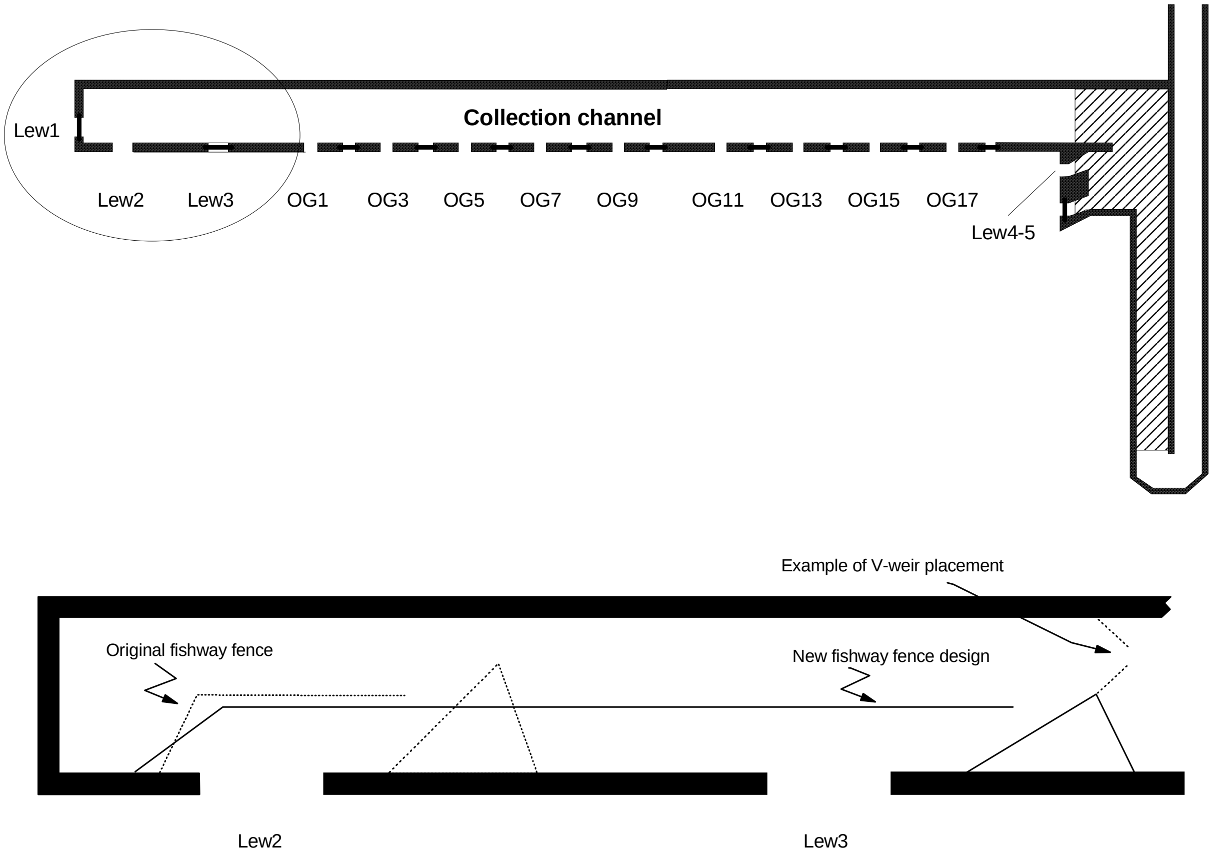

Figure 21. West end of collection channel at Priest Rapids Dam showing fishway fence used in 1997 and modified fishway fence design extending across Lew2 and Lew3.

For future studies, we recommend altering the dimensions of the fishway fence at Lew2 in the following ways. Lengthen the fence so that the opening is further upstream and the fence covers both Lew2 and Lew3 entrances. Make the fence narrower so fish that move behind (downstream from) the fence are not confined to as small an area (Figure 21). Alternatively, use a V-shaped weir, or some other device, at the upstream end of the fence to discourage fish from entering the area behind the fence.

Passage Past the Counting Station at Priest Rapids Dam

The counting station was not an area of delay for most chinook and sockeye salmon in 1997. Chinook salmon and sockeye salmon moved passed the fish counting station in the east-shore ladder at Priest Rapids Dam, in about 18 and 12 min, median times. One of 58 chinook salmon and 11 of 89 sockeye salmon took more than 1 h to pass this section of the ladder, the remaining fish passed in less than 1 h.

Passage Past the Coded-Wire-Tag Trap at Priest Rapids Dam

Most chinook salmon also moved quickly past the CWT trap near the top of the east-shore fish ladder at Priest Rapids Dam, in a median of 24 min as compared to total time to pass up the ladder of 2.3 h. The median time for sockeye salmon to pass the CWT trap was 1.3 h as compared to the median of 4.1 h to pass up the entire ladder. Chinook and sockeye salmon took about three times longer to pass the CWT trap when the trap was operating as compared to the same section of ladder when the trap was not in operation. This equated to a median increase in passage times of 42 min for chinook salmon and 2.1 h for sockeye salmon. Large numbers of sockeye were seen in the ladder downstream from the trap during the peak of the run. The area where fish congregate is also just downstream from where the ladder passes under a roadway and where there is a transition from overflow weirs to a section with weirs with submerged orifices only between pools. The combination of these factors may contribute to delay some salmon from passing through the top section of the ladder at Priest Rapids Dam.

Use of the West-Shore Slotted Entrance at Wanapum Dam

We do not have telemetry data for use of Rew2 from prior to installation of the new gate, so comparisons were made to use of Se2 and Se3 (both vertical slot entrances), the nearest comparable openings. Salmon used the new vertical-slot gate placed at the Rew2 west-shore entrance as readily as they used Se2 and Se3 at Wanapum Dam in 1997. At Rew2, a successful entry was made for every 1.1 approaches made by chinook salmon and for every 1.6 approaches made by sockeye salmon. At Se2, a successful entry was made for every 5.8 approaches by chinook salmon and for every 3.1 approaches made by sockeye salmon. At Se3, a successful entry was made for every 3.3 approaches by chinook salmon and every 1.6 approaches by sockeye salmon.

Passage Through Transition Pools

About two-thirds of the salmon turned around and moved downstream after initially entering the transition pools at both dams. Passage times through transition pools were highest at both dams for salmon that exited the transition pool and then exited the dam and returned to the tailrace before eventually returning and passing over the dam. At Priest Rapids Dam, 35% of the chinook salmon and 15% of the sockeye salmon passed quickly through the transition pool. Another 32% of the chinook and sockeye salmon left the transition pool but then returned and moved through the transition pool in a total of 1-3 h. But the 32% of chinook salmon and 53% sockeye salmon that returned to the tailrace took about 30 h and 12 h longer to pass through the transition pool than those fish that did not exit to the tailrace. A similar pattern was seen at Wanapum Dam. At least half of the salmon exited to the tailrace before passing through the transition pool, and took about 16-20 h longer to do so than the salmon that did not exit to the tailrace.

In 1997, there were 38 chinook salmon that were tracked through the transition pools at both Priest Rapids and Wanapum dams. Of those 38 fish, 12 (32%) exited to the tailrace before passing through the transition pool and later six (50%) of those 12 fish exited to the tailrace before passing through the transition pool at Wanapum Dam. These values are the same as was seen for the entire run. For sockeye salmon, there were 73 fish that were tracked through both transition pools. Of those 73 sockeye salmon, 36 (49%) exited to the tailrace before passing through the transition pool. From those same 36 sockeye salmon, 27 (75%) later exited to the tailrace before passing through the transition pool at Wanapum Dam, which is about five fish more than would have been expected using the 61% for this category that was seen for the entire run. A concern is that adult salmon must pass over a series of dams during their upstream migration. If a single fish uses a additional 12 to 30 h to pass each dam because it repeatedly exits to the tailrace, significant delays will occur that could effect survival to spawning. This was not the case for chinook salmon in 1997, but may have been the case for a few sockeye salmon at the two dams. However, it is difficult to draw conclusions using these low numbers of fish.

Fallback

Fallback rates in 1997 were 3.0% and 4.1% for chinook salmon and 3.9% and 4.5% for sockeye salmon at Priest Rapids and Wanapum dams. In 1996, the fallback rate for chinook salmon at Priest rapids Dam was 5.2% (6 of 115 fish; Bjornn et al 1997). In 1993, the fallback rate for chinook salmon was 8.5% (39 of 458 fish) at Priest Rapids Dam and 4.5% (19 of 420 fish) at Wanapum Dam (Stuehrenberg et al. 1995). Fallback rates reported for chinook salmon at the four lower Snake River dams ranged 1.9 to 3.2% in 1993. Of the 49 salmon that fell back at the two dams in 1997, 39 (80%) are known to have re-crossed the respective dam with mean delays ranging from 26 h to 48 h. The average delay for four chinook salmon that fell back and re-crossed Priest Rapids Dam in 1996 was significantly longer at 9.8 d (Bjornn et al. 1997). Most of the fallback-salmon re-crossed the respective dams. One chinook salmon was caught in a sport fishery and none of the fallback fish were captured at hatcheries in the area.

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Appendix

Comments from Draft Report and Response to Comments