Technical Report 2003-5

ADULT SPRING AND SUMMER CHINOOK SALMON PASSAGE THROUGH FISHWAYS AND TRANSITION POOLS AT BONNEVILLE, McNARY, ICE HARBOR, AND LOWER GRANITE DAMS, 1996

A report for Project MPE-P-95-1

by

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Preface

Studies of adult salmon and steelhead *Oncorhynchus* spp. migrations past dams, through reservoirs, and into tributaries began in 1990 with planning, purchase, and installation of radio telemetry equipment for studies at the Snake River dams. Adult spring and summer chinook salmon *O. tshawytscha* were outfitted with transmitters at Ice Harbor Dam in 1991 and 1992, and at John Day Dam in 1993; reports of those studies are available (Bjornn et al. 1992; 1994; 1995; 1998). The focus of adult salmon passage studies included the lower Columbia River dams in 1995, when telemetry equipment was set up at the dams and tributaries, and spring/summer chinook salmon were outfitted with transmitters at Bonneville Dam in 1996. In this report we present information on the use of fishway entrances and movements of chinook salmon through transition pools and past Bonneville, McNary, Ice Harbor, and Lower Granite dams, the four dams that had a full complement of receivers and antennas to monitor use of fishways and transition pools during the 1996 migration.

Acknowledgments

Many people assisted in the field work and data compilation for this project and the successful completion was made possible by Bob Dach and Teri Barila, the Corps of Engineers project officers. Michelle Feeley, Brian Hastings, Michael Jepson, and Jay Nance of the University of Idaho assisted in data collection and analysis.

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Abstract

Evaluation of fishway entrances used, and passage through the fishways by chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* at dams in the lower Columbia and Snake rivers was an objective of the adult salmon and steelhead passage project. In 1996, we monitored passage through the fishways by outfitting chinook salmon with radio transmitters and installing full antenna/receiver coverage at Bonneville, McNary, Ice Harbor, and Lower Granite dams. Critical parameters studied were times for a fish to first approach the dam and first enter a fishway, total time to pass over the dam, which entrances were approached, where fish entered and exited the fishways, and their passage through transition pools and over the dams.

In 1996, 853 spring and summer chinook salmon were outfitted with radio transmitters at the adult trapping facility adjacent to Bonneville's Washington-shore fishway and then released ~10 km downstream from the dam at Dodson and Skamania landings. Of these fish, 834 were subsequently recorded at Bonneville Dam, 307 were recorded at McNary Dam, 127 were at Ice Harbor Dam and 106 were at Lower Granite Dam. Median passage times from release after tagging to first record at the four dams were 0.8, 11.1, 16.2, and 25.1 d.

After passing a tailrace receiver, median times for chinook salmon to first approach fishways was 1.7 to 3.1 hours (h) for all dams monitored in 1996. Median times to first enter fishways were 9.7 to 10.7 h at Bonneville, McNary, and Ice Harbor dams and 6.5 h at Lower Granite Dam. Median times from tailrace receiver to exit from the top of a ladder were 17.5 h at Ice Harbor, 23.1 h at Bonneville, 25.4 h at McNary, and 38.2 h at Lower Granite dams. The longer passage time at Lower Granite Dam was likely caused by trapping of the tagged fish in the adult trap in the ladder.

First approaches to fishways by chinook salmon occurred at all entrances, with a tendency toward shoreline entrances, particularly at Ice Harbor and Lower Granite dams. The highest numbers of first approaches at Bonneville Dam were at Powerhouse I sluice gates and at shoreline entrances. At McNary Dam, the highest number of first approaches were at orifice gates at the southern end of the powerhouse and at north-shore entrances. Median numbers of approaches to fishway entrances by chinook salmon in 1996 were 19 to 25 at Bonneville, McNary, and Ice Harbor dams and 50 at Lower Granite Dam.

Entrances used by chinook salmon in 1996 were more restricted than entrances approached. The highest number of first and subsequent entries at Bonneville Dam were at the north-shore, south-spillway, and south-shore entrances. At McNary Dam, most first and subsequent entries were at shoreline entrances, and at both Ice Harbor and Lower Granite dams, most first and subsequent entries were at shoreline and north-powerhouse entrances. Median numbers of entries by chinook salmon in 1996 were one at Ice Harbor, two at Bonneville and McNary, and three at Lower Granite Dam.

At most fishway entrances more fish entered than exited. Salmon that exited the fishways from the collection channels did so mostly at shoreline and powerhouse entrances closest to the bottoms of ladders and at entrances adjacent to spillways. Overall, however, the shoreline and powerhouse entrances had the highest net number of entries, in part because they were larger entrances, had greater depths, and higher flows. Although many chinook salmon approached orifice and sluice gates, relatively few used them to enter or exit fishways.

We also analyzed behavior in the fishways and passage time for chinook salmon that passed Bonneville Dam, fell back over the dam, and subsequently reascended. Overall, 110 fish fell back a total of 130 times, of which 82% initially passed the dam via the Bradford Island fishway. Of the 110 fish, 102 reascended ladders and passed the dam a second time. Fish that had fallen back moved through fishways more quickly, and with fewer entrances and exits from the fishway, on their second passage.

In 1996, entries, exits, movements in, and passage through the transition pools were analyzed for 679 chinook salmon outfitted with transmitters at Bonneville Dam, 294 at McNary Dam, 86 at Ice Harbor Dam, and 85 at Lower Granite Dam. From 55% to 60% of the chinook salmon at McNary and Ice Harbor dams passed through transition pools on the first attempt, without exiting to a collection channel or to the tailrace. At Bonneville Dam, 36% passed through on the first attempt, and at Lower Granite Dam 20% passed the transition pool on the first attempt. Four to 25% turned around in transition pools and moved downstream into the collection channel but did not exit into the tailrace. At McNary and Ice Harbor dams, 27% and 35% of the chinook salmon monitored turned around in the transition pool, moved downstream, exited the fishway into the tailrace, and then reentered the fishway at least once before passing the dam; at Bonneville and Lower Granite dams, 53 to 55% exited transition pools into the tailrace.

Median time for chinook salmon with transmitters to first enter a transition pool after entering a fishway ranged from 4 to 11 min at all fishways, except at Lower Granite Dam where median time to first enter the transition pool was 50 min. Median times for all fish from the first entry into a transition pool to entry into a ladder were 35 min to 1.29 h at Bonneville, McNary and Ice Harbor dams and was 3.82 h at Lower Granite Dam. Median times for all chinook salmon to ascend ladders from a transition pool were 2.1 to 2.9 h at Bonneville, McNary and Ice Harbor dams and was 9.15 h at Lower Granite Dam. Median times for all fish from first fishway entry to exit from the top of a ladder were 8.51 h at Bonneville, 5.62 h at McNary, 3.75 h at Ice Harbor and 25.99 h at Lower Granite dams.

For chinook salmon that passed through transition pools on their first attempt, median times to pass through the pools ranged from 13 to 23 min (0.22 to 0.38 h) at each dam. Median times for chinook salmon that moved back into collection channels, but did not exit into the tailrace, were 0.43 to 1.56 h; for chinook salmon that exited to a tailrace, median passage times through transition pools ranged from 2.00 h at Ice Harbor Dam to 9.19 h at Bonneville Dam. Passage rates differed between individual fishways and pools at each dams based on fishway configuration, but in all cases fish that exited pools into the tailrace had the longest passage times through pools.

Median times for all chinook salmon with transmitters to ascend ladders were between 2.1 and 2.9 h at Bonneville, McNary, and Ice Harbor dams. At Lower Granite Dam, median time to ascend the ladder was 9.2 h.

Median times to pass from first fishway entry to exit from the ladders were 2.52 to 3.95 h for chinook salmon that moved straight through a transition pool at Bonneville, McNary and Ice Harbor dams and was 20.83 h at Lower Granite Dam. For fish that moved downstream in a transition pool at these two dams but did not exit to a collection channel or tailrace, median times to pass a dam were 3.08 to 4.47 h at the three lower dams and was 22.84 h at Lower Granite Dam. Fish that exited to a collection channel at Bonneville, McNary, and Ice Harbor dams had median times to pass from first fishway entry to exit from the top of a ladder from 3.96 to 4.81 h; for fish that exited to a tailrace at these dams, median times to pass were 7.86 h at Ice Harbor, 22.29 h at McNary, and 17.31 h at Bonneville dams. At Lower Granite Dam, median times to pass from first fishway entry to exit from the ladder were approximately 45 h for fish that did not exit the fishway after exiting the transition pool, and 29 h for fish that exited to the tailrace.

Passage time comparisons based on behavior in transition pools showed that chinook salmon that exited into the tailrace from transition pools were delayed 7 to > 36 h at Bonneville, 7 to 24 h at McNary, 5 to 20 h at Ice Harbor Dam, and 6 to 8 h at Lower Granite dams. Chinook salmon that moved through pools on their first attempt had the shortest passage times through fishways and past dams in 1996.

We also evaluated behavior in transition pools for 89 chinook salmon that passed Bonneville Dam, fell back over the dam, and then reascended. Eighty-one had complete transition pool records on both first and second passages of the dam, and for most measures of transition pool passage, median times were shorter on the second passage than on the first. Chinook salmon that fell back had median passage times from first fishway entry to exit from the top of a Bonneville ladder of 8.55 h on the first passage and 5.17 h on the second passage. Fewer fish exited the fishway into the tailrace and more passed through transition pools into ladders on their first attempt than on their second passage of the dam.

Introduction

An important aspect of the adult salmon *Oncorhynchus* spp. passage project was to describe how fish moved past dams in the lower Columbia and Snake rivers. Accurately monitoring movements at the dams of fish outfitted with transmitters was significantly enhanced with the development of digital spectrum processors (DSP), which, when combined with SRX radio receivers (SRX/DSP units), allowed simultaneous monitoring of all transmitter frequencies. SRX/DSP radio receivers were first used to monitor entrance use by steelhead at Lower Granite Dam in fall 1992 (Bjornn et al. 1994).

Monitoring of fishway entrance use and movements within the fishways by adult salmon and steelhead at all four of the lower Snake River dams began in spring 1993 and continued through 1994. Antennas connected to SRX/DSP receivers were placed near entrances to fishways, within fishways, and at the top of the ladders at all four lower Snake River dams. With the telemetry system, we could monitor movements of individual fish outfitted with transmitters as they approached entrances to fishways, determine openings used by fish to enter and exit fishways and their movements within fishways, and assess the time for fish to pass the dams. Detailed information on fishway use and passage for chinook salmon in years prior to 1996 was reported in Bjornn et al. (1995) and in Part III of Bjornn et al. (1998).

The objectives for 1996 included monitoring fishway entrance use, movements in the fishways and transition pools, and determining times for fish to enter fishways and pass lower Columbia and Snake River dams. Entrances approached and used to enter fishways and entrances and fishways used to pass dams were of particular interest. Transition pools were defined as the area from the last unsubmerged weir at the bottom of a ladder, downstream to the median that separated the collection channel from fishway entrances.

In 1996, river conditions diverged from the averages. Flow and spill in the Columbia and Snake rivers were nearly double the prior 10-year averages (1986-1995, Appendix A). During April through July period, daily flows averaged 328 kcfs at Bonneville Dam, 318 kcfs at McNary Dam, and about 109 kcfs at Ice Harbor and Lower Granite dams. Spill was continuous during the migration season at Bonneville, McNary, and Ice Harbor dams, and through early July at Lower Granite Dam. Water temperatures at the dams were about 1 to 2 degrees C cooler than the 10-year average and turbidity was higher than average, in response to the higher flows.

Methods

Chinook salmon used for the 1996 study were collected and outfitted with radio transmitters at the adult fish facility (AFF) at Bonneville Dam on the Columbia River (river kilometer [RKM] 235.1). Salmon were tagged from 4 April to 27 June on a predetermined schedule based on historic run timing, with 10 days of tagging followed by 4 days with no tagging. Of 853 chinook tagged, 703 (82%) were likely spring chinook (tagged before 1 June) and 150 (18%) were likely summer chinook salmon (tagged in June). During the

tagging period, approximately 1.4% of spring chinook and 0.9% of summer chinook salmon that passed Bonneville Dam were tagged with a radio transmitter. Fish were tagged unselectively as they passed through the AFF, and we believe the sample was approximately random. However, no salmon were tagged at night, no jacks (sub-adult, by size) were tagged, no summer chinook salmon were tagged in July, and only fish passing the Washington-shore ladder were sampled (for a complete description of tagging methods used in 1996, see Bjornn et al. 2000).

Fish with transmitters were monitored in the tailraces of the four lower Columbia River dams and the four lower Snake River dams using SRX receivers connected to nine-element yagi antennas. Antennas were set up in each tailrace (1.5 to 2.7 km) downstream from the dams. In 1996, SRX/DSP receivers connected to underwater coaxial cable antennas were installed near all fishway entrances and exits, and inside fishways at Bonneville (Figure 1), McNary, Ice Harbor, and Lower Granite dams. The Dalles, John Day, Lower Monumental, and Little Goose dams had less coverage with SRX/DSP receivers during the chinook salmon migration in 1996. Tailrace SRX receivers were used to determine when fish first entered the tailrace area of the dam. The SRX/DSP receivers were used to determine when a fish approached the dam at a fishway entrance, entered a fishway, moved within the fishway, and exited the fishway. A detailed description of tagging and monitoring methods used throughout the basin can be found in Bjornn et al. (2000).

Passage Times

An important aspect of adult salmon and steelhead passage at dams in the Columbia and Snake rivers is a breakdown of the time to pass each dam. Emphasis on analysis was placed on determining passage times for fish from release to first approach at the dam, first entry in a fishway, and the total time to pass over the dam. Start times were the time released, time fish were first recorded on tailrace receivers 1.5 to 2.7 km downstream from the dams, and time of first approach or entry into a fishway entrance. Only fish with records at both sites bracketing the passage areas and fish with clearly discernable movement histories were included in analyses.

At the monitored dams in 1996, from 3% to 7% of chinook salmon with transmitters were recorded inside fishways before being recorded at an antenna outside the fishway. In these cases, the location of a fish's first approach at the dam was treated as unknown and the time of the first approach was recorded as 2 s prior to the first record inside the fishway. We then compared median passage time calculations for fish with known and unknown first approach records and found median time differences of less than 5 min. Thus, fish with unknown first approaches were included in passage time analyses in this report. Similarly, the time or exact location of the first entry into fishways was unknown for approximately 17% of chinook with transmitters in 1996. In the majority of these cases, the time and location of the approach prior to a fish's entry into the fishway were known and the first record inside the fishway was also known, but it was uncertain which of two adjacent entrances the fish used. One second was added to the approach record to estimate time of entry for these fish; the

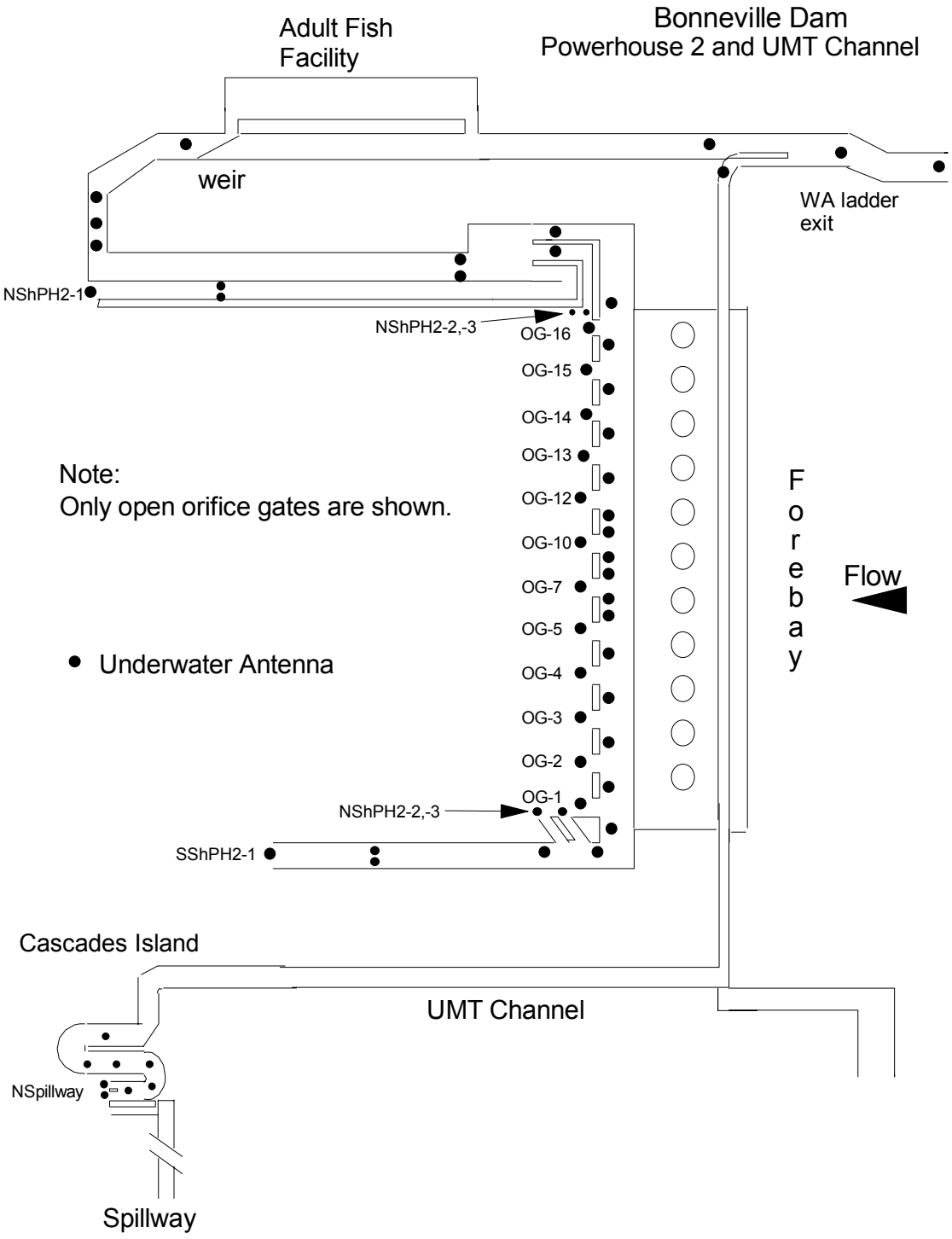


Figure 1. Location of antennas and fishway entrances for the Bradford Island and Washington-shore fishways at Bonneville Dam in 1996 when chinook salmon were passing the dam.

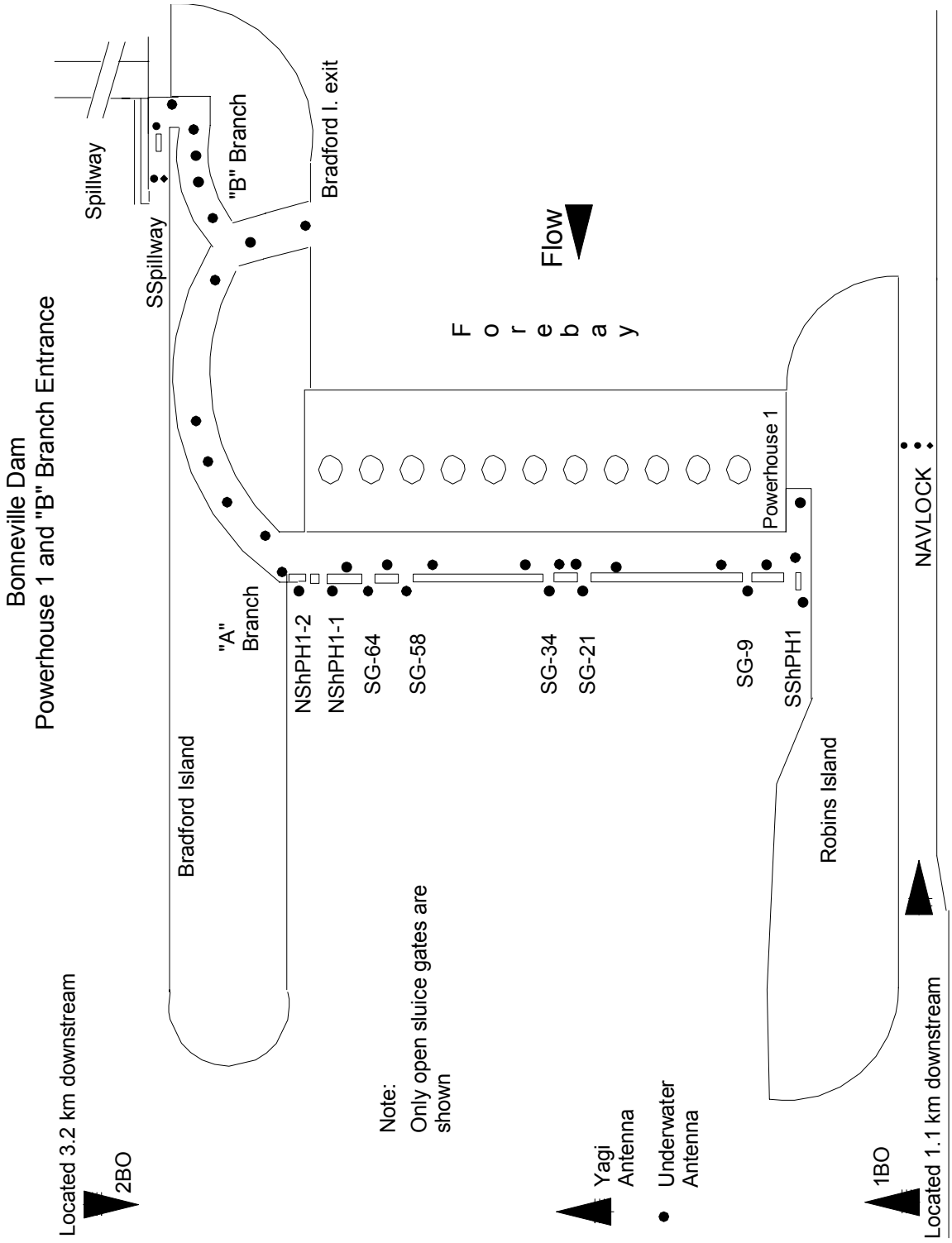


Figure 1. Continued.

inclusion of these fish in passage time analyses had minimal impact on median passage times. Like the fish with unknown approach dates, chinook salmon with unknown entrance dates were included from travel time analysis, but were excluded in the entrance location analysis.

Most passage times were determined from the time of first record of a fish at the tailrace receiver sites prior to the first approach at the dam. In the analysis of fishway use by chinook salmon that fell back over Bonneville Dam, passage times were calculated from the first approach at a fishway (after the fallback) to exit from the top of the ladders. Passage variables (time to first approach, time to first entry, time to pass a dam) were summarized over the entire migration period for all flow and spill conditions. In most cases we present medians of variables because passage times tend to be skewed to the right and means may not be the best descriptor of time to pass. In evaluations of passage times for different groups of fish (e.g. based on behavior in transition pools), Kruskal-Wallis χ^2 tests were used to compare median times. Paired *t*-tests were also used to compare first- and second-passage times for fish that fell back at Bonneville Dam.

Fishway Use

With the antenna/receiver setups at Bonneville, McNary, Ice Harbor, and Lower Granite dams we were able to determine the movements of adult salmon with transmitters in the tailrace, approaches at entrances to the fishways, entrances used to enter and exit the fishways, and fishways used to pass dams. Since fish could approach and enter fishways more than once, first and total approaches, entries, and exits made by fish were also summarized. Bonneville, McNary and Ice Harbor dams had two fishways, while Lower Granite Dam has one fishway. Fishways at Bonneville Dam are the most complex and required more elaborate telemetry coverage. Some fish were found to move extensively in the tailrace and in the fishways of all dams. The amount of searching by fish to find a route past the dam was evident in the number of approaches they made at the different entrances.

The migration history of each fish at the dams was contained in the thousands of telemetry records collected as the fish passed the various antennas at the entrances, in the fishways, and at the top of the ladders. Processing these data involved inspecting telemetry records at the receiver and antenna sites to determine each fish's behavior (e.g. approach, entry, or exit at fishway entrances). This process was facilitated by using a semi automated program developed in ArcView that provided data processors with likely codes that could be accepted or rejected to describe a fish's behavior while skipping redundant telemetry records at a single site. The program helped the data processors move through the records at a site quickly and presented behavior codes that could be accepted or rejected.

Movement Through Transition Pools

In 1996, we also collected data on chinook salmon outfitted with transmitters as they passed through transition pools during their passage at Bonneville, McNary, Ice Harbor, and Lower Granite dams. Underwater antennas were installed in the downstream portion of each transition pool to record when fish with transmitters entered or exited the transition pools. One or more antennas were also installed at the bottom of each ladder and in sequence up the ladder to record when fish passed through the transition pools and entered ladders; the sequence of antennas were set to accommodate fluctuating water elevations in the fishway and tailrace. For fishways without powerhouse collection channels, the transition pool extended from just inside the entrance upstream in the fishway to the first unsubmerged weir in the ladder. The upstream end of the WA-shore pool, and the location of the last transition pool record for chinook salmon in 1996, varied with tailwater elevation. A sequence of four paired antennas at different elevations in the ladder was used to mark a fish's exit from the transition pool into the ladder as tail-water elevations changed. In fishways with powerhouse collection channels, the transition pools extended from the upper end of the collection channel upstream to the first unsubmerged weir. At some dams there was a main shoreline entrance near the upstream end of the collection channel and the transition pools started upstream from that entrance channel. We could identify at which entrance and when each fish first entered fishways, when fish first entered transition pools, how much time fish spent in transition pools, whether or not fish passed directly into the ladder from the transition pools, when fish passed through transition pools and began to ascend a ladder, and when fish exited the top of the ladders.

Based upon earlier studies by Bjornn et al. (1998), fish behavior at the transition pools was categorized into four groups. Chinook salmon that passed through the pools without delay, those that delayed (moved downstream) in the transition pools but did not exit the pool, those that exited the transition pools to the collection channels, and those that exited to a tailrace.

Results- Bonneville Dam

Passage Times

In 1996 we monitored time to pass, fishway entrance use, and movements within the fishways at Bonneville Dam (Figure 1) by recording the movements of 853 chinook salmon outfitted with transmitters. Chinook salmon were outfitted with transmitters at the trapping facility adjacent to Bonneville Dam's Washington-shore fishway. These fish were released ~9.5 km downstream from the dam at boat landing at Dodson, Oregon and Skamania, Washington. Of the 853 fish, 834 were subsequently recorded in the Bonneville tailrace or at the dam, 814 had recorded approaches at the dam, and 801 passed the dam one or more times. Seven fish first passed the dam through the navigation lock at the south shore, 422 first passed through the Bradford Island fishway, and 372 first passed via the Washington-shore fishway and ladder. In 1996, 110 chinook salmon with transmitters fell back over

Bonneville Dam after passing the dam; records for these fish after first passage were analyzed separately.

Median passage times of chinook salmon from release downstream of Bonneville Dam to the Bonneville tailrace receiver site was 0.80 d and was 2.03 d from release to passage over the dam (Figure 2). A few fish took several days to return to the tailrace, and five were recorded at the tailrace antenna more than 25 d after their release downstream of Bonneville Dam. Median times from the tailrace receiver (1.4 to 2.5 km downstream from the Bradford Island and Washington-shore fishways at the dam) to first recorded approach at a fishway entrance, first entry into the fishways, and passage from the top of the ladders were 3.09 h, 10.74 h, and 23.07 h (Figure 3). Median time from first approach at a fishway to first entry into the fishway at Bonneville Dam was 1.85 h, and median time from first entry into the fishway to exit from the top of the ladders was 7.94 h (Figure 4). Distributions of passage times were skewed to the right, with a few fish taking several days to approach the entrances, enter the fishways, or pass over the dam. Consequently, mean passage times were longer than median times.

Most chinook salmon (76% of 757 fish) entered fishways within 1 d after passing the tailrace receiver, but 21 took more than 5 d to enter fishways after passing the tailrace. About 50% of the 750 fish that passed the dam via the fishways did so within 2 d after passing the tailrace receiver, though 8% (66 fish) took more than 5 d to pass the dam. Longer passage times occurred when fish spent 1 d (or night) or more in the fishways or spent time migrating up and down powerhouse collection channels, exiting and reentering fishways multiple times, or migrating between Bradford Island and Washington-shore fishways (e.g. Figures 5-7). Passage times between the tailrace and passage from the tops of the ladders included time used by some fish that exited a fishway via one of the entrances into the tailrace and then reentered a fishway.

Fishway Use

Approaches to fishways: Chinook salmon first approached most of the entrances at Bonneville Dam 1996. Sixty-two percent (501) of the fish first approached entrances to the Bradford Island fishway, which included all entrances at Powerhouse 1 and the south end of the spillway. Sluicegate entrances 21 and 34 and the south-shore entrances had the most first approaches to the Bradford Island fishway (Figure 8). Thirty-eight percent (313) of the fish first approached entrances to the Washington-shore fishway, which included all entrances at Powerhouse 2 and the north end of the spillway. First approaches at the Washington-shore fishway were primarily (59%) at the north end of Powerhouse 2. Entrance 1 at the north shore of Powerhouse 2 (NShPH2-1) is the downstream, shoreline entrance to the Washington-shore fishway.

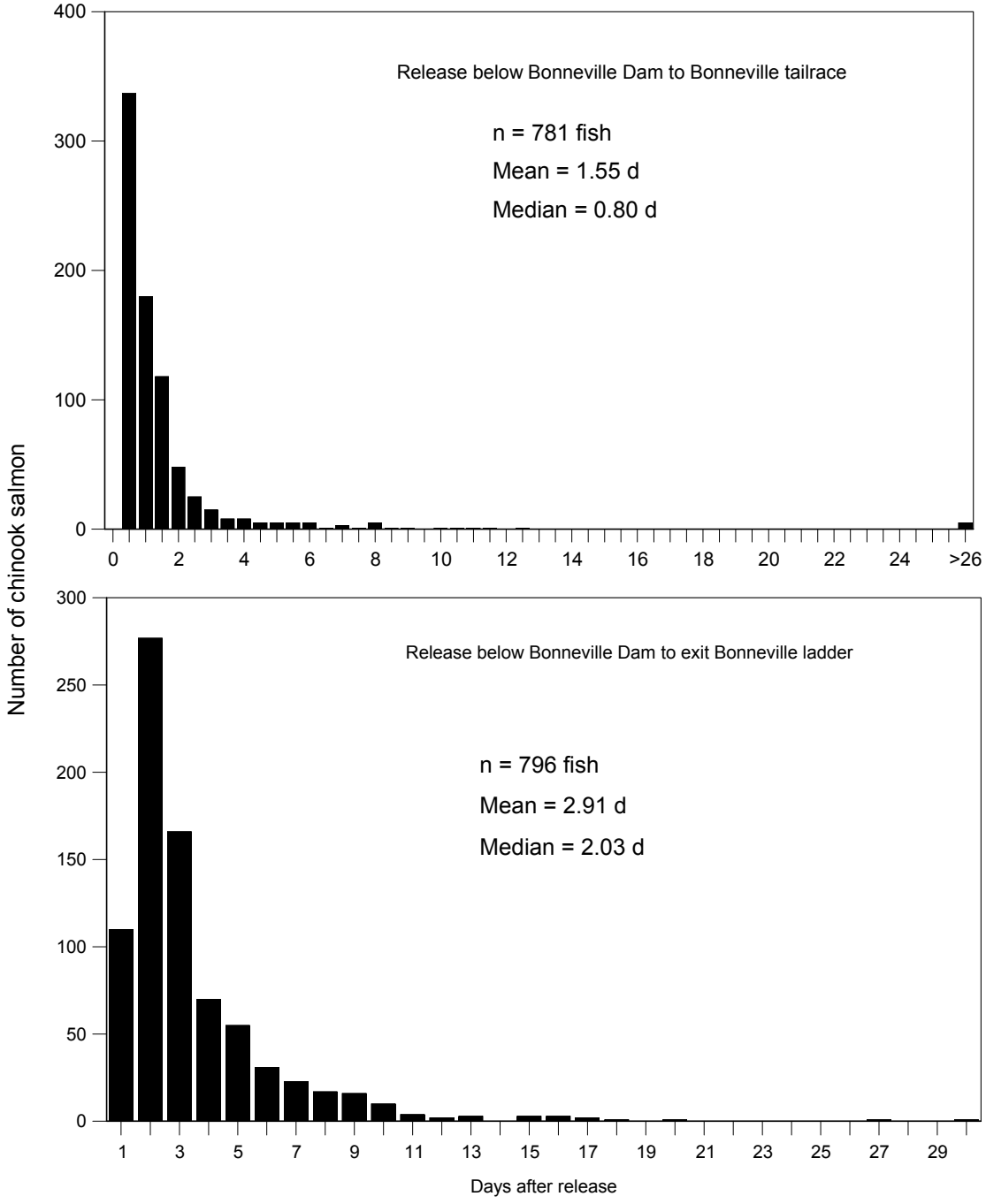


Figure 2. Number of chinook salmon and days to migrate from the release site downstream from Bonneville Dam to the tailrace and to exit from the top of the ladders at Bonneville Dam in 1996.

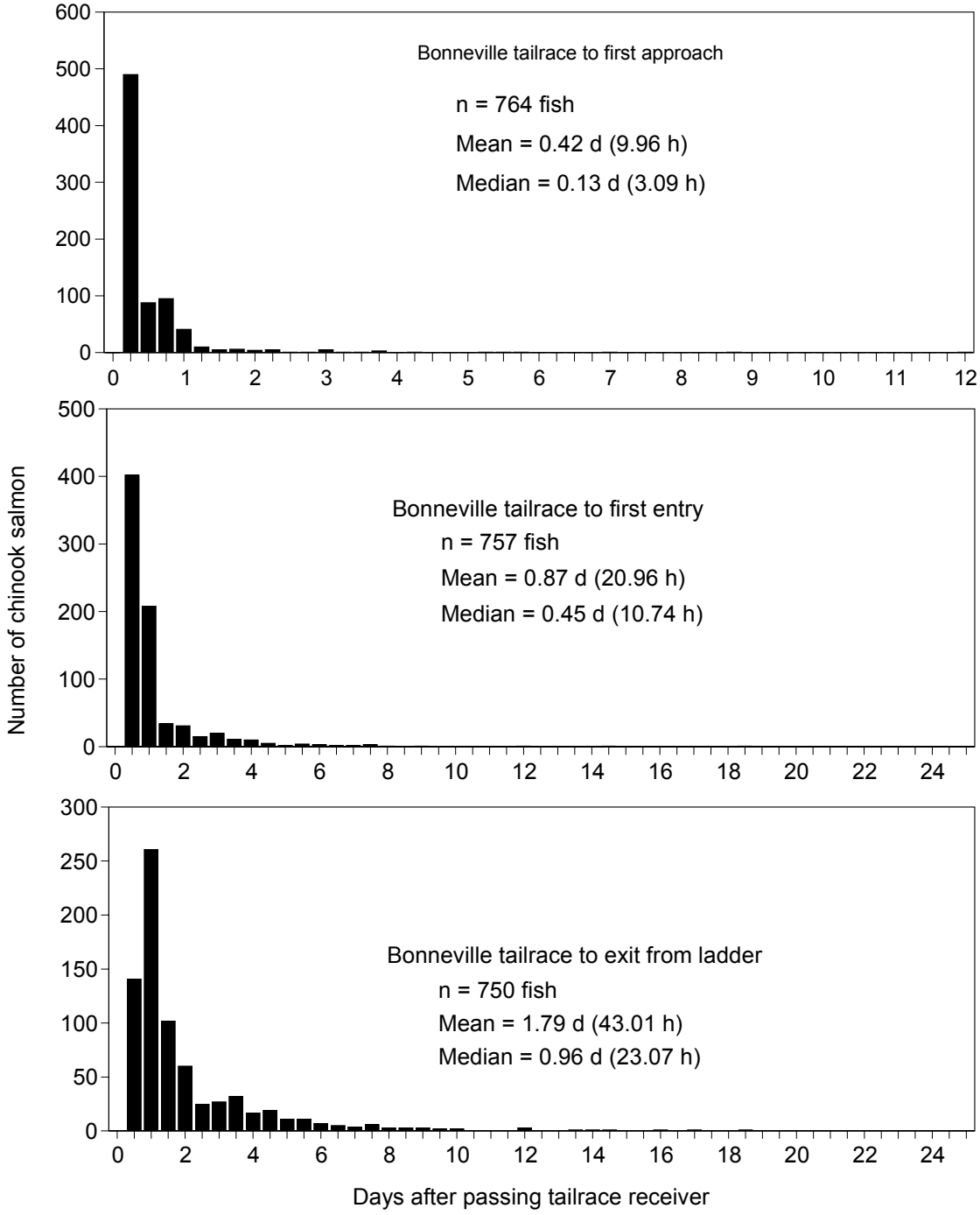


Figure 3. Number of chinook salmon and time to pass from the Bonneville Dam tailrace receivers to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladders in 1996.

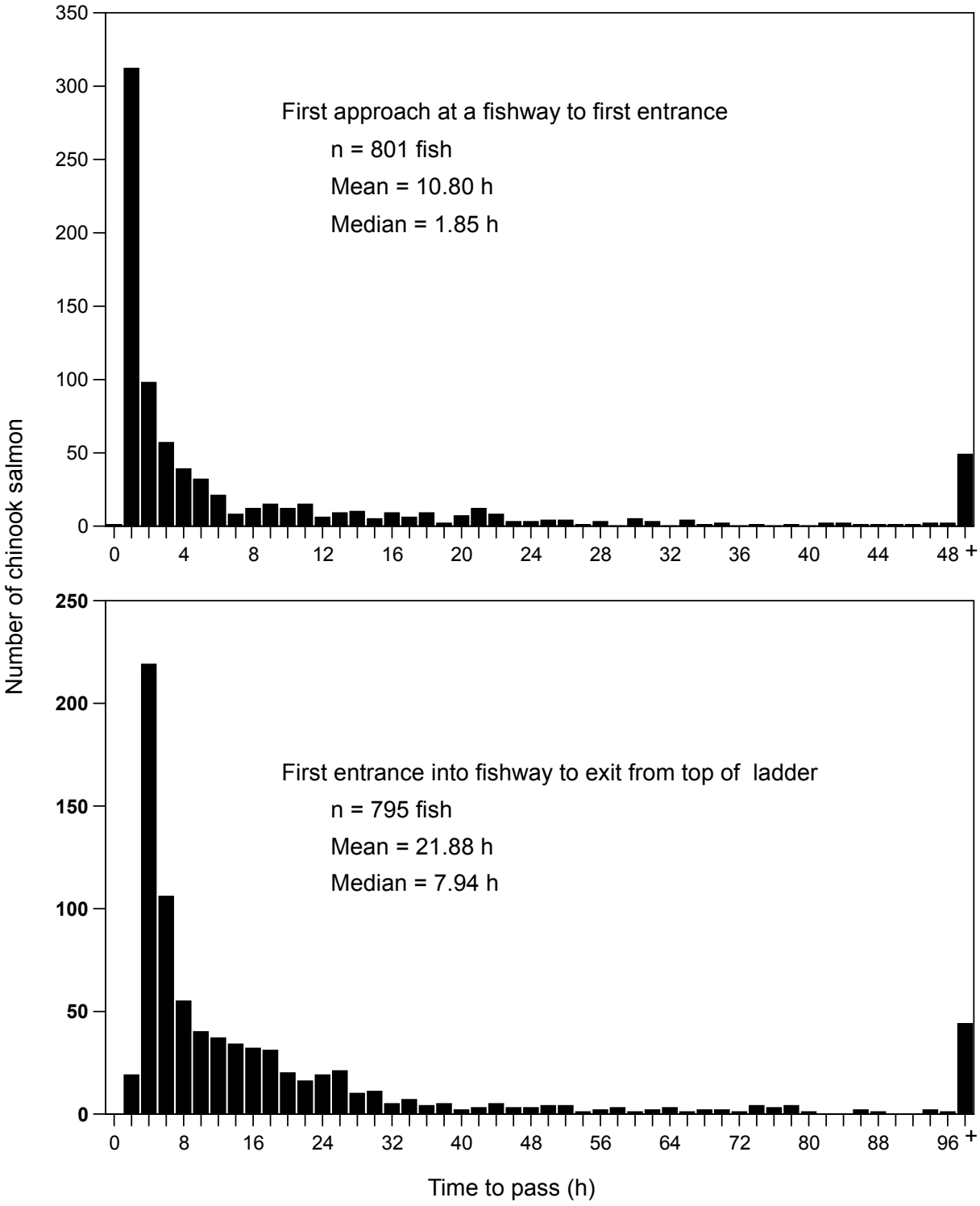
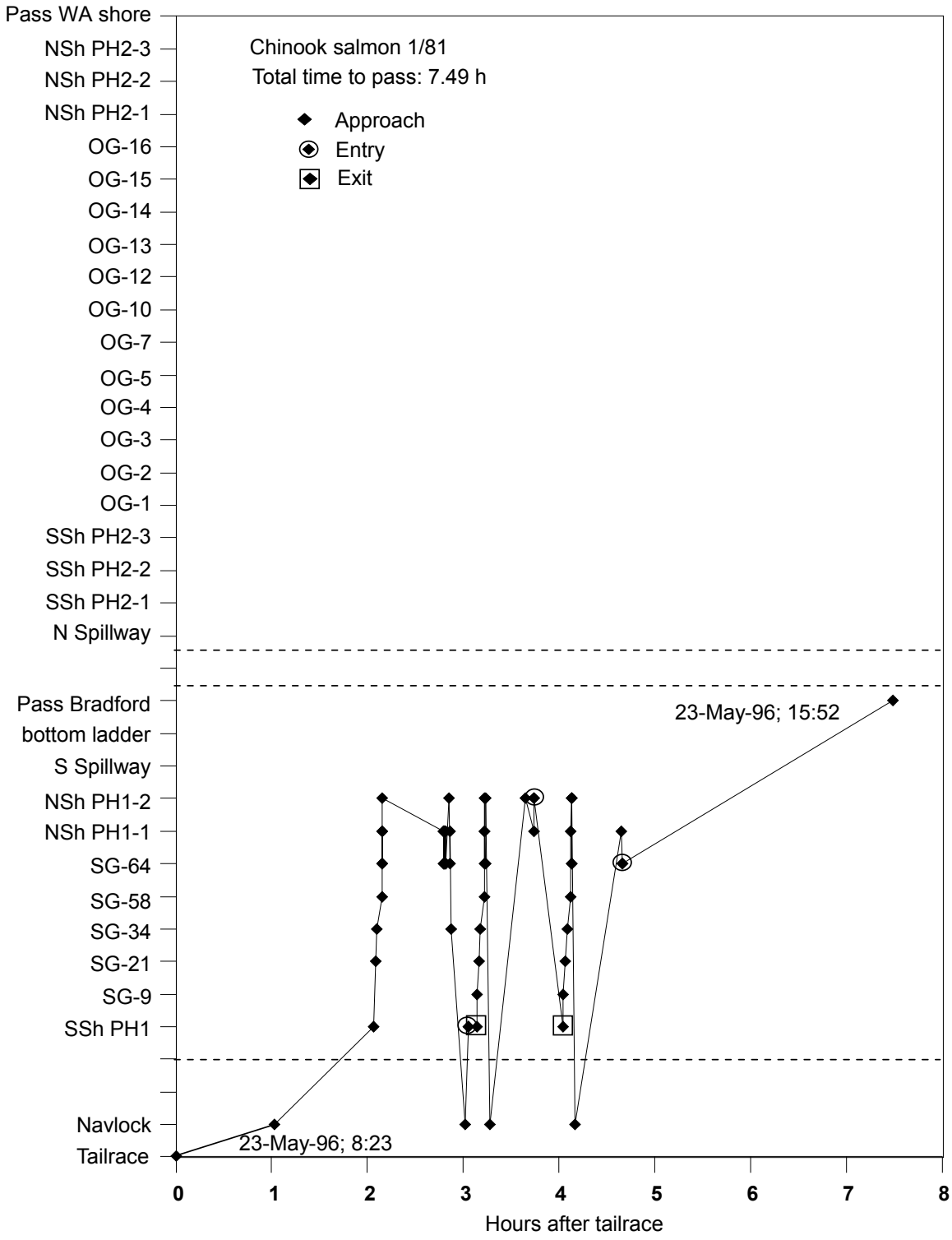
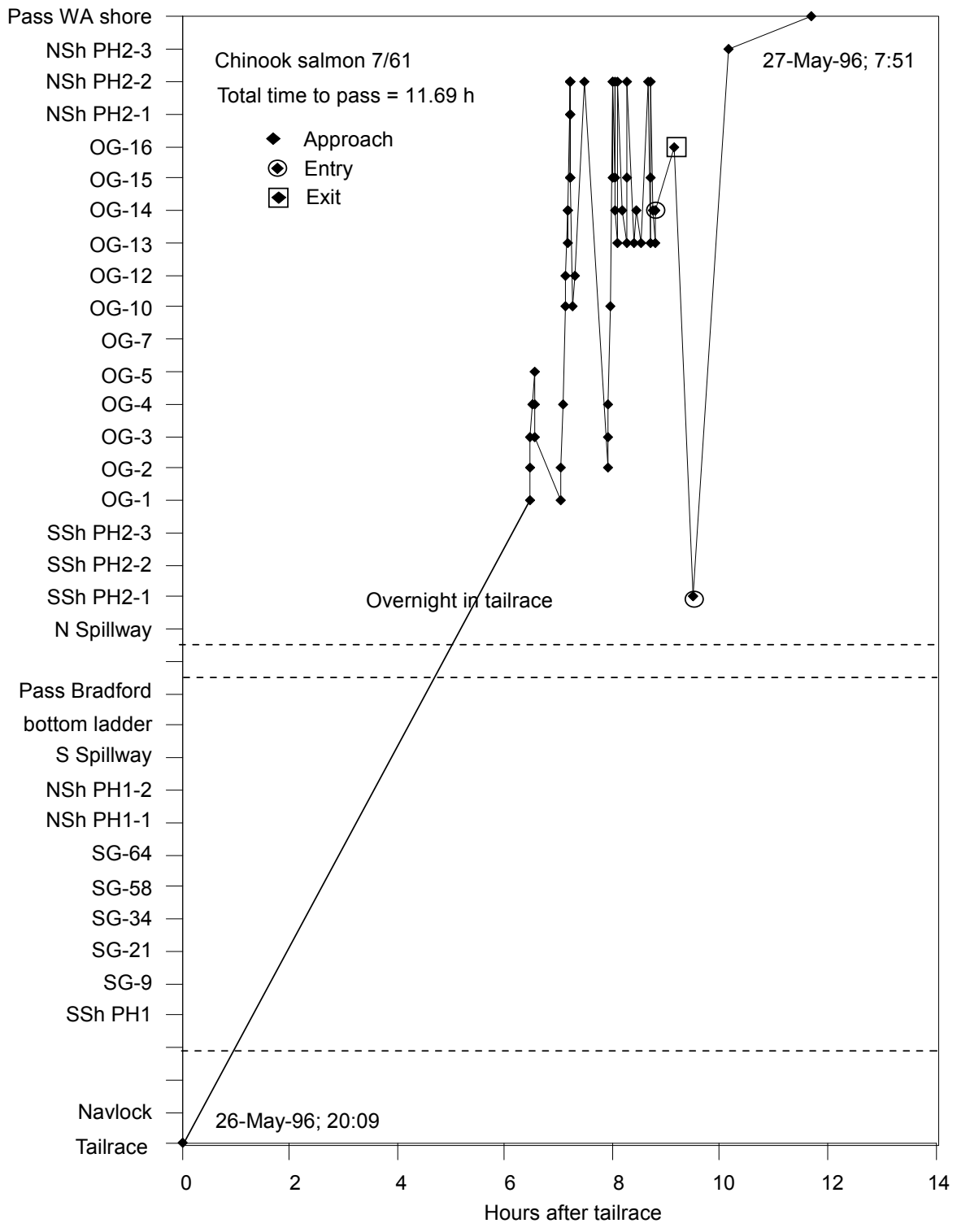


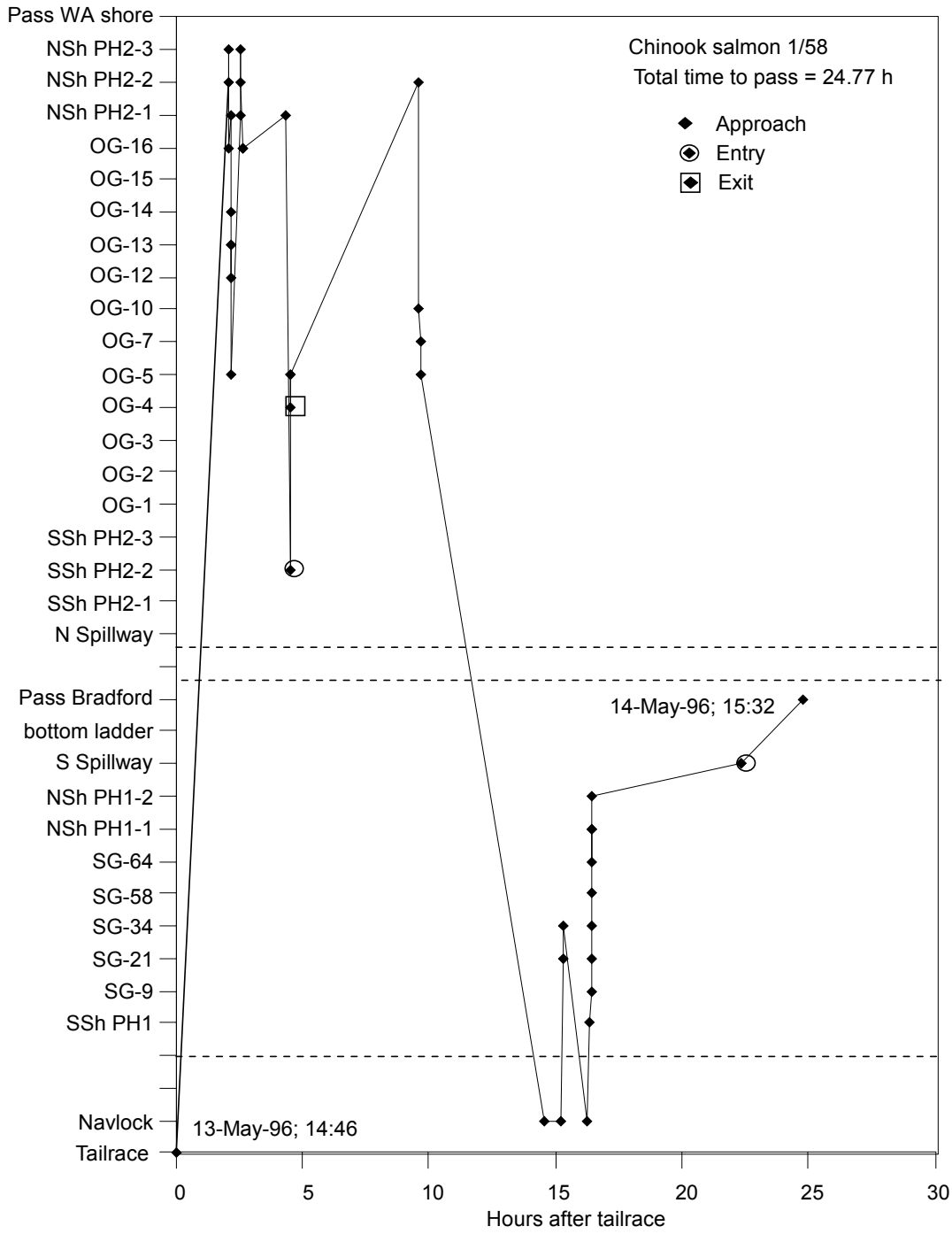
Figure 4. Number of chinook salmon and time from first approach at a fishway to first entry and time from first entry into a fishway to exit the top of the ladders in 1996.



Figures 5. Illustration of the movements of a chinook salmon that approached, entered and passed over Bonneville Dam via the Bradford Island fishway in 1996.



Figures 6. Illustration of the movements of a chinook salmon that approached, entered and passed over Bonneville Dam via the Washington-shore fishway in 1996.



Figures 7. Illustration of the movements of a chinook salmon that first approached and entered the Washington-shore fishway, then exited, and moved back downstream where it entered the navigation lock channel and then moved up to the Powerhouse 1 tailrace to approach, enter and eventually pass over Bonneville Dam via the Bradford Island fishway in 1996.

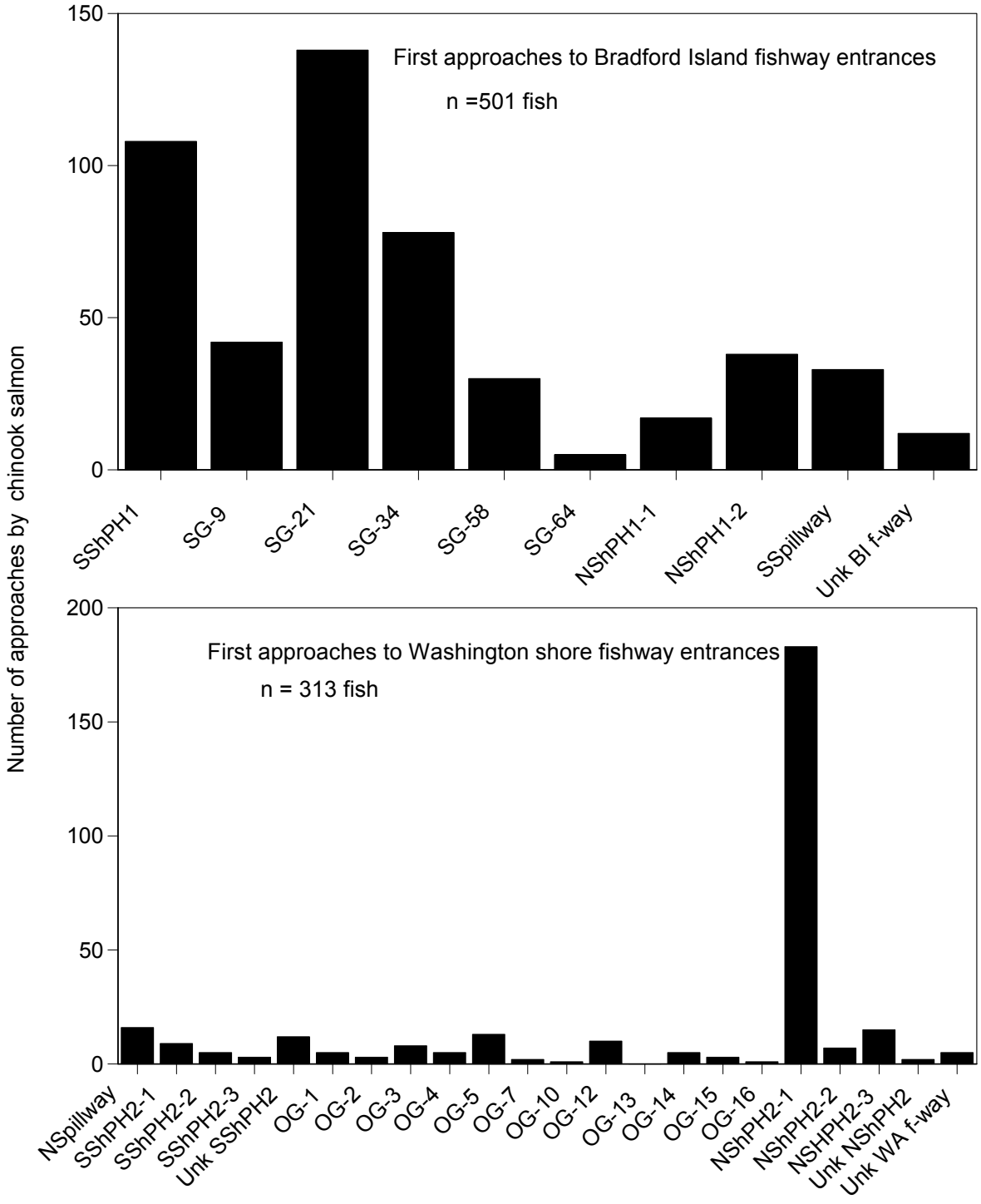


Figure 8. Number of first approaches by chinook salmon at Bonneville Dam fishway entrances in 1996.

Total approaches made by chinook salmon in 1996 were distributed more evenly among entrances than first approaches. At the Bradford Island fishway, 569 fish made a total of 8,624 approaches for an average of 15.2 per fish. The highest number of approaches to the Bradford Island fishway occurred at the north shore entrances of Powerhouse 1, but many salmon also approached sluice-gate entrances (Figure 9). At the Washington-shore fishway, 512 fish made a total of 7,700 approaches for an average of 15.0 per fish. The highest number of approaches occurred at the north-shore entrances of Powerhouse 2 (31%), but unlike first approaches, many fish also approached the orifice gates, particularly gates 5 and 12 (Figure 9).

Many fish moved between the spillway and both powerhouses and made approaches at entrances to both fishways. When all fishway approaches were considered together, 814 chinook salmon made 16,324 approaches at fishway entrances for an average of 20.1 (median 13) per fish (Figure 10).

When comparing the location of first approaches versus all approaches, it becomes more obvious that fish move back and forth along the powerhouses and come within range of several of the antennas outside entrances before eventually passing the dam (Figure 11). The entrances that were approached first by the most fish continued to be high approach sites for all approaches, but approaches at many of the other sites increased disproportionately.

Of 501 chinook salmon that first approached entrances to the Bradford Island fishway, 376 (75%) first entered there (though they may have made approaches to the Washington fishway before their first entry), 121 (24%) first entered the Washington-shore fishway, and 4 did not enter a fishway (Table 1). Of the 313 chinook salmon that first approached entrances to the Washington-shore fishway, 246 (79%) first entered there, 62 (20%) first entered at the Bradford Island fishway, and 5 did not enter (Table 1).

Of the 376 chinook salmon with transmitters that first approached and first entered the Bradford Island fishway, 78% (294) eventually passed the dam via that fishway but sometimes after approaching and/or entering the second fishway at least once. The same proportion (78%, 193 of 246) of salmon that first approached and first entered the Washington-shore fishway eventually passed there. About 21% of the fish monitored exited the first fishway they entered, then entered and passed via the other fishway (Table 1).

We further analyzed a random sample of 100 chinook salmon outfitted with transmitters to identify how many approached and entered only one fishway before passing the dam and how many moved between fishways multiple times before passing. Of the 100 fish, 59 first approached entrances to the Bradford Island fishway. Of the 59 fish, 46% entered and passed via the Bradford Island fishway without approaching the Washington-shore fishway, and 12% exited the Bradford Island fishway, then entered and passed via the Washington-shore fishway. Another 20% did not enter the Bradford Island fishway after first approaching

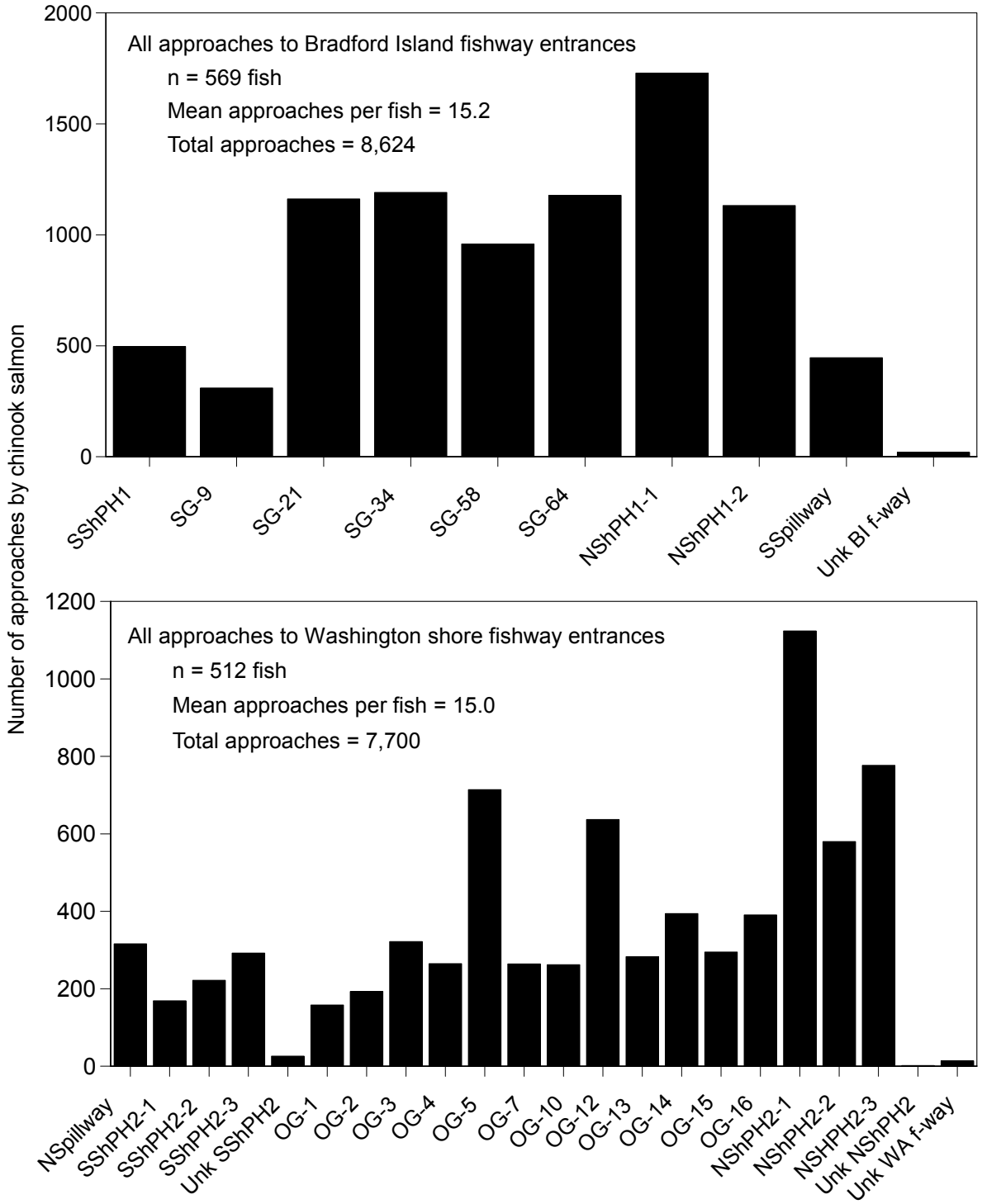


Figure 9. Number of total approaches by chinook salmon at entrances to both fishways at Bonneville Dam in 1996.

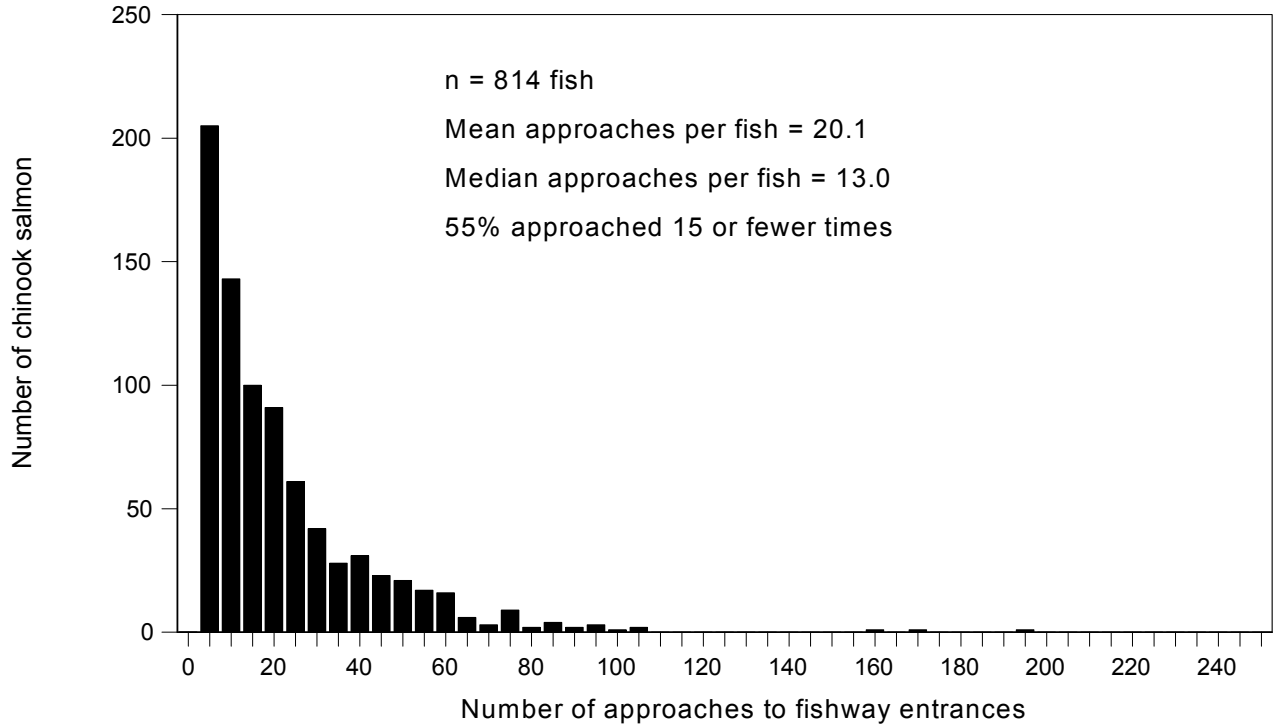


Figure 10. Distribution of chinook salmon with one or more approaches to fishway entrances at Bonneville Dam in 1996.

there but entered and passed via the Washington-shore fishway. The remaining fish (22%) that first approached the Bradford Island fishway approached or entered both fishways two or more times before passing the dam. Of the random sample, 41 first approached the Washington-shore fishway; 54% of the 41 fish entered and passed the Washington-shore fishway without approaching entrances to the Bradford Island fishway, and 20% exited from the Washington-shore fishway, then entered and passed via the Bradford Island fishway. Five fish (12% of 41) did not enter the Washington-shore fishway after first approaching there but entered and passed via the Bradford Island fishway. The remaining 6 fish (14% of 41) approached and/or entered both fishways two or more times before passing the dam.

Although seven chinook salmon with transmitters passed Bonneville Dam via the navigation lock adjacent to the Oregon shore, approaches at the lock were not included in the above analyses. About half (408) of the chinook salmon monitored at Bonneville Dam in 1996 were recorded at antennas in the approach channel of the lock one or more times, and approaches there added to passage times at the dam. Median passage time from the last record at a tailrace receiver to exit from a ladder was 1.20 d for 381 chinook salmon that were recorded at both the downstream receiver and the navigation lock, compared to 0.82 d for 370 fish not recorded in the lock channel ($P < 0.001$, Kruskal-Wallis χ^2 test). Median time to first enter a fishway was 0.58 d for 384 fish that were recorded at the navigation lock, and 0.32 d for 373 fish not recorded there ($P < 0.001$).

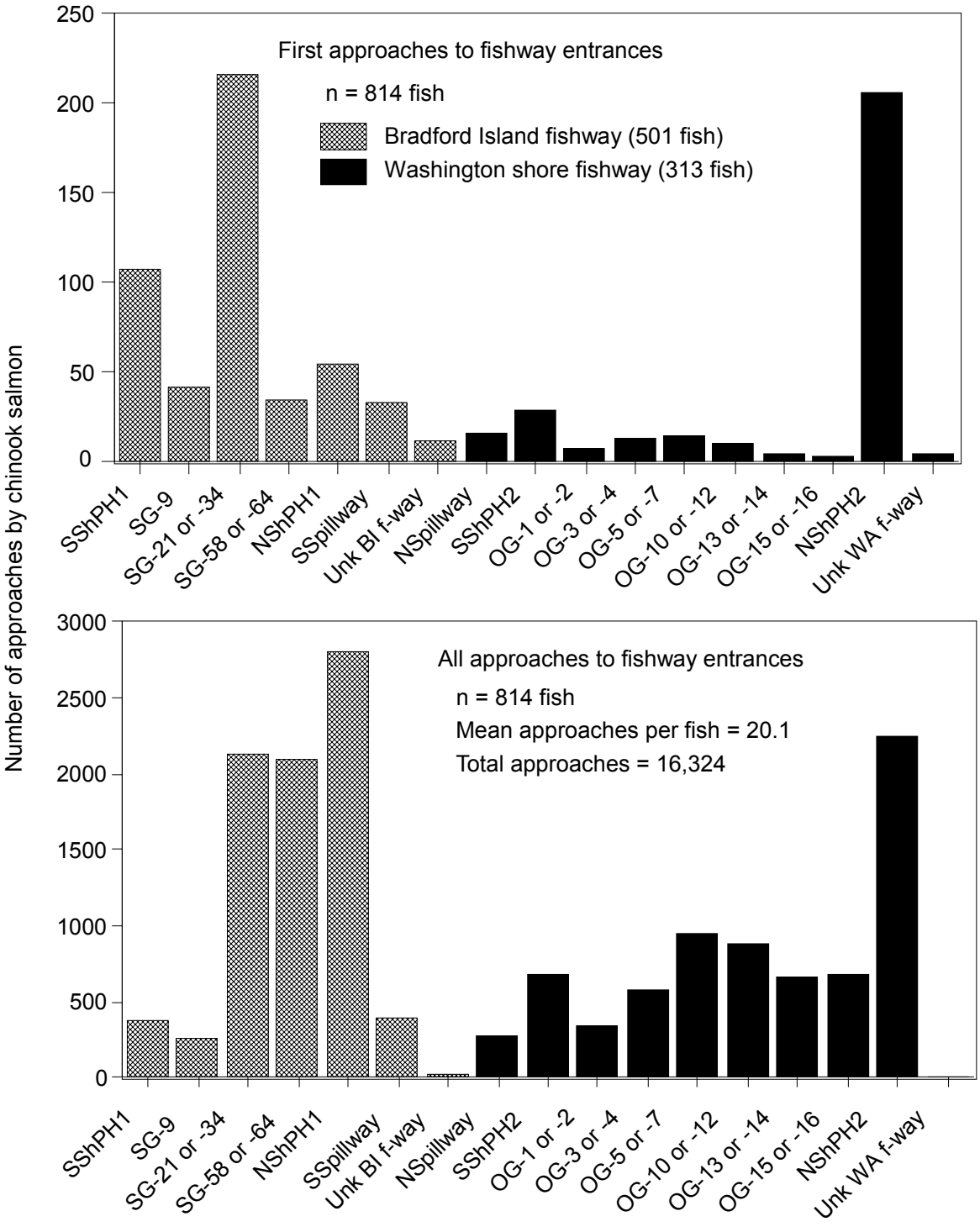


Figure 11. Comparison of location of first and all approaches by chinook salmon at Bonneville Dam fishway entrances in spring and summer 1996. For ease of interpretation, approaches at some entrances grouped.

Table 1. Summary of movements by chinook salmon, including first approach and entry at a fishway, fishways passed, and movements between fishways at Bonneville Dam in 1996.

	Number of fish	Percent of category	Percent of 814	
Chinook salmon that approached fishways in 1996	**814**	**100**	**100**	
First approached Bradford Island fishway	**501**	**62**	**62**	
First entered Bradford Island fishway	376	75	46	
Passed via Bradford Island fishway	294	78	36	
Passed via Washington-shore fishway	77	20	9	
Did not pass dam	5	1	< 1	
First entered Washington-shore fishway	121	24	15	
Passed via Bradford Island fishway	28	23	3	
Passed via Washington-shore fishway	93	77	11	
Did not enter	4	1	< 1	
First approached Washington-shore fishway	**313**	**38**	**38**	
First entered Bradford Island fishway	62	20	8	
Passed via Bradford Island fishway	50	81	6	
Passed via Washington-shore fishway	10	16	1	
Did not pass	2	3	< 1	
First entered Washington-shore fishway	246	79	30	
Passed via Bradford Island fishway	50	20	6	
Passed via Washington-shore fishway	193	78	24	
Did not pass	3	1	< 1	
Did not enter	5	2	< 1	

Entries to fishways: Entrances used by chinook salmon to enter fishways at Bonneville Dam differed from those they approached. First entries of 438 chinook salmon (54% of all first entries) were at the Bradford Island fishway, mostly at the south end of the spillway and at the south shore of Powerhouse 1 entrances (Figure 12). Relatively few first entries were at sluice gates. Of the 366 fish (46%) that first entered the Washington-shore fishway, the highest number entered at entrance 1 at the north shore of Powerhouse 2, with smaller numbers at the south end of the powerhouse entrances, and the north end of the spillway entrance (Figure 12). For both fishways combined, chinook salmon first entered primarily at shoreline entrances of both powerhouses and the spillway (Figure 12). Few salmon entered the fishways for the first time via orifice gates or sluice-gate entrances.

For all (first and subsequent) entries combined, the entrances used did not change much from those used for first entries (Figure 13). At the Bradford Island fishway, 629 chinook salmon made 1,005 entries for an average of 1.6 per fish. The 454 chinook salmon that entered the Washington-shore fishway did so 1,099 times for an average of 2.4 per fish.

Many fish moved between fishways and entered at more than one location. When both fishways were considered together, 804 salmon made 2,104 entries, and the mean number

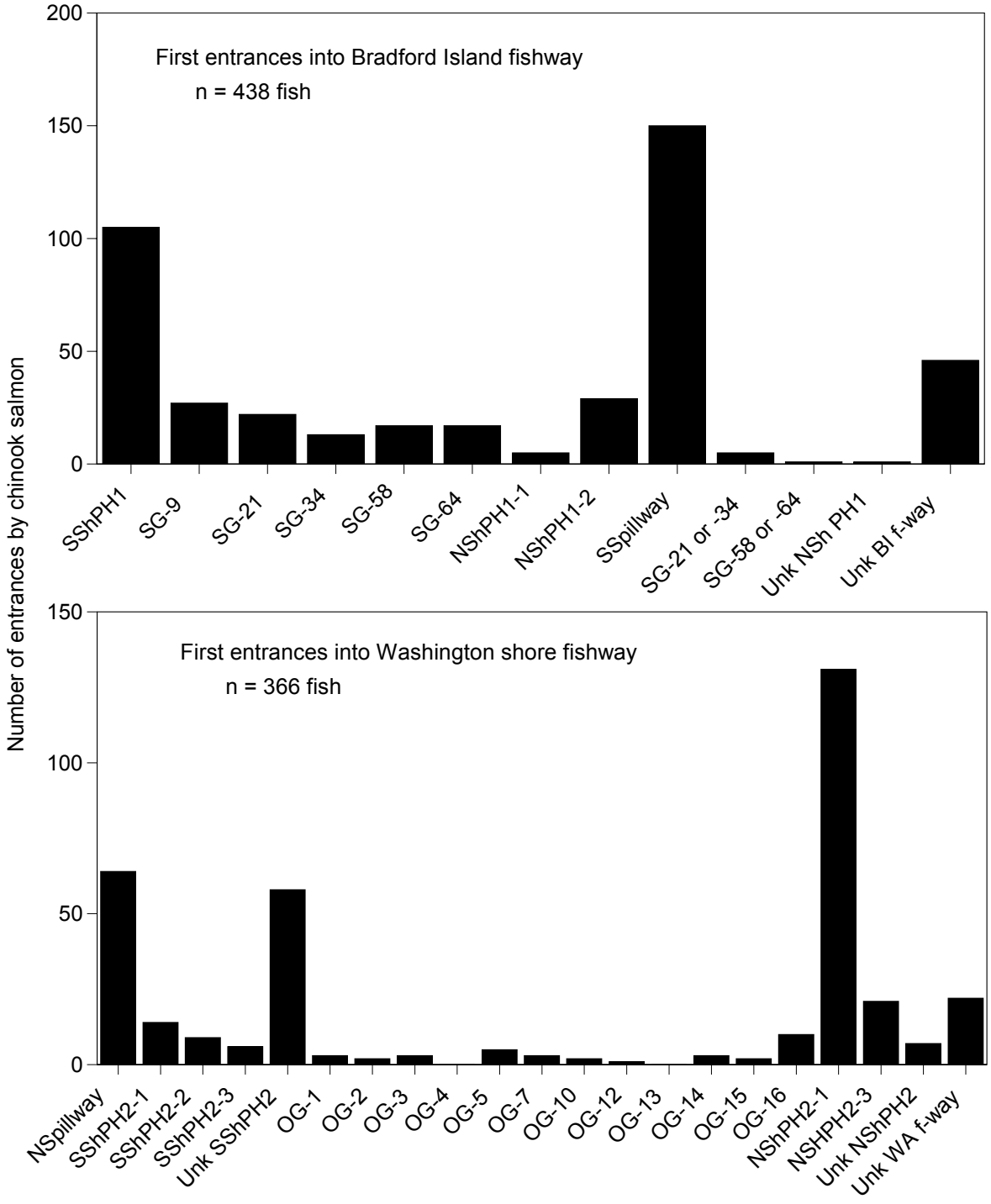


Figure 12. Number of first entries at Bonneville Dam fishway entrances by chinook salmon in 1996.

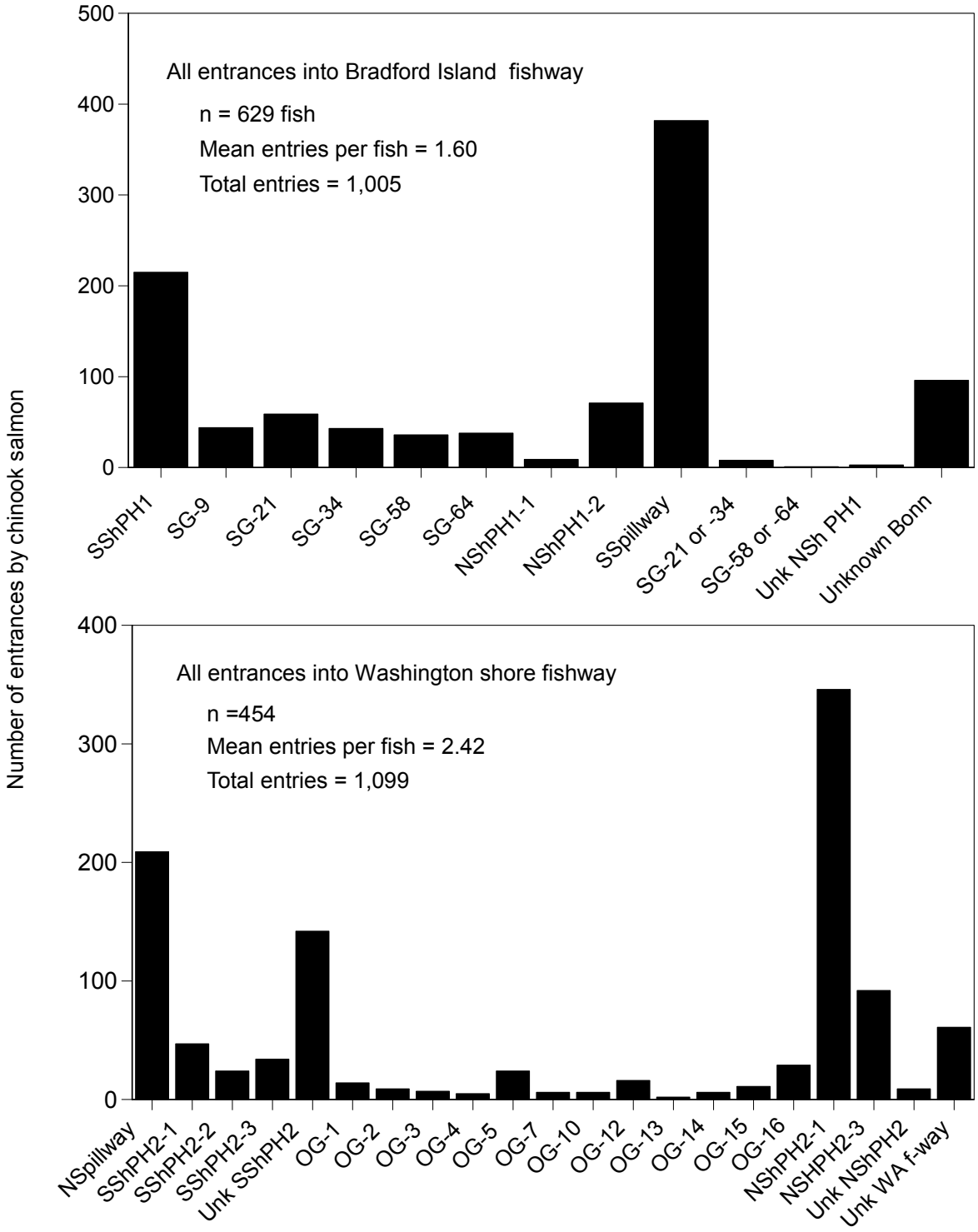


Figure 13. Number of total entries by chinook salmon at Bonneville Dam fishway entrances in 1996.

of entries per fish was 2.6 (median of 2) (Figure 14). Thirty-eight percent (309) of the salmon made only one entry.

For the dam as a whole, the entrances used for first entries were similar to those used for subsequent entries (Figure 15). Distributions of fish by entry location indicted that the main entrances are most heavily used and selected for the first and subsequent entries. Amount of discharge, size of opening, and ease of following attractive flow to the opening were probably important factors in which entrances were used by chinook salmon. Orifice gates were 0.61 m wide and 1.83 m deep with discharges of 60 to 80 cfs, and sluice gates were 0.41 m wide with variable depths and discharges. The south-shore and north-powerhouse entrances at Powerhouse 1 were 2.44 m wide and at least 2.44 m deep. North- and south-spillway entrances were all 3.05 m wide and a minimum of 3.05 m deep. The south-shore entrance at Powerhouse 2 was 3.91 m wide and 3.05 m deep, and similar in size at the north shore of Powerhouse 2.

Exits from fishways: Eight hundred four chinook salmon entered fishways at Bonneville Dam and exited an average of 1.6 times (median of 1 exit) per fish (Figure 16). Of 438 fish that first entered the Bradford Island fishway, 252 (58%) exited; most exits were at south-shore and south-spillway entrances (Figure 17). Of 366 salmon that first entered the Washington-shore fishway, 247 (67%) exited; most exits were at the north- and south-shore entrances and the north-spillway entrance (Figure 17). The median time from the first entry and first exit from fishways at Bonneville Dam was 0.24 h.

The distribution of total exits from fishways at Bonneville Dam was similar to that of first exits, with most occurring at entrances at the north shore of Powerhouse 2, the south end of Powerhouse 1, and at both spillway entrances (Figure 18). There were 625 chinook salmon in the Bradford Island fishway and they made 578 exits from the fishway, an average of 0.92 exits per fish. At the Washington-shore fishway, 478 salmon made 729 exits, an average of 1.53 exits per fish. When both fishways were considered, the 804 chinook salmon that entered in 1996 had 1,307 exits (1.62 per fish); most exits occurred at shoreline and spillway entrances (Figure 19).

Net entry rates (entries minus exits) for salmon that first entered the Bradford Island fishway ranged from 1 at entrance 1 at the north shore of Powerhouse 1, to 77 at the south-spillway entrance (Figure 20). The south-spillway entrance was also the most effective (fewest exits per entry) when all entrances to the Bradford Island fishway were considered, with a net entry rate of 198. The south-shore entrance of Powerhouse 1 was least effective with a net rate of -21 (Figure 20).

At the Washington-shore fishway, several orifice-gate entrances had more exits than entries for both first and total entries (Figure 21). The most effective entrances for first and total net entries at the Washington-shore fishway were the north-spillway entrance and the north- and south-shore entrances of Powerhouse 2. When both fishways were considered,

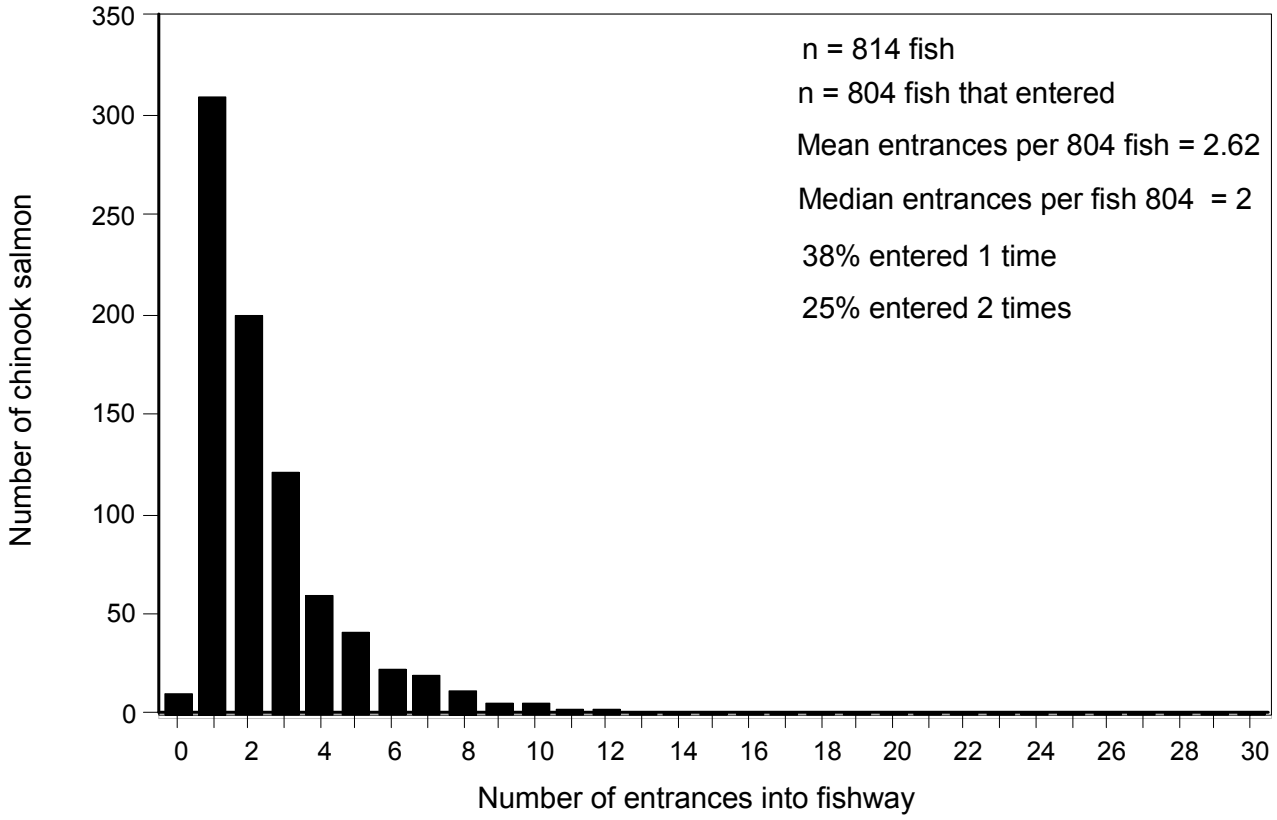


Figure 14. Number of chinook salmon that entered fishways one or more times at Bonneville Dam in 1996.

the south- and north-spillway entrances and south- and north-shore entrances of Powerhouse 2 were the most effective (Figure 22). Sluice-gate entrances at Powerhouse 1 were slightly less effective than shoreline and spillway entrances, while orifice-gate entrances at Powerhouse 2 and the south-shore entrance to Powerhouse 1 were the least efficient entrances.

We determined the most upstream receiver antenna where fish were recorded before making their first exits from fishways. About one third (167 fish, 33.5%) of the 499 chinook salmon that exited the fishway did so after being recorded on antennas inside fishway or collection channel entrances (Table 2). The largest single-site number from this group (55 of 167 fish) was fish that entered and then exited from the south shore entrance at Powerhouse 1. The largest group (318 fish, 63.7%) of the 499 chinook salmon that exited, did so after first reaching one of the four transition pool areas in the Bonneville fishways (Table 2). The largest number were from fish that had reached the Washington-shore transition pool, followed by the B- and A-branch transition pools of the Bradford Island fishway, and then the Cascades Island ladder transition pool. We recorded 12 fish (2.4%)

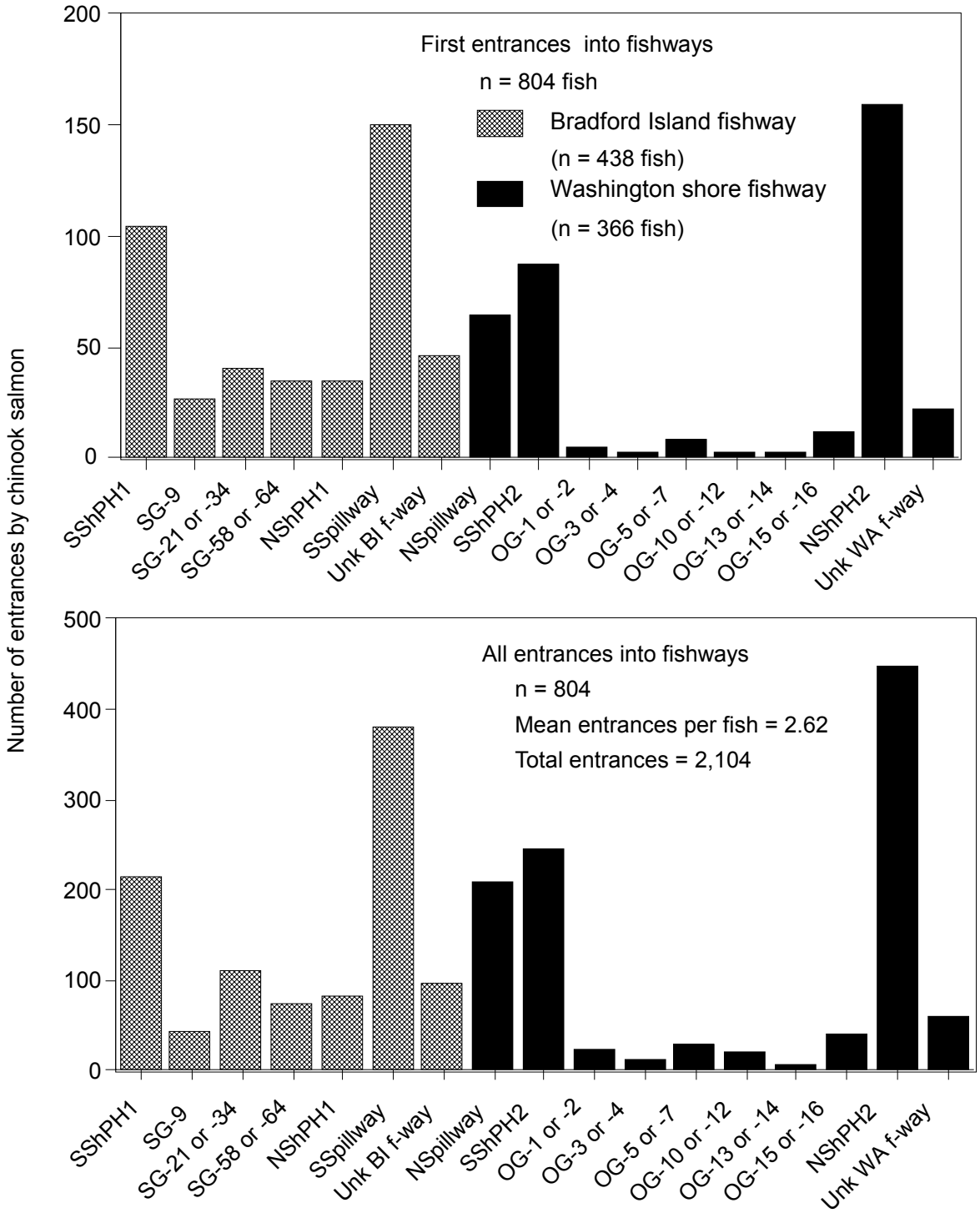


Figure 15. Number of first and total entries at Bonneville Dam fishway entrances in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

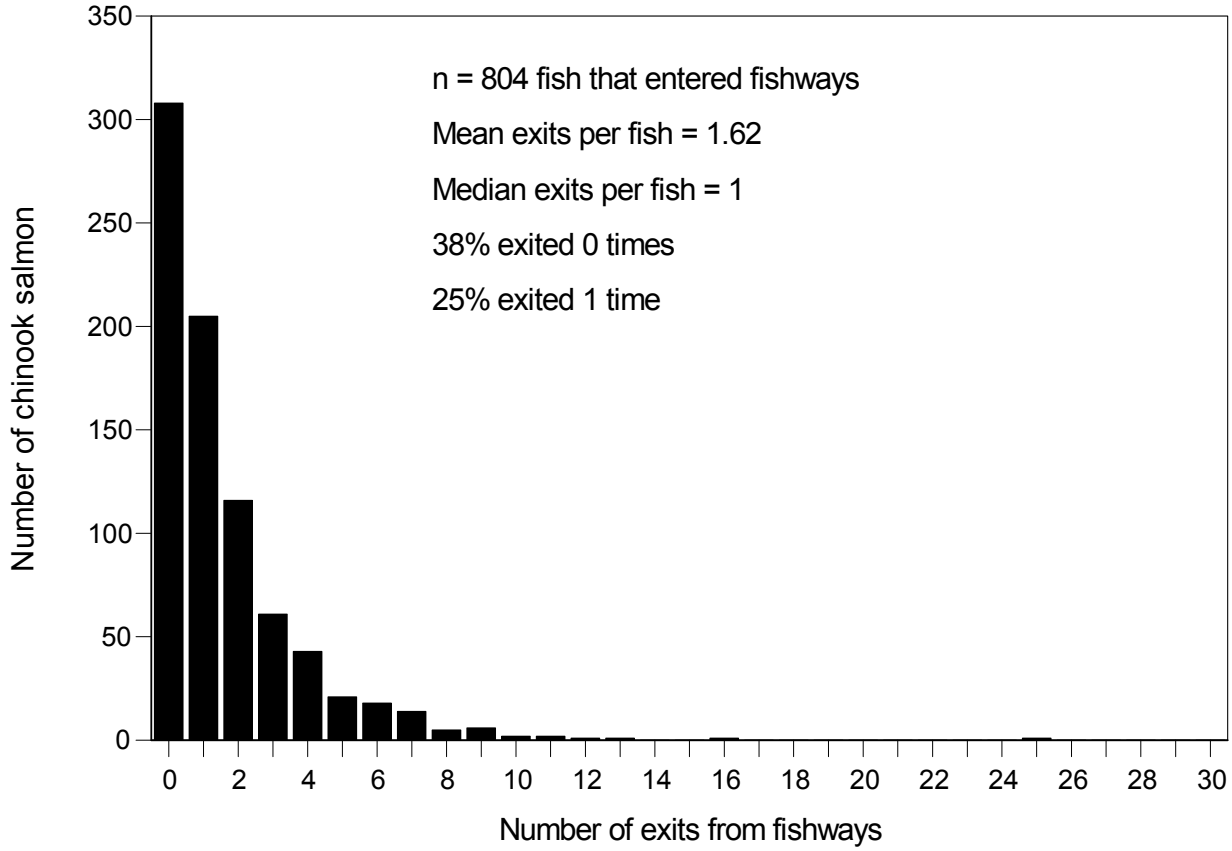


Figure 16. Number of chinook salmon that exited fishways at Bonneville Dam one or more times in 1996.

that moved downstream and exited to the tailrace after reaching antennas located at tops of the ladders. The indication from this analysis is that most of the fish that exited, had halted their passage of Bonneville Dam in the transition pools. The number may have been greater than we were able to decipher from the existing telemetry records, since some fish last recorded on antennas inside fishway entrances may have been affected by transition pool conditions although they had not yet been recorded on 'transition pool' antennas. Likewise, a few fish last recorded on the most upstream transition pool antennas may have moved into weired section of ladders (where no antennas exist) before moving downstream and exiting to the tailrace.

Twenty-five fish returned to Bonneville Dam but then did not pass the project. Of those 25 fish, 4 (16%) were later recorded at a downstream tributary or hatchery, and the remaining 21 fish could not be accounted for, although some were presumed to have lost their transmitters. Thirteen (52%) of the 25 fish reached the tailrace receivers or navigational lock, 3 fish (12%) made approaches to fishway entrances, 5 fish (20%) entered

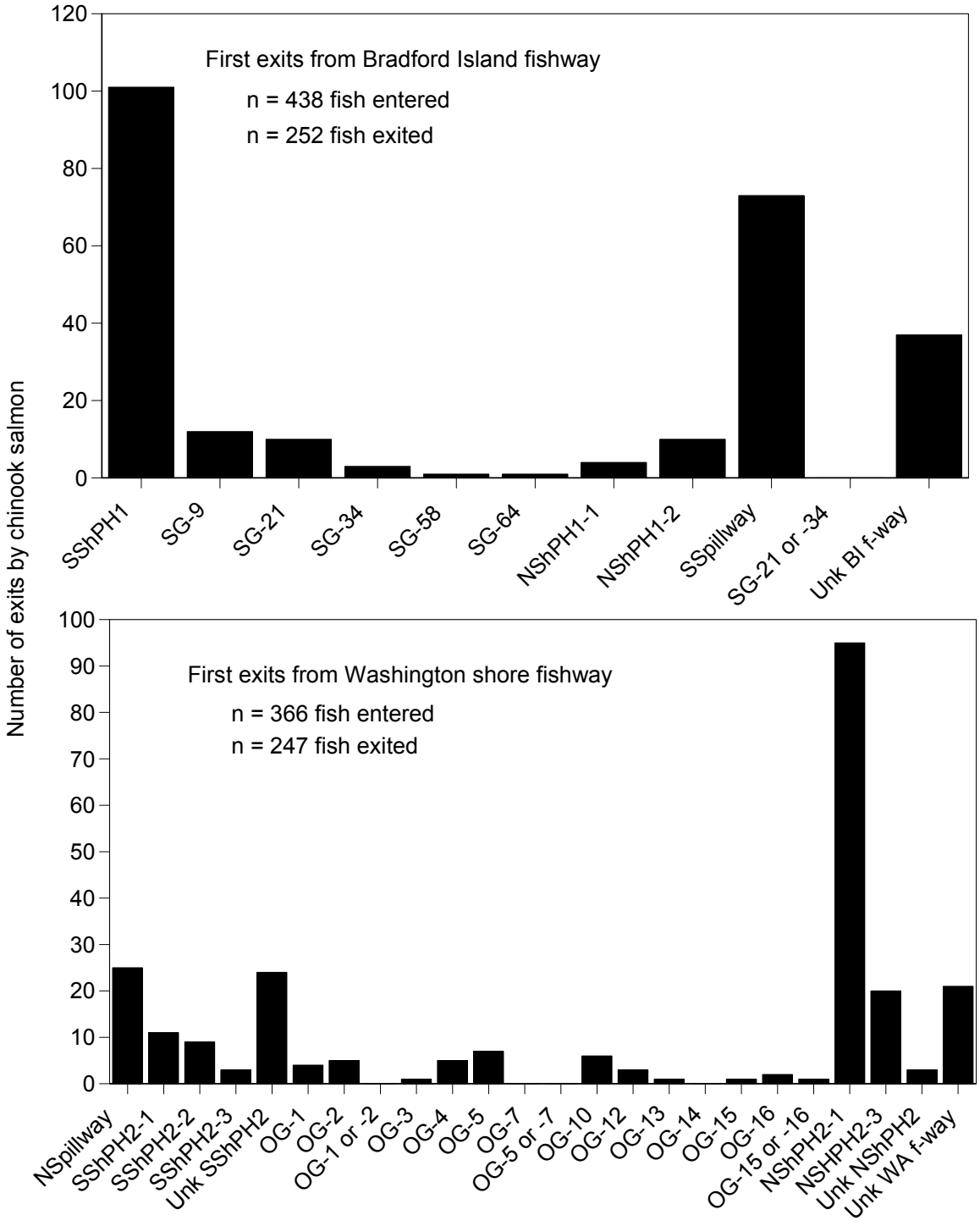


Figure 17. Number of first exits from Bonneville Dam fishway entrances by chinook salmon in 1996.

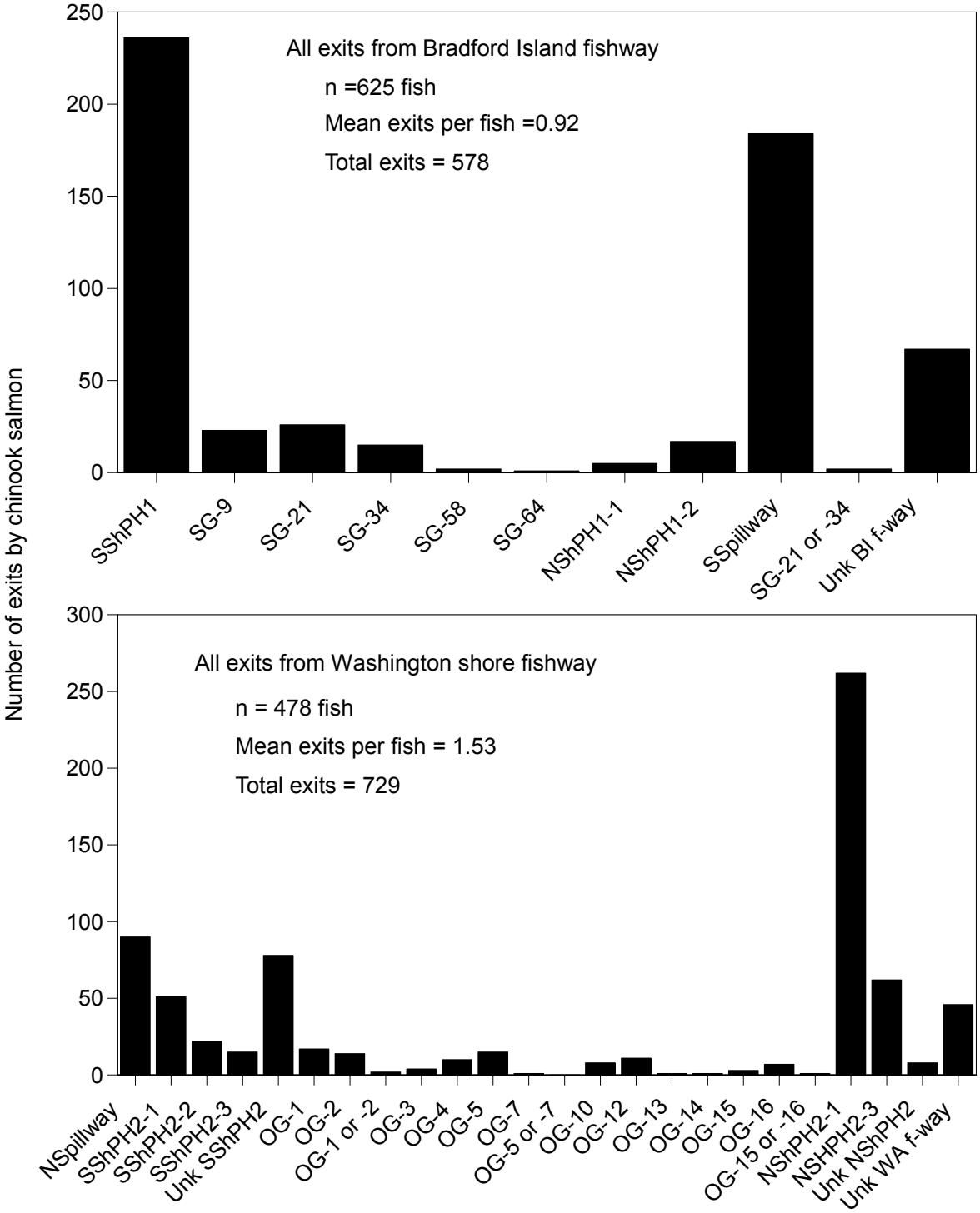


Figure 18. Number of total exits by chinook salmon from Bonneville Dam fishway entrances in 1996.

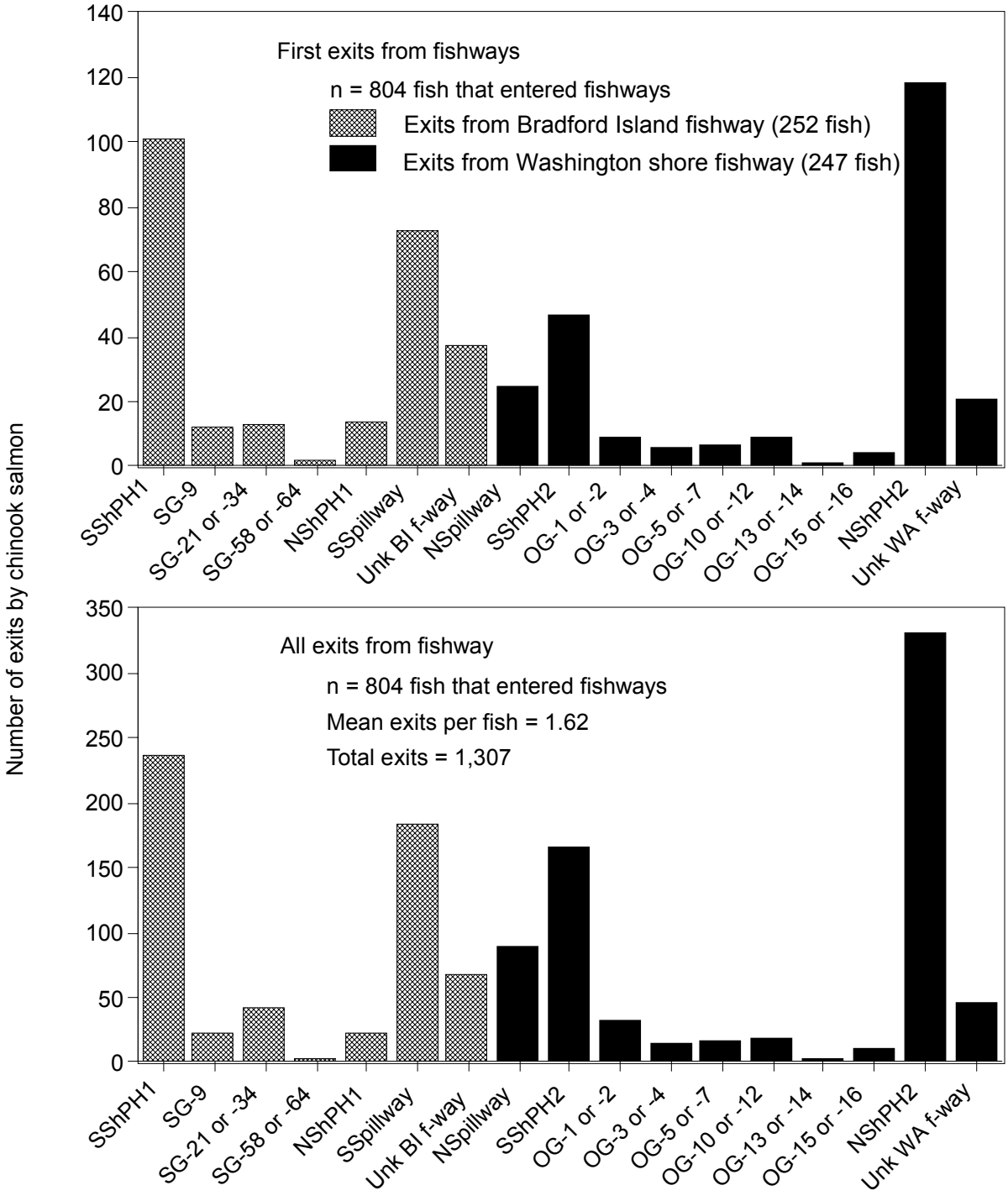


Figure 19. Number of first and total exits by chinook salmon from Bonneville Dam fishway entrances in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

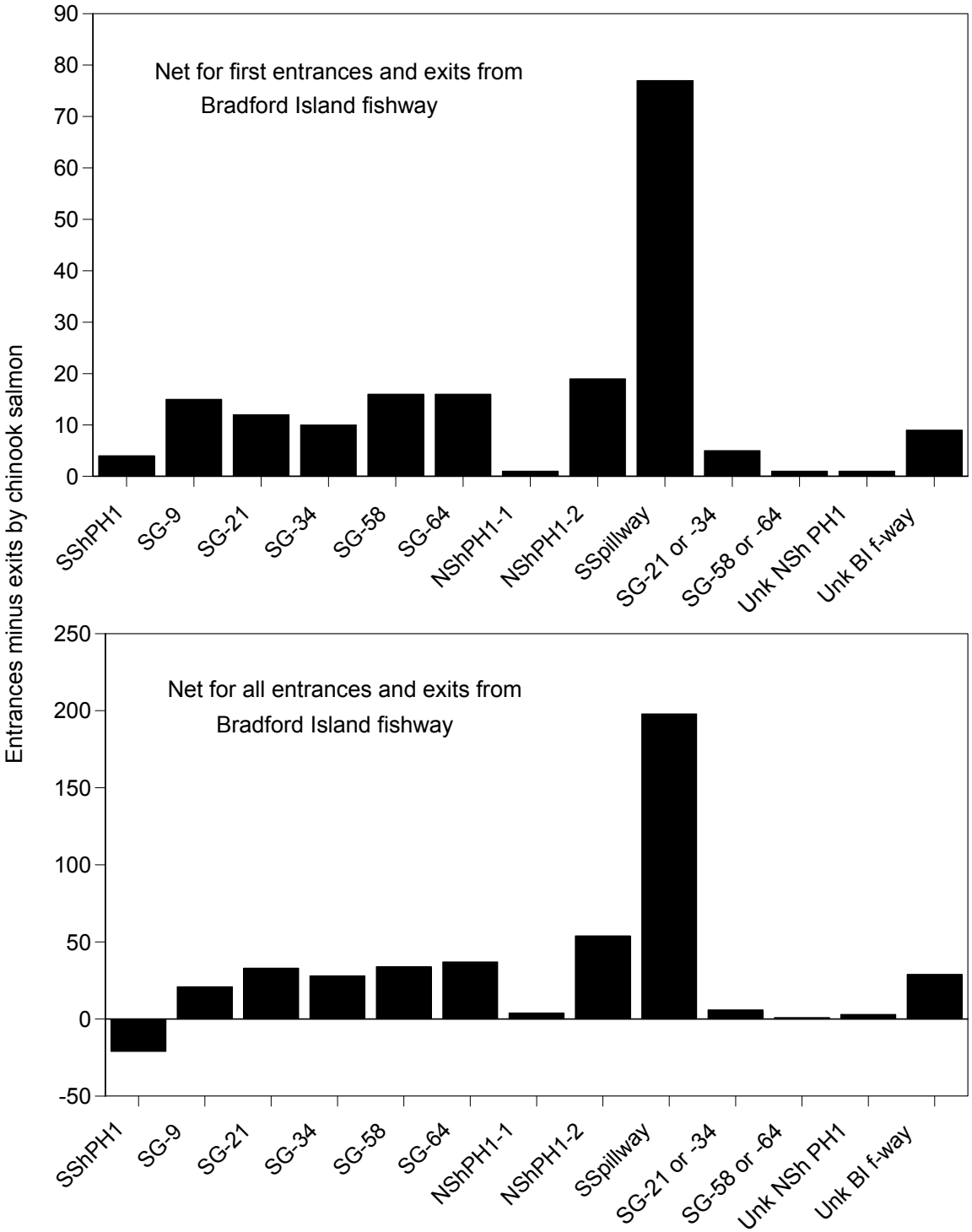


Figure 20. Net number of first and total entries and exits of chinook salmon from the Bradford Island fishway entrances at Bonneville Dam in 1996.

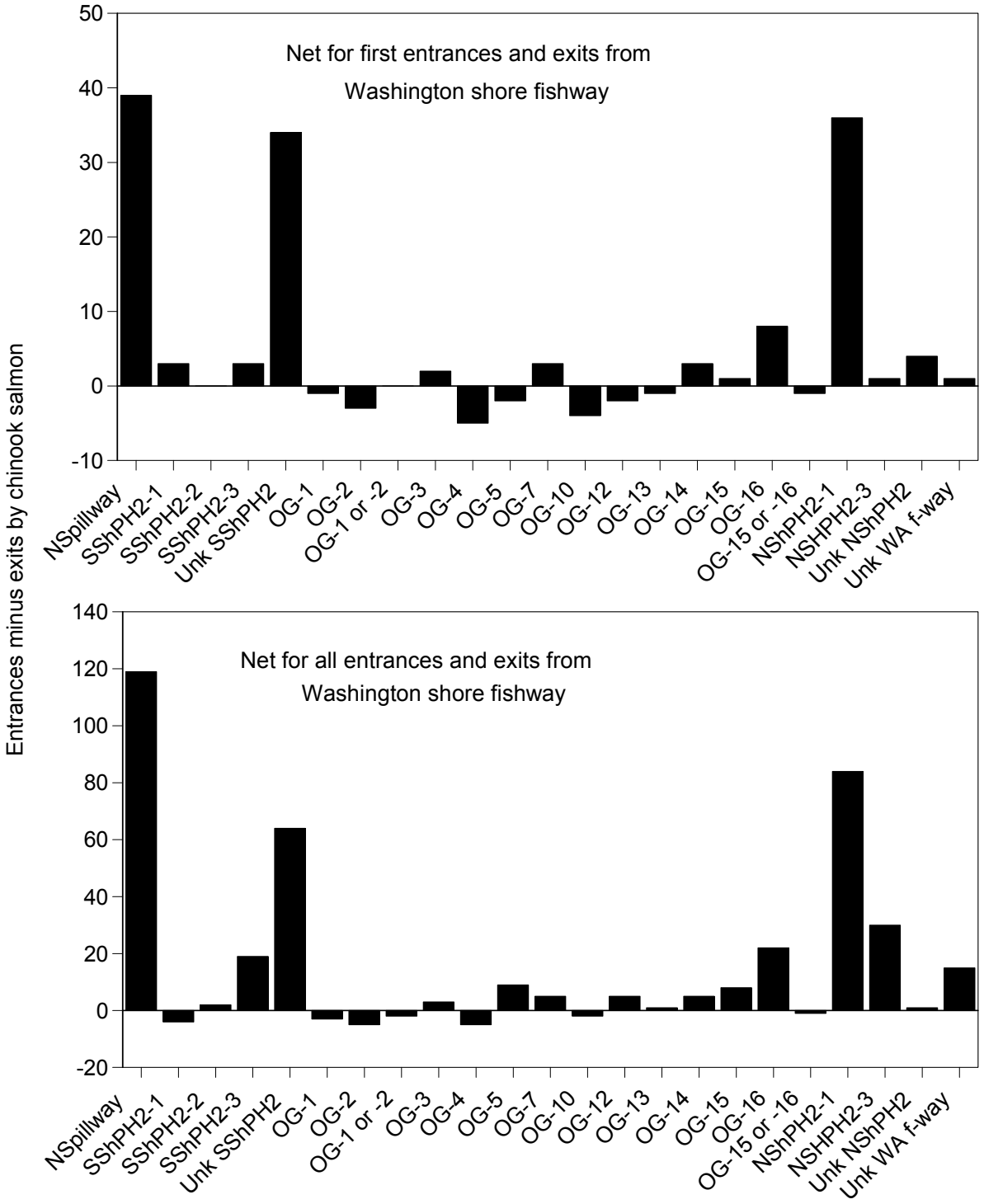


Figure 21. Net number of first and total entries and exits of chinook salmon from the Washington-shore fishway entrances at Bonneville Dam in 1996.

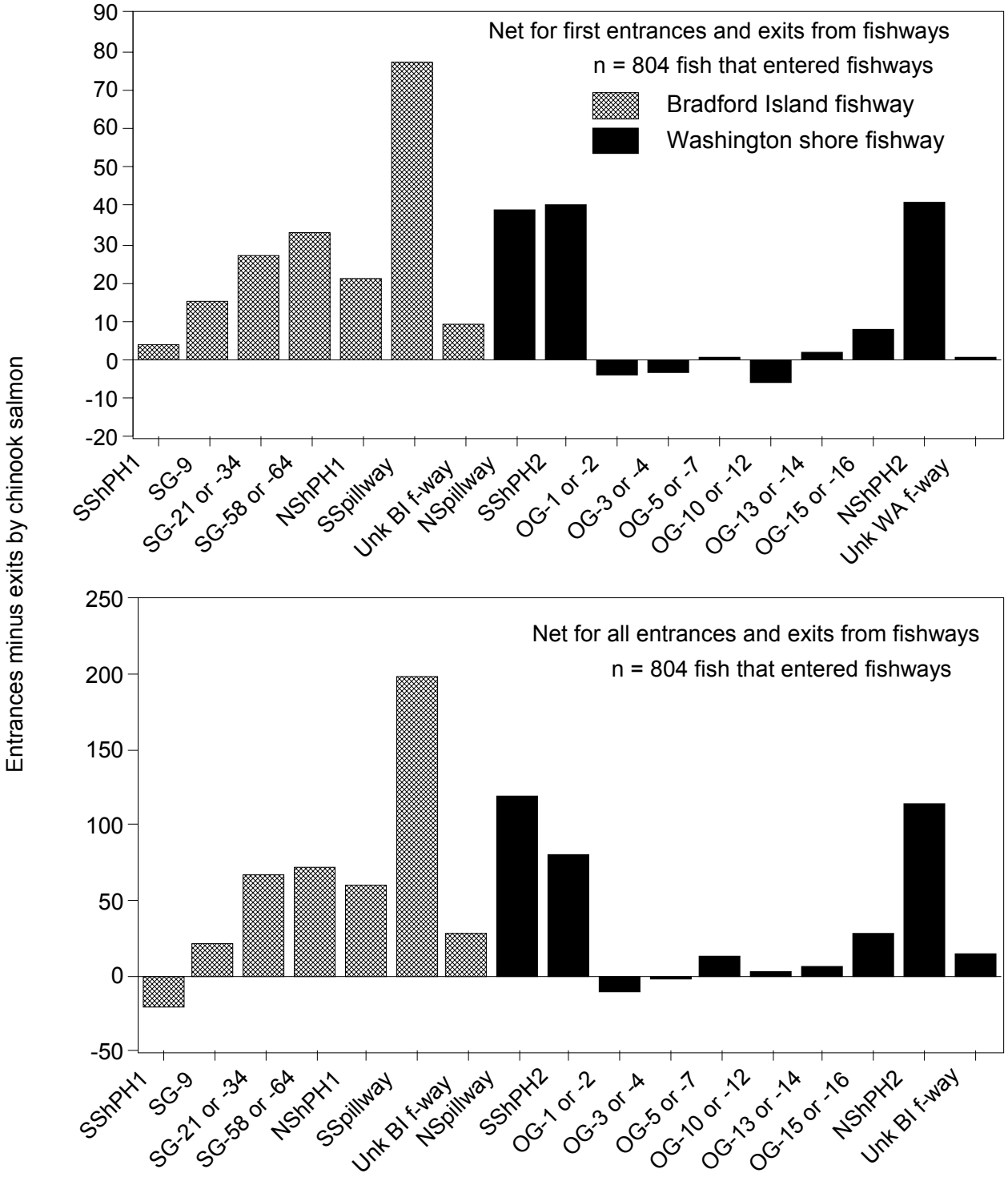


Figure 22. Net number of first and total entries and exits of chinook salmon from entrances to both fishways at Bonneville Dam in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

Table 2. Most upstream point reached in fishways before fish first exited into tailraces at Bonneville, McNary, Ice Harbor and Lower Granite dams.

Most upstream point reached	Antenna location	N	Percent of all fish that exited
Bonneville Dam (n = 499)			
Fishways	S. Shore Powerhouse 1	55	11.0%
	Other Powerhouse 1	45	9.0%
	Powerhouse 2	67	13.4%
	Total	**167**	**33.5%**
Transition pools	A-Branch	72	14.4%
	B-Branch	74	14.8%
	Cascades Island	23	4.6%
	WA-shore (near N. entrance)	64	12.8%
	WA-shore (above N. entrance)	85	17.0%
	Total	**318**	**63.7%**
Top of ladders	OR fishway	4	0.8%
	WA fishway	8	1.6%
	Total	**12**	**2.4%**
Unknown		2	0.4%
McNary Dam (n = 161)			
Fishways	S. Shore	43	26.7%
	Other Powerhouse	33	20.5%
	N. Shore	1	0.6%
	Total	**77**	**47.8%**
Transition pools	S. Shore	20	12.4%
	N. Shore	63	39.1%
	Total	**83**	**51.6%**
Top of ladders	OR fishway	1	0.6%
	WA fishway	1	0.6%
	Total	**2**	**1.2%**

Table 2 - Continued

Ice Harbor Dam (n = 41)			
Fishways			
	S. Shore	8	19.5%
	Other Powerhouse	5	12.2%
	N. Shore	3	7.3%
	Total	**16**	**39.0%**
Transition pools	S. Shore	16	39.0%
	N. Shore	9	22.0%
	Total	**25**	**61.0%**
Lower Granite Dam (n = 74)			
Fishway			
	S. Shore	9	12.2%
	Other Powerhouse	30	40.5%
	N. Shore	9	12.2%
	Total	**48**	**64.9%**
Transition pool	S. Shore	26	35.1%
	Total	**26**	**35.1%**

a fishway, and the remaining 4 fish (16%) reached as far upstream as one of the four transition pools before leaving the project.

Fallback fish: Of 801 chinook salmon with transmitters that passed Bonneville Dam in 1996, 110 (13.7%) fell back over the dam a total of 130 times. Salmon had passed the dam via the Bradford Island ladder prior to 84% (92 of 110) of first recorded fallbacks and 82% (107 of 130) of all recorded fallbacks. After their first fallback event, 102 of the 110 fish (93%) that fell back entered fishways, reascended the ladders, and passed the dam a second time. Ten fish fell back and passed the dam a third time, and two passed a total of four times. We analyzed data from chinook salmon that fell back and reentered fishways or reascended ladders at Bonneville Dam to assess whether fishway entrance use, movements within the fishways, or passage times differed between first and second passages of the dam.

For the 102 fish that passed the dam twice, median passage time from the first approach at a fishway entrance to exit from the top of a ladder was 0.60 d on the first passage and 0.51 d on the second passage (P = 0.75, Kruskal-Wallis χ^2 test) (Figure 23). Median first passage time from first approach to pass from a ladder for the 801 chinook salmon that

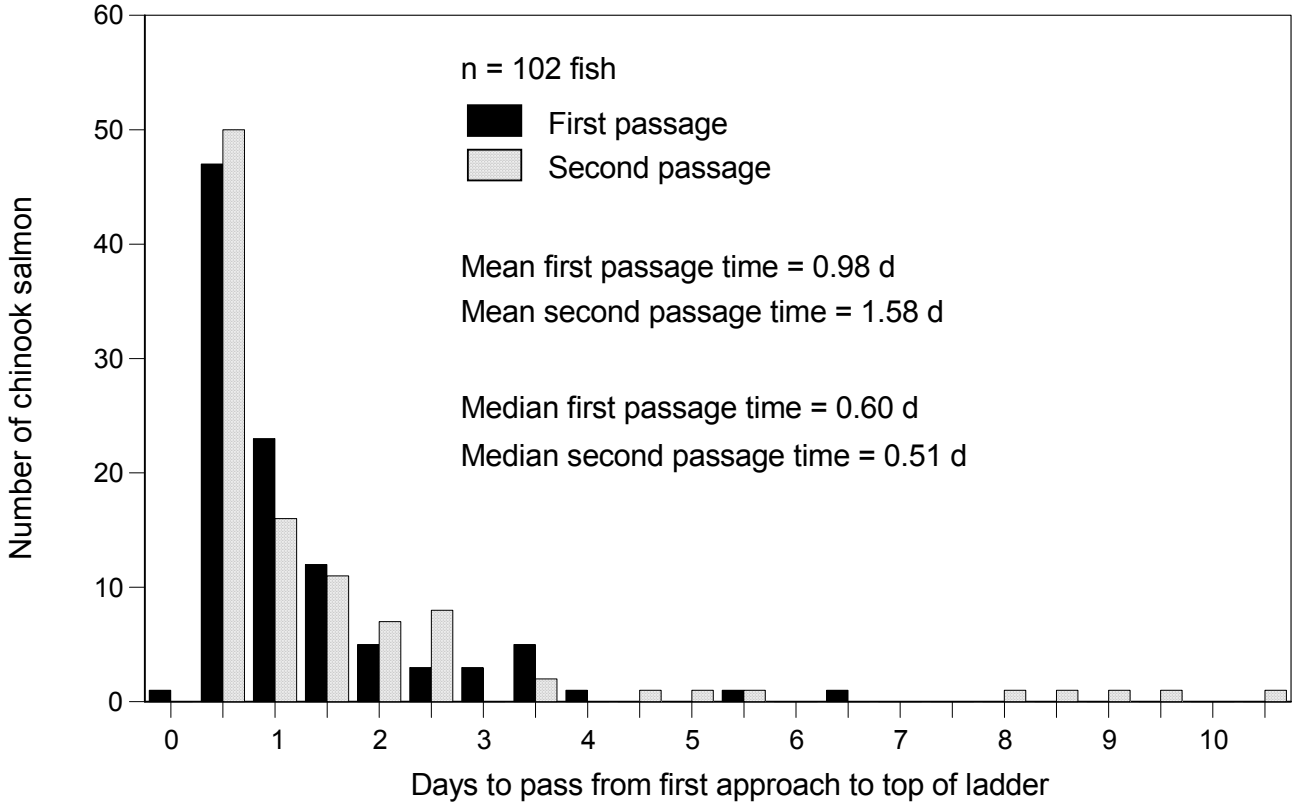


Figure 23. Passage times from the first approach at a fishway entrance to exit from a ladder for the first and second passages of chinook salmon that fell back at Bonneville Dam in 1996.

passed Bonneville Dam in 1996 was 0.71 d. Nine of the fish that fell back moved downstream after approaching a fishway entrance and took more than 5 d to eventually pass the dam. Consequently, mean passage time for the 102 fish that passed twice was 0.98 d for the first passage and 1.58 d for the second (P = 0.17, paired t-test). In paired tests, 49%of fallback fish passed more slowly on their second passage than on their first. Mean first passage time from first approach at an entrance to exit a ladder for all 801 chinook salmon that entered at Bonneville Dam was 1.34 d.

After falling back, 65 fish (64%) first approached entrances to the Bradford Island fishway and 37 (36%) first approached entrances to the Washington-shore fishway (Figure 24), a distribution between fishways similar to first approaches by the 814 chinook salmon with transmitters that approached Bonneville Dam in 1996 (Figure 11).

The entrances first approached after falling back differed some from the entrances approached first on the fallback fish's first passage. On the first passage, the entrances approached by the largest numbers of fish were those at the south end of Powerhouse 1, sluice gates 21 or 34, and those at the north end of Powerhouse 2 (Figure 24). On the

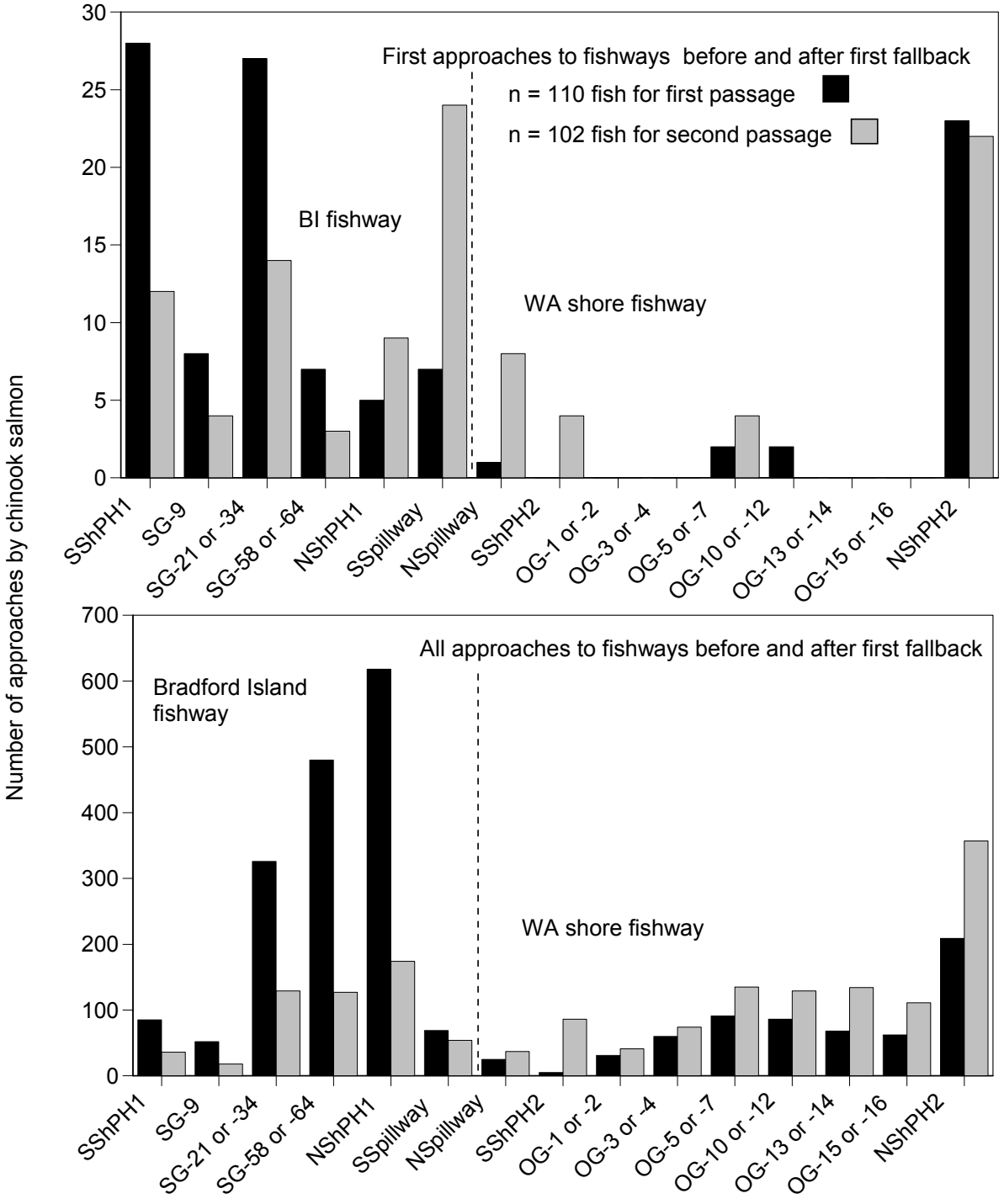


Figure 24. Distribution of first and total approaches to fishways before and after fallback for the 102 salmon that fell back and reascended in 1996.

second passage, entrances at the south end of the spillway and north end of powerhouse 2 were approached first by the largest number of fish. For comparison, only 4% of the first approaches by all 814 fish occurred at the south spillway, and 6% of the 110 fish that fell back made their first approaches at the south spillway on their first passage (Figure 24). The relative distribution of all approaches among entrances was similar for fish after they fell back (Figure 24) to that of the larger sample of 814 chinook salmon with transmitters (Figure 11). On their first passage, however, the fish that fell back made up to three times more approaches at sluice gate entrances and at the north-shore entrances of Powerhouse 1 as on their second passage (Figure 24).

The 102 chinook salmon that reascended made a median of 14.5 approaches to fishway entrances on their first passage, and 7 approaches on their second passage (Figure 25). By comparison, the entire sample of 814 fish made a median of 13 approaches per fish.

Distributions of the number of fish with one or more fishway entries were similar for chinook salmon that fell back and the larger sample of 804 salmon that entered fishways in 1996 (Figures 25 and 14). Of 102 fish that fell back and reascended, 40% made one entry on their first passage, and 59% made only one entry on their second passage (Figure 25). Fallback fish made a mean of 2.3 entries on the first passage and 2.0 on the second, compared to 2.62 for the 804 chinook salmon with transmitters that entered Bonneville fishways in 1996.

Of fish that fell back, 3.4 first entered the Bradford Island fishway on the first passage to every 1 that first entered the Washington-shore fishway (Figure 26). On the second passage, the ratio was 1.2 to 1, a distribution similar to that for all 804 fish that entered the fishways. First entries after a fallback for chinook salmon were concentrated at the shoreline entrances of the powerhouses and spillway (Figure 26).

The relative distributions of first and subsequent exits from fishways were similar for the first and second passage of fish that fell back, as well as for the larger sample of 804 fish that entered fishways (Figures 27 and 18). Most fish exited via shoreline and spillway entrances. Mean and median numbers of exits were lower, however, for chinook salmon on their second passage (Figure 24). Mean exits were 1.6 for all first passage fish, 1.2 on the first passage of fish that fell back and reascended, and 1.0 on the second passage of fish that fell back. On their first passage 43% (44) of the chinook salmon did not exit the fishway; on the second passage 60% (61) did not exit.

On the first passage of fish that fell back, 70% of first exits and 66% of total exits by chinook salmon were from entrances to the Bradford Island fishway (Figure 27). On the second passage, more first exits (58%) and total exits (69%) were from Washington-shore fishway entrances. By comparison, for all 804 chinook salmon monitored, 51% of first exits and 57% of total exits were from entrances to the Washington-shore fishway. Exit locations for salmon that fell back were similar to where they entered fishways; most occurred at the

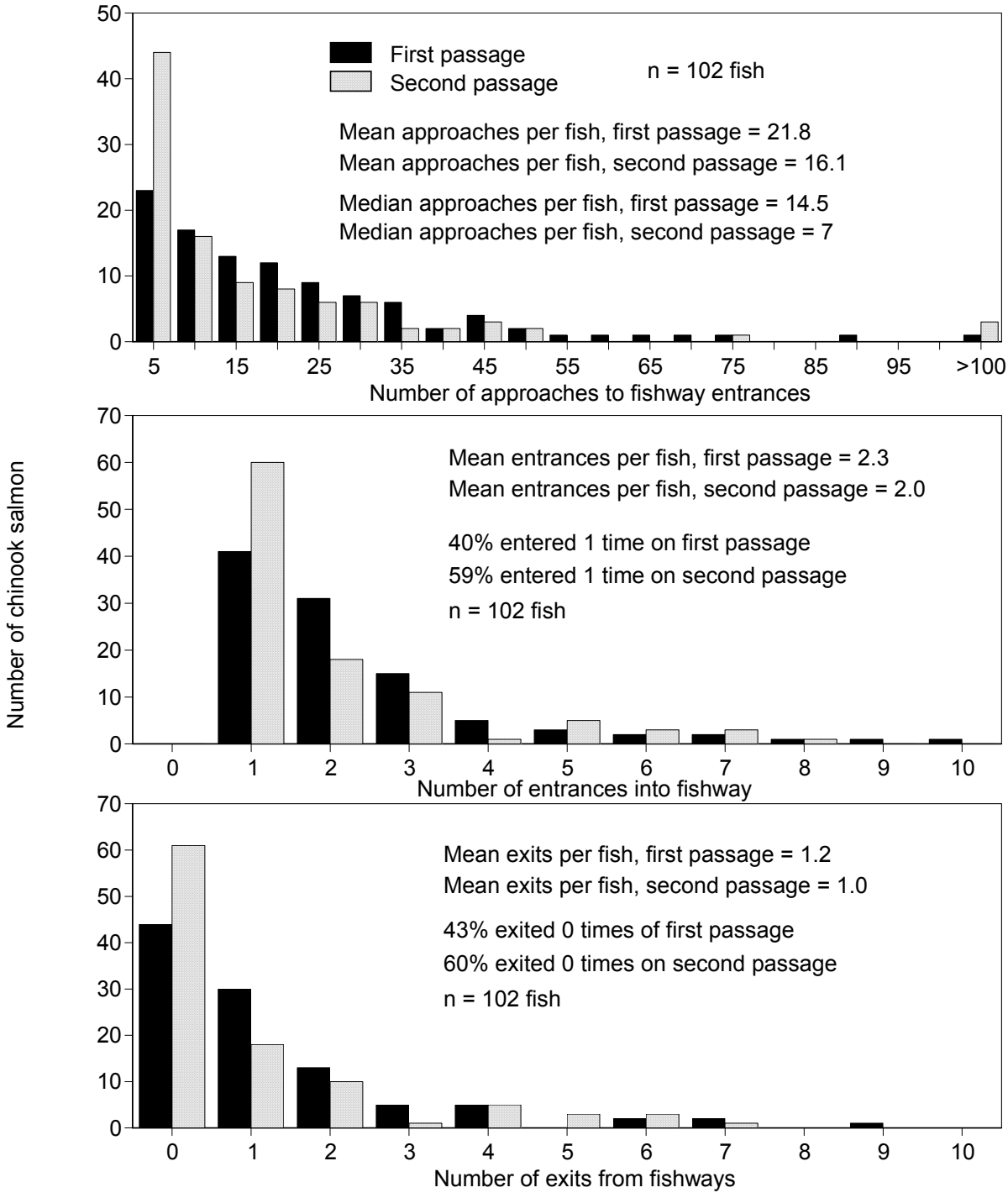


Figure 25. Number of approaches, entries, and exits by chinook salmon at Bonneville Dam fishway entrances on their first and second passages of the dam in 1996.

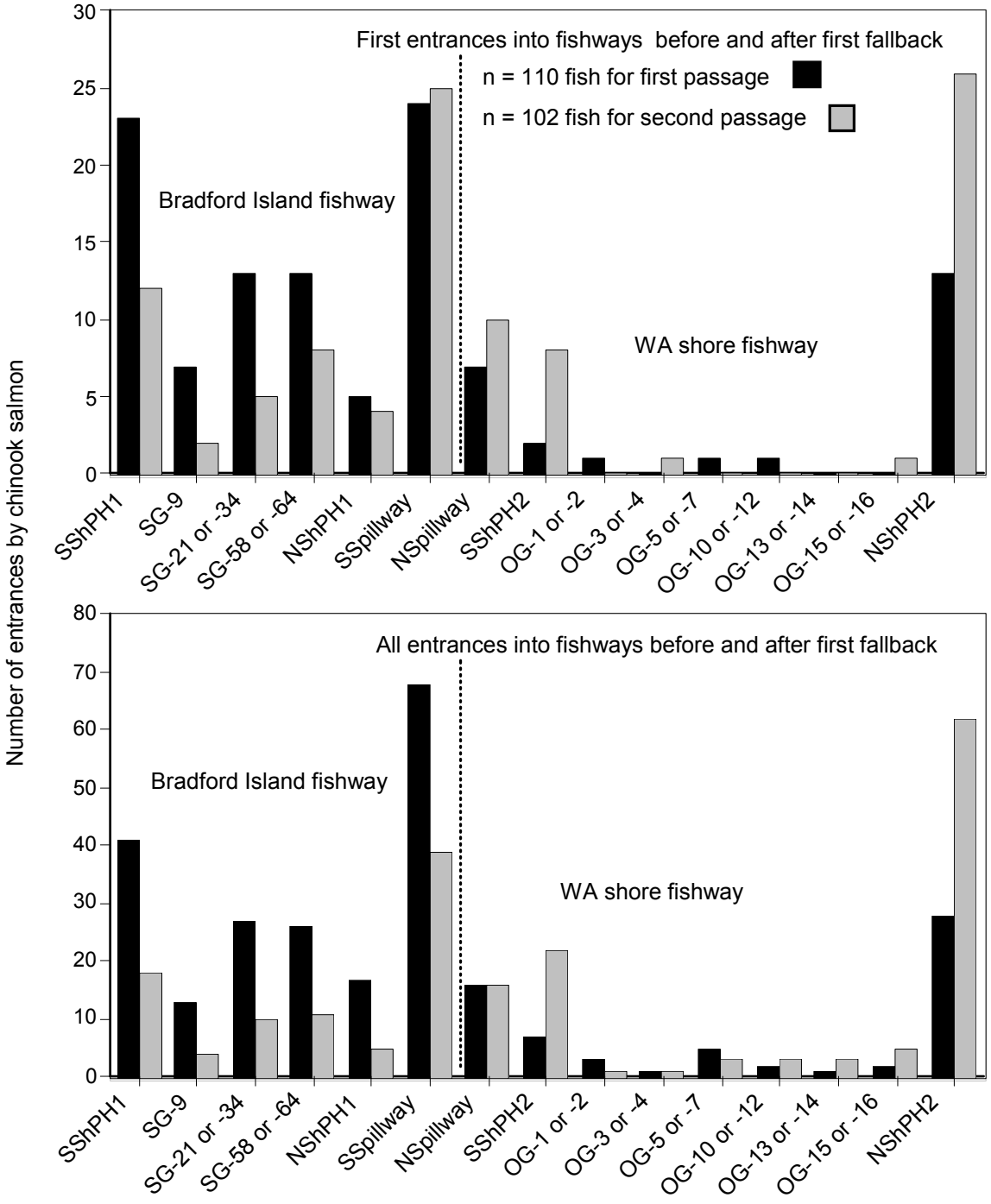


Figure 26. Number of first and total entries by chinook salmon into Bonneville Dam fishway entrances before and after their first fallback in 1996.

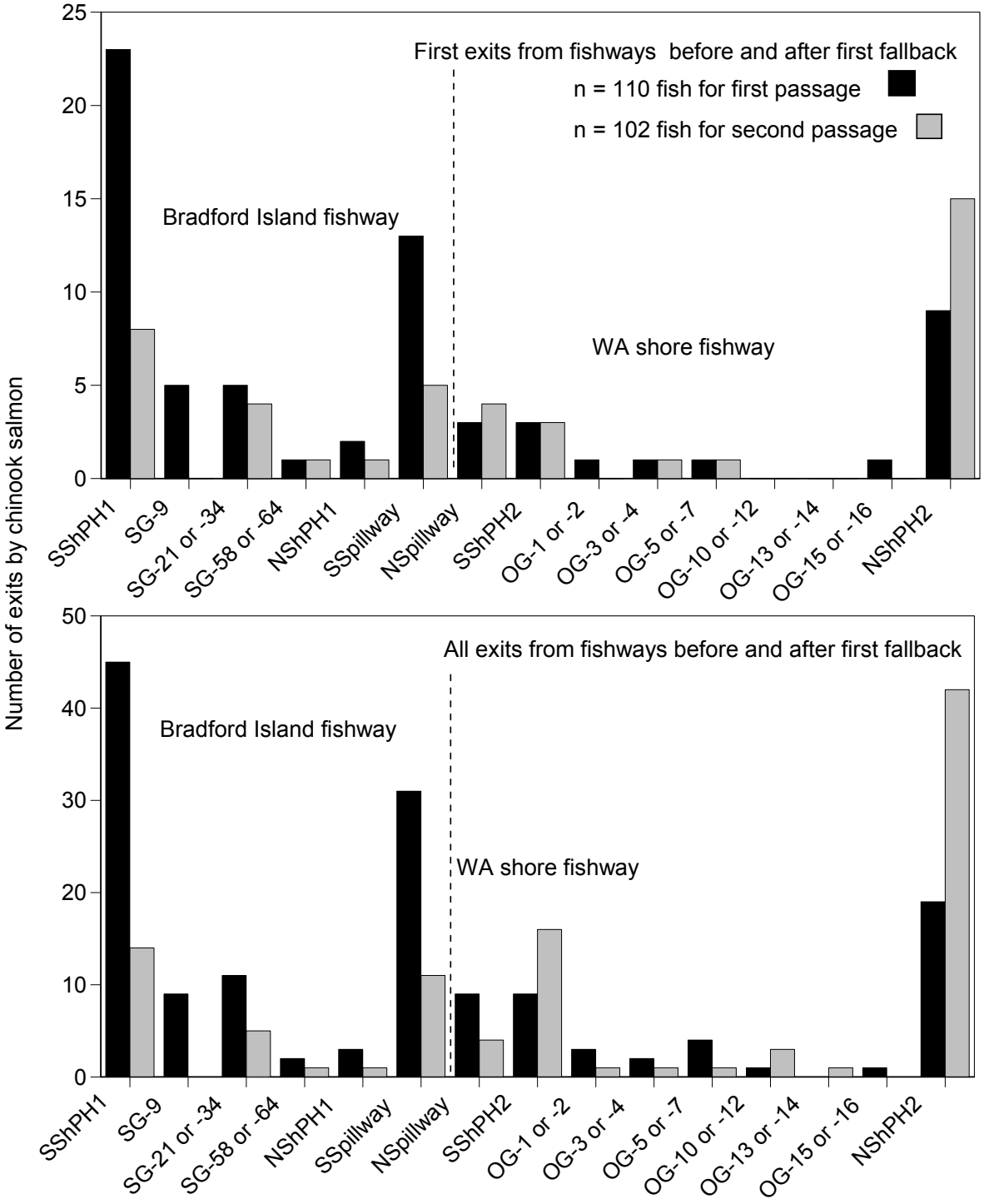


Figure 27. Number of first and total exits by chinook salmon from Bonneville Dam fishway entrances before and after their first fallback in 1996.

south-shore entrance to Powerhouse 1, the north-shore entrances to Powerhouse 2, and the spillway entrances (Figure 27).

Movements Through Transition Pools

We analyzed behavior of 679 chinook salmon that were recorded at all of the fishway transition points (approach, entry, first and last transition pool records, and ladder exit) as they moved within the four transition pools at Bonneville Dam in 1996. Thirty percent (202) of the monitored chinook salmon first entered the transition pool at the base of the A Branch ladder of the Bradford Island fishway (A Branch pool), 22% (149) first entered at the transition pool at the base of the B Branch ladder of the Bradford Island fishway located at the south end of the spillway (B Branch pool); 11% (75%) first entered at the transition pool at the base of the Cascades Island ladder located at the north end of the spillway (Cascades Island pool); and 38% (255) first entered at the Washington-shore transition pool (WA-shore pool) (Figure 28). Of the 679 fish, 74% (504) eventually passed the dam via the ladder associated with the pool they first entered. The remaining 26% entered one transition pool, turned around and exited the transition pool and fishway into the tailrace, then entered another fishway and transition pool and passed over the dam.

More than 52% (357) of the chinook salmon monitored at Bonneville transition pools exited into the tailrace one or more times before they passed through a pool and over the dam (Figure 29). Twenty-three percent (155) moved straight through a transition pool and into a ladder with no downstream movement, and 13% (91) moved downstream in a transition pool but did not exit the pool before passing the dam. The remaining 11% (76) entered the WA-shore or A Branch transition pool, moved downstream, and exited the pool into a collection channel but did not exit to the tailrace.

Median passage time for all 679 chinook salmon from first fishway entry to first entry into a transition pool was 4 min (0.07 h); median time from first transition pool entry to exit a pool into a ladder was 1.29 h (Figure 30, Table 3). Median time for all fish to ascend a ladder after exiting a transition pool into a ladder was 2.85 h, and median passage from first fishway entry to exit from the top of a ladder was 8.51 h (Figure 30, Table 3). Distributions of passage times for chinook salmon passing through Bonneville transition pools were skewed to the right, so median times were more representative indicators of overall chinook behavior than mean times.

For the 155 chinook salmon (23%) that moved straight through a transition pool with no downstream movement, median times were 6 min (0.10 h) from first fishway entry to first entry in a transition pool and 8 min (0.13 h) from first pool entry to exit a pool into a ladder (Table 3). Median passage times for the 155 fish were 3.17 h to ascend a ladder and 3.95 h from first fishway entry to exit from the top of a ladder (Table 3). Two-thirds of the 155 fish that moved straight through a transition pool passed Bonneville Dam in less than 6 h, and 6% (9 fish) took more than 24 h to pass the dam. Ninety-one (13%) chinook salmon moved

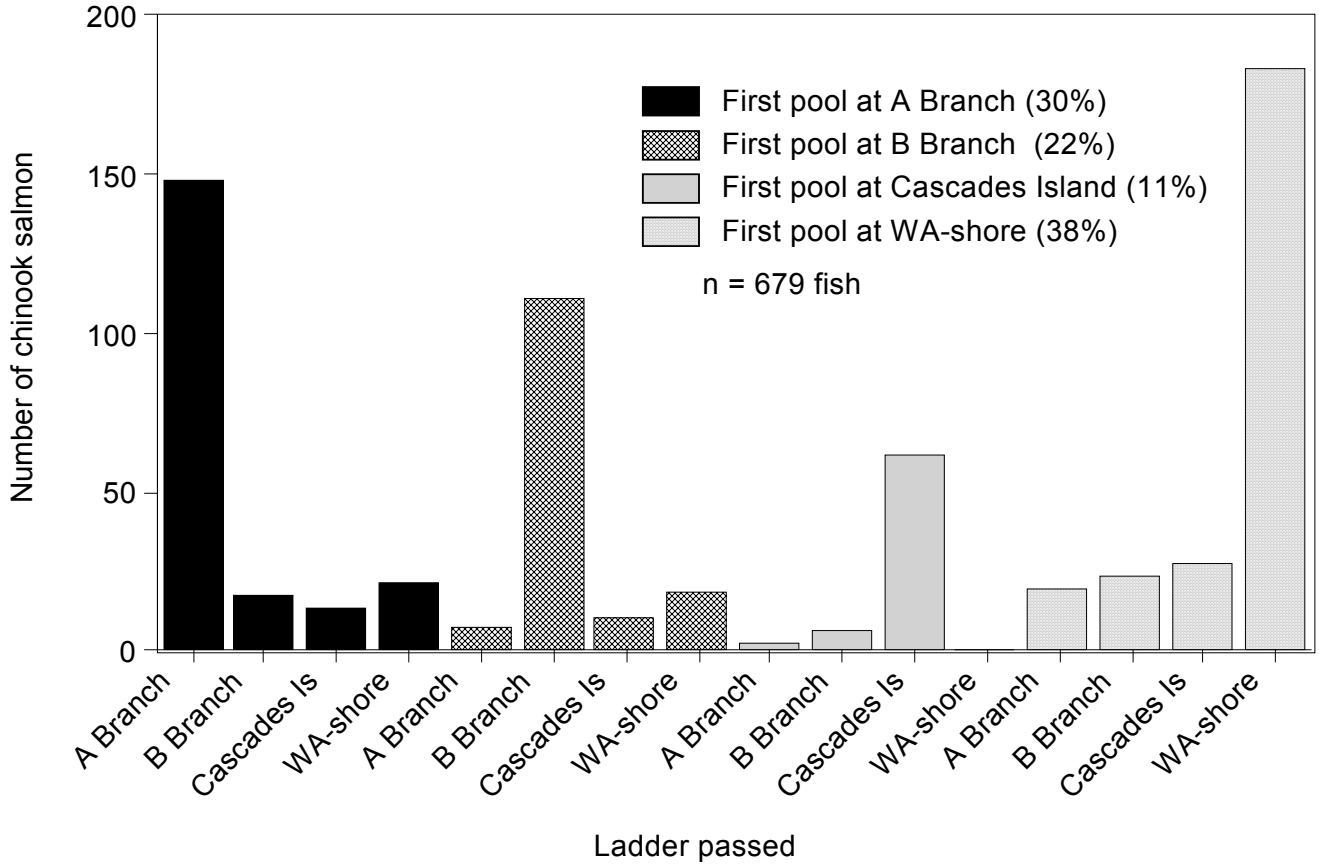


Figure 28. Number of chinook salmon that passed Bonneville Dam in 1996, the transition pool first entered, and the ladder used to pass the dam.

downstream in a transition pool after they first entered, but they did not exit to a collection channel or the tailrace. Median passage times for these 91 fish were 1 min (0.02 h) from first fishway entry to first transition pool entry, 23 min (0.38 h) from first pool entry to exit a pool into a ladder, 2.82 h to ascend a ladder, and 4.47 h from first fishway entry to exit from the top of a ladder (Table 3). Sixty-three percent (57) of the fish that moved downstream in a transition pool but did not exit the pool passed Bonneville Dam in less than 6 h, and 7% (6 fish) took more than 24 h to pass the dam.

After they entered the WA-shore or A Branch transition pools, 76 (11% of 679) chinook salmon moved downstream, exited into the adjacent collection channel, and then passed the dam without exiting to the tailrace. Median passage times for these 76 fish were 13 min (0.21 h) from first fishway entry to first transition pool entry, 34 min (0.53 h) from first pool entry to exit a pool into a ladder, 2.70 h to ascend a ladder, and 3.96 h from first fishway entry to exit from the top of a ladder (Table 3). Sixty-eight percent (52) of the 76 fish that exited a transition pool into a collection channel but did not enter the tailrace passed the dam in less than 6 h; 5% (4 fish) took more than 24 h to pass the dam.

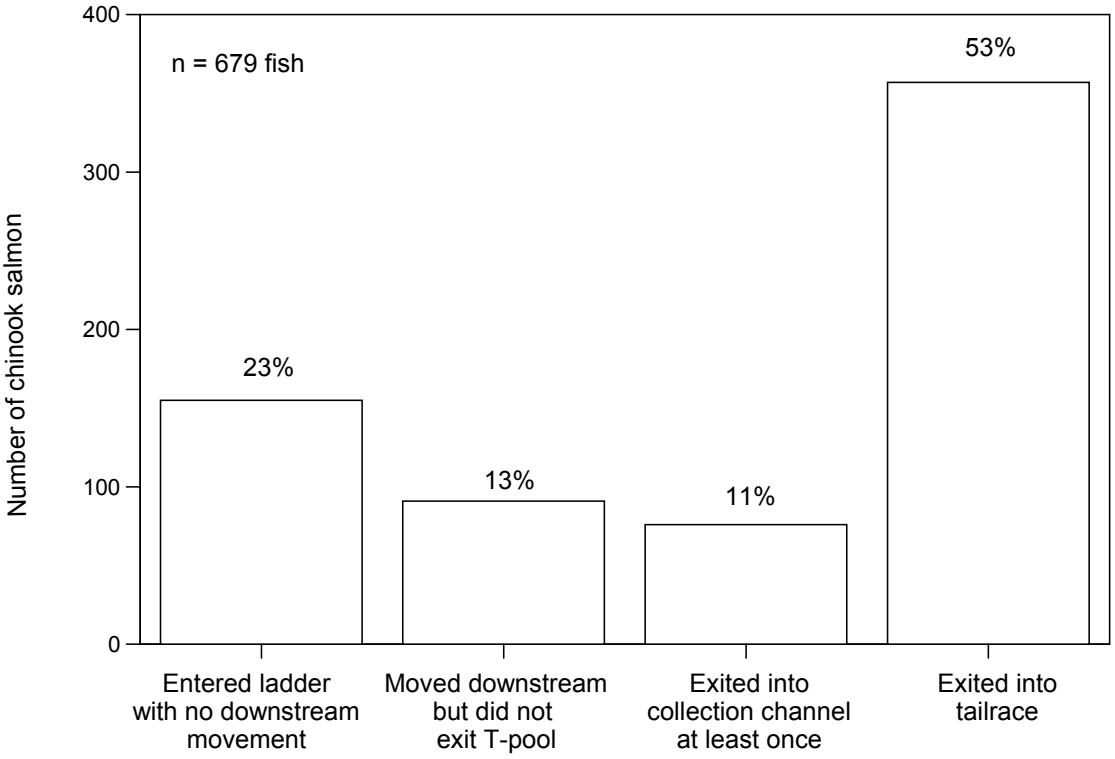


Figure 29. Number of chinook salmon that passed straight through a Bonneville transition pool into a ladder, moved downstream in a pool before entering the ladder, exited a pool into a collection channel, or exited a pool into the tailrace in 1996.

The remaining 357 (53%) chinook salmon monitored in transition pools at Bonneville Dam entered a pool, moved downstream, and exited into the tailrace one or more times before passing the dam. Median passage times for these 357 fish were 2 min (0.04 h) from first fishway entry to first transition pool entry, 9.19 h from first pool entry to exit a pool into a ladder, 2.80 h to ascend a ladder, and 17.31 h from first fishway entry to exit from the top of a ladder (Table 2). Of the 357 fish that exited into the tailrace, 74 (21%) took less than 6 h to pass the dam. About 129 (36%) fish took more than 24 h to pass the dam, and 29 (8%) chinook salmon took more than 5 d to pass the dam after first entering the fishway.

When all pools were considered together, median passage times from first fishway entry to first transition pool entry and to ascend a ladder were relatively independent of chinook salmon behavior in the pools. Median times from first fishway entry to first transition pool entry ranged from 1 min (0.02 h) for fish that moved downstream in a pool but did not exit to 13 min (0.21 h) for fish that exited a transition pool into a collection channel (Table 3). Median times to ascend ladders ranged from 2.70 h to 3.17 h (mean times 3.96 to 6.24 h) (Table 3).

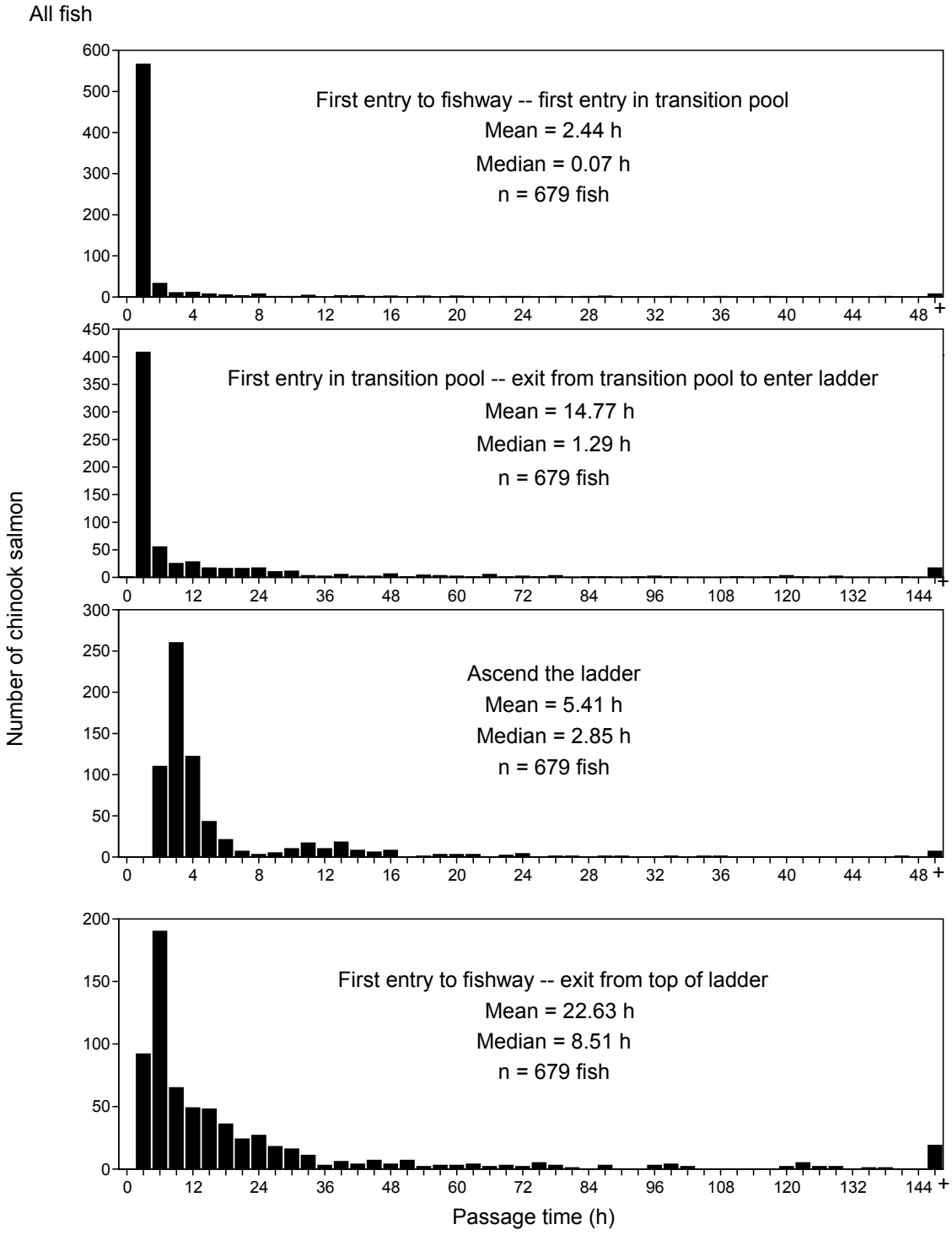


Figure 30. Time to first enter and to pass through a transition pool, to ascend a ladder, and to exit from the top of a ladder at Bonneville Dam by chinook salmon in 1996.

Table 3. Median and mean passage times for chinook salmon that moved through a transition pool at Bonneville Dam with no downstream movement, moved downstream in a transition pool but did not exit before passing into a ladder, exited a transition pool into a collection channel but not into the tailrace, or exited into the tailrace in 1996.

		Median passage time (h) from:			
Transition pool behavior	N	First entry to first pool	First pool to last pool	Ascend ladder	First entry to exit ladder
All behaviors	679	0.07	1.29	2.85	8.51
Moved straight through	155	0.10	0.13	3.17	3.95
Moved downstream, but didn't exit	91	0.02	0.38	2.82	4.47
Exited pool to collection channel	76	0.21	0.53	2.70	3.96
Exited pool to tailrace	357	0.04	9.19	2.80	17.31
		Mean passage time (h):			
All behaviors	679	2.44	14.77	5.41	22.63
Moved straight through	155	2.13	0.44	6.24	8.82
Moved downstream, but didn't exit	91	3.86	1.23	4.05	9.14
Exited pool to collection channel	76	1.85	1.96	3.96	7.77
Exited pool to tailrace	357	2.34	27.18	5.71	35.23

Median passage times from first transition pool entry to entry into a ladder and from first fishway entry to exit from the top of a ladder were significantly different with different chinook salmon behavior in the transition pools. For salmon that moved straight through a transition pool, median time from first transition pool entry to enter a ladder was 8 min (0.13 h) (Table 3). Median pool passage times increased to 23 min (0.38 h) for fish that moved downstream in a transition pool but did not exit into a collection channel before entering a ladder, to 32 min (0.53 h) for fish that exited into a collection channel, and to 9.19 h for fish that exited into the tailrace before entering a ladder ($P < 0.0001$, Kruskal-Wallis χ^2 test) (Table 3). Using median values, chinook salmon that exited to the tailrace took 17 times longer to enter the ladder after first entering a transition pool than fish that exited to the collection channel only and 71 times as long as fish that moved straight through a transition pool. Median passage times from first fishway entrance to exit from the top of a ladder were 3.95 h for fish that moved straight through a pool on their first attempt, 4.47 h for fish that moved downstream in a transition pool but did not exit before entering a ladder, 3.96 h for fish that exited into a collection channel, and 17.31 h for fish that exited into the tailrace ($P < 0.0001$) (Table 3).

We also analyzed movements by chinook salmon at individual transition pools to determine whether differences in behavior or passage times could be attributed to fishway and transition pool configuration and/or the location of monitoring antennas. In 1996, 202

(30%) of the 679 chinook salmon monitored first entered the A Branch transition pool. Of these 202 fish, 46% (93) exited to the tailrace, 31% (63) exited to the collection channel, 17% (35) moved straight through the pool into the ladder, and 5% (11) entered the ladder after moving downstream in the pool but not exiting (Figure 31). Chinook salmon could enter the A Branch transition pool only via the collection channel at Powerhouse 1 (Figure 32). The pool was relatively straight and short, with antennas approximately 15.2 m apart. Because the transition between the A Branch pool and the start of overflow weirs in the ladder varied with tailwater elevation, the actual passage times of fish in the A Branch transition pool may have been longer than those recorded when the tailwater was higher than the upper antenna.

Another 255 chinook salmon outfitted with transmitters (38%) first entered the WA-shore transition pool, of which 65% (166) exited to the tailrace, 23% (58) moved straight through the pool into the ladder, 7% (18) entered the ladder after moving downstream in the pool, and 5% (13) moved downstream and exited to the collection channel but did not enter the tailrace (Figure 31). The Washington-shore fishway and transition pool were configured with three distinct routes into the WA-shore pool. Fish could enter via the long channel from North shore Entrance 1 (NSE1), from North shore Entrances 2 and 3 (NSE2, 3), or via the collection channel at Powerhouse 2 (Figure 32). In 1996, antenna coverage of the WA-shore pool was such that fish that entered the pool via NSE1 received their first transition pool record in the channel approximately 36.6 m downstream from the turn into the main body of the transition pool. Because of this distance fish that entered via NSE1 took somewhat longer to pass through the pool (median of 15 min) than fish that entered via the Powerhouse 2 collection channel or NSE2,3 (median of 9 min). Chinook salmon could also enter the WA-shore pool via any route, then move downstream into the channel from NSE1; if a fish did not exit the NSE1 channel into the tailrace, time spent in the Washington-shore channel upstream of the antenna was considered time in the transition pool. As a result, we may have under- represented both the number of fish described as exiting to a collection channel and those described as moving downstream without exiting the WA-shore transition pool.

The remaining 222 fish (33%) first entered transition pools at the base of the spillway ladders, 149 (22%) at the B Branch pool at the south end of the spillway, and 73 (11%) at the Cascades Island pool at the north end of the spillway. These transition pools were nearly identical (Figure 33); each had two adjacent entrances 3.05 m wide by a minimum of 3.05 m deep. Approximately 12.2 m upstream from the entrances were antennas that recorded the first transition pool entry by chinook salmon, and antennas that recorded the exits of fish from the transition pool were another 12.2 m upstream. There were no collection channels and, in 1996, no antennas to adjust for changes in tailrace water elevation. More chinook salmon passed straight through the spillway pools or passed through after some downstream movement than at other Bonneville transition pools. Overall 50% (73) of the chinook salmon that first entered the B Branch transition pool and 68% (50) that first entered the Cascades Island pool passed through on their first attempt (Figure 31). Fifty percent (75) of fish

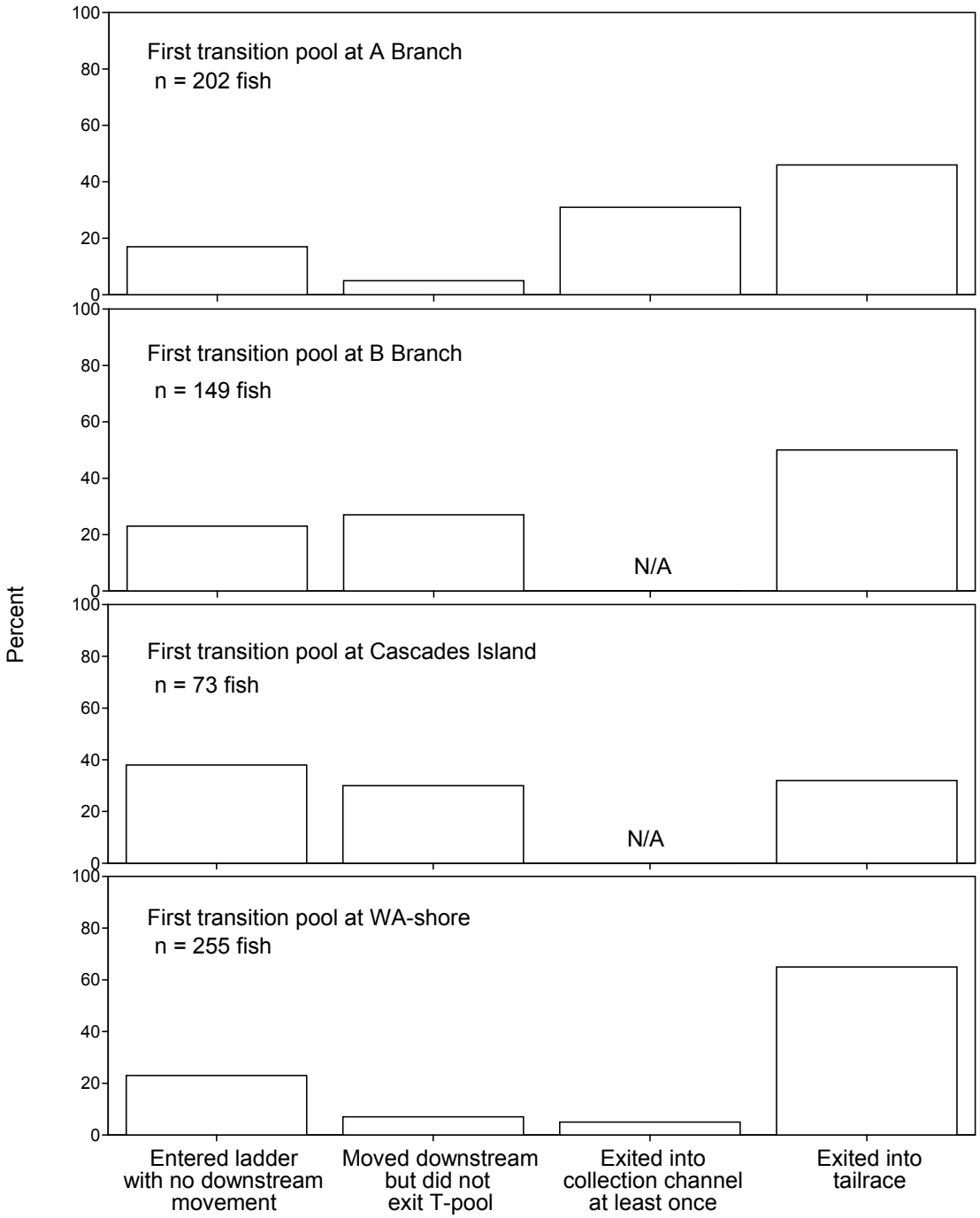


Figure 31. Percentage of chinook salmon in 1996 that passed straight through a Bonneville transition pool into a ladder, moved downstream in a pool before entering a ladder, exited a pool into a collection channel, or exited a pool into the tailrace based on which transition pool was first entered.

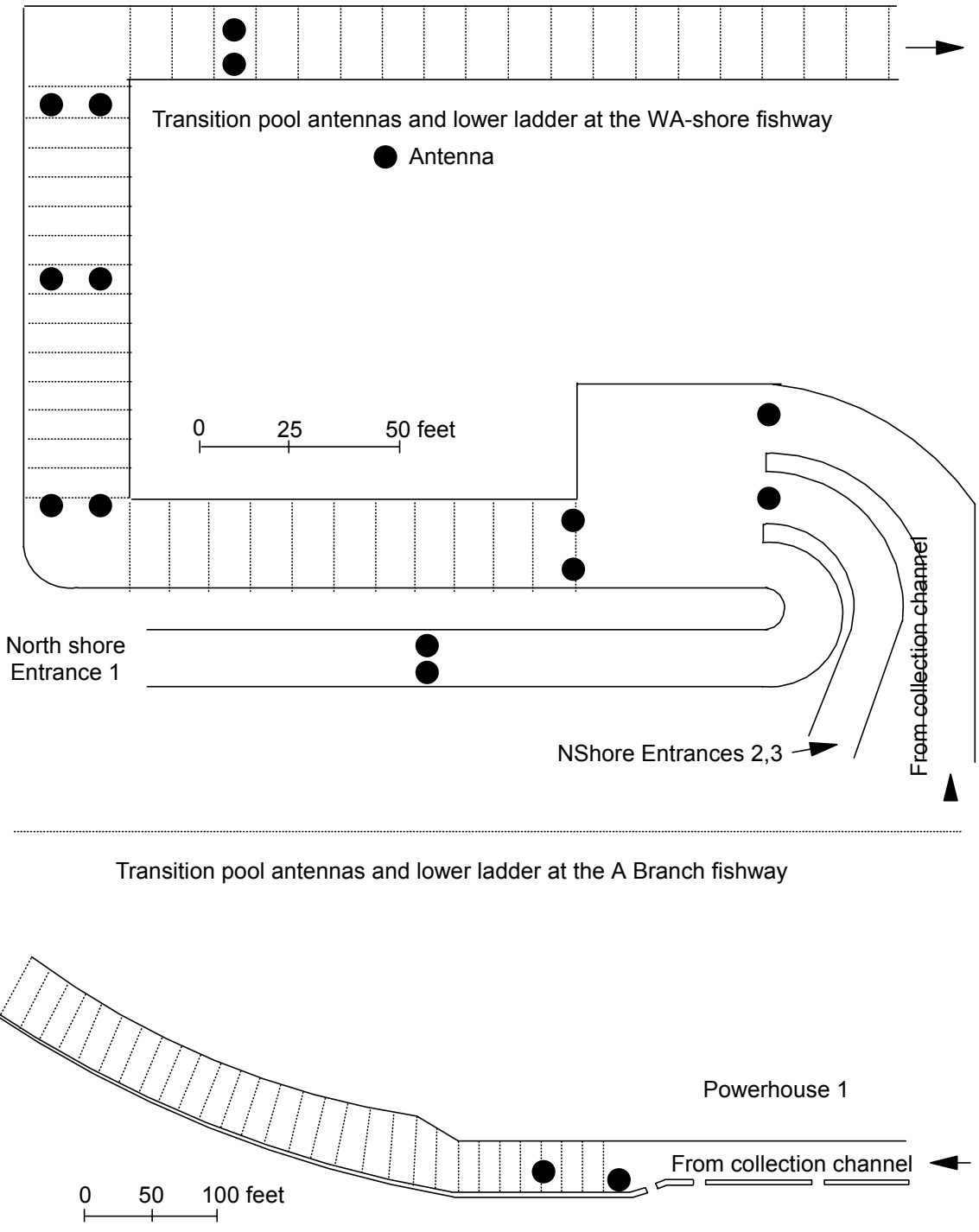


Figure 32. Location of antennas installed in the WA-shore transition pool of the Washington-shore fishway and the A Branch transition pool at Bonneville Dam in 1996.

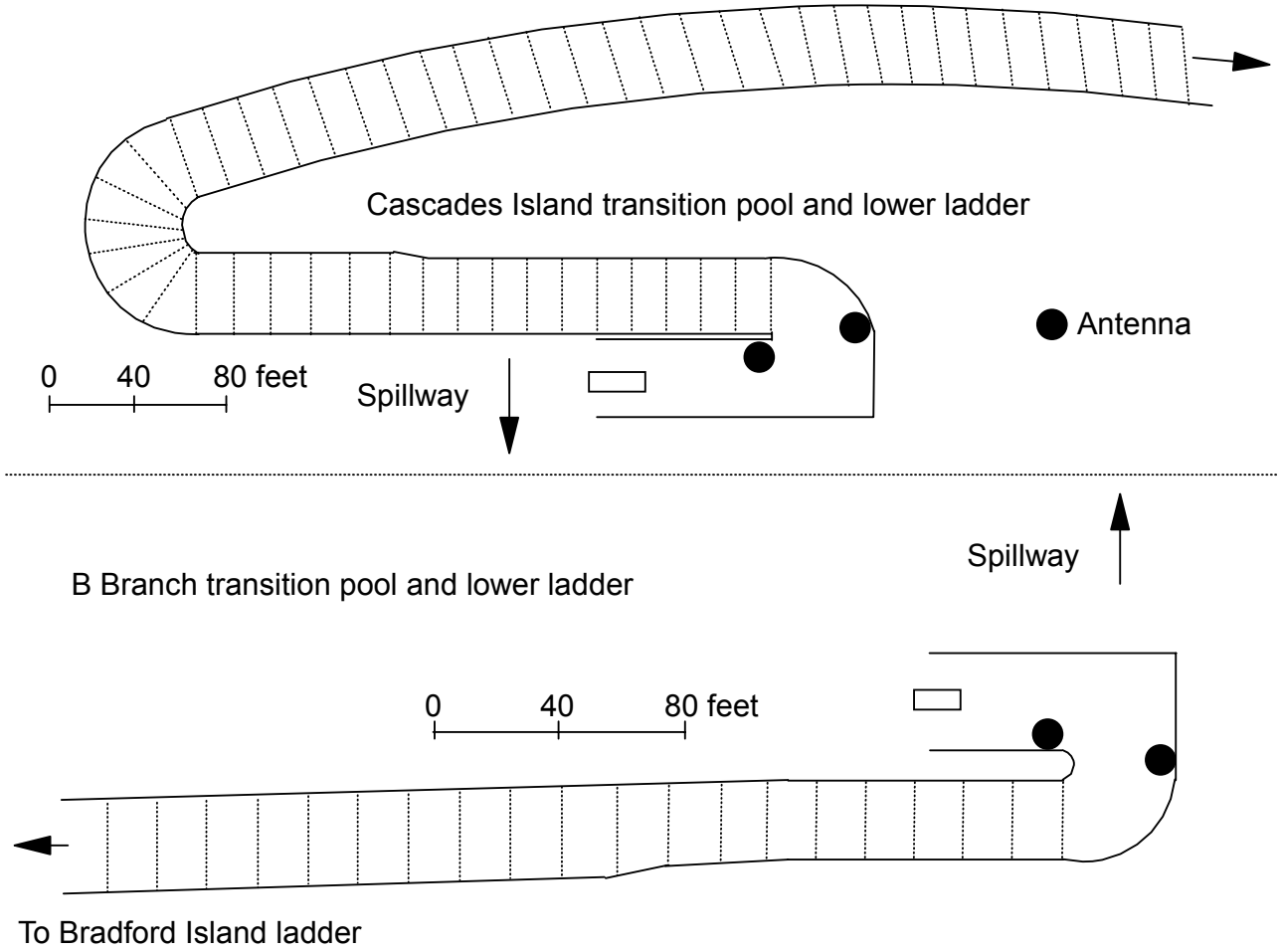


Figure 33. Location of antennas installed in the Cascades Island and B Branch transition pools in ladders adjacent to the spillway at Bonneville Dam in 1996.

exited from the B Branch pool to the tailrace, and 32% (23) exited to the tailrace from the Cascades Island pool.

Differences in individual pool and fishway configurations were reflected in passage times of chinook salmon. Chinook salmon that moved straight through a transition pool had median passage times of less than 2 min (0.03 h) from first fishway entry to first transition pool entry at both the Cascades Island and B Branch pools (Table 4). By comparison, median times from first fishway entry to first transition pool entry were 6.6 min (0.11 h) for fish that passed straight through the WA-shore pool and 16 min (0.26 h) for fish that moved straight through the A Branch pool. Median times from first transition pool entry to exit a pool into a ladder were about 12 min (0.20 h) at Cascades Island and B Branch pools, and at the WA-shore pool when all possible routes into the WA-shore pool were combined (Table 4).

Table 4. Median passage times at Bonneville Dam for chinook salmon that moved through the A Branch, B Branch, Cascades Island, or Washington-shore transition pools and had no downstream movement, moved downstream in a transition pool but did not exit before passing into a ladder, exited a transition pool into a collection channel but not into the tailrace, or exited into the tailrace in 1996.

			Median passage time (h) from:			
Transition pool behavior	First pool entered	N	First entry To first pool	First pool To last pool	Ascend Ladder	First entry To exit ladder
No downstream	A Branch	35	0.26	0.01	2.90	3.25
movement in pool	B Branch	33	0.01	0.18	2.76	3.64
	Cascade Is.	28	0.03	0.20	4.27	10.21
	WA-shore	58	0.11	0.21	3.05	3.81
Moved downstream	A Branch	11	0.70	0.12	2.62	6.91
but did not exit pool	B Branch	40	0.01	0.39	2.58	3.49
	Cascade Is.	22	0.01	0.75	3.90	6.30
	WA-shore	18	0.22	0.36	3.24	5.02
Exited pool to	A Branch	63	0.23	0.38	2.61	3.74
collection channel	B Branch	N/A	--	--	--	--
	Cascade Is.	N/A	--	--	--	--
	WA-shore	13	0.08	1.28	3.46	5.97
Exited pool to	A Branch	93	0.32	16.01	2.74	21.32
Tailrace[1]	B Branch	75	0.01	8.03	2.65	17.63
	Cascade Is.	23	0.01	3.40	2.78	19.14
	WA-shore	166	0.03	6.99	2.89	14.16

[1] Breakdown of among-fishway movements summarized in Table 4

Fish that moved straight through the A Branch transition pool did so in a median time of less than 1 min. Median times for chinook salmon to ascend ladders after passing transition pools were 2.76 h at the B Branch ladder and 4.27 h at the Cascades Island ladder. Longer passage times up the Cascades Island ladder included time fish spent negotiating the upstream migrant transportation (UMT) channel and the junction pool at the top of the WA-shore ladder. Median time from first fishway entry to exit from a ladder was less than 3.81 h for chinook salmon that passed straight through the A Branch, B Branch, and WA-shore transition pools (Table 4); fish that passed straight through the Cascades Island pool took almost three times as long to pass the dam (median of 10.2 h), perhaps due to time required to pass the UMT channel, although median time to ascend the ladder (4.3 h) did not seem to reflect this.

Chinook salmon that moved downstream in a transition pool but did not exit to a collection channel or the tailrace had median passage times from first fishway entry to first transition pool entry of less than 1 min (0.01 h) at B Branch and Cascades Island transition pools, 13 min (0.22 h) at the WA-shore pool, and 42 min (0.70 h) at the A Branch pool (Table 4). Median times from first transition pool entry to exit a pool into a ladder were 7 min (0.12 h) through the A Branch pool, 22 min (0.36 h) through the WA-shore pool, 23 min (0.39 h) at the B Branch pool, and 45 min (0.75 h) at the Cascades Island pool (Table 3). Median times for fish to ascend ladders after passing a transition pool ranged from 2.58 h at the B Branch pool to 3.90 h at the Cascades Island pool, and were similar to those for fish that moved straight through pools (Table 4). Median times from first fishway entry to exit from the top of a ladder were 3.49 h for chinook salmon that passed through the B Branch pool, 5.02 h through the WA-shore pool, 6.30 h through the Cascades Island pool, and 6.91 h through the A Branch pool (Table 4).

In 1996, 63 chinook salmon with transmitters exited the A Branch transition pool into the collection channel but did not enter the tailrace before passing the dam. Median passage times for these fish were 14 min (0.23 h) from first fishway entry to first transition pool entry, 23 min (0.38 h) from first transition pool entry to exit the pool into the ladder, 2.61 h to ascend the ladder, and 3.74 h from first fishway entry to exit from the top of the ladder (Table 4). Thirteen fish exited the WA-shore pool into the powerhouse collection channel but did not exit into the tailrace. Median passage times for the 13 fish were 5 min (0.08 h) from first fishway entry to first transition pool entry, 1.28 h from first transition pool entry to exit the pool into the ladder, 3.46 h to ascend the ladder, and 5.97 h from first fishway entry to exit from the top of the ladder.

Median passage times for fish that exited transition pools to the tailrace were similar to other groups from first fishway entry to first pool entry and to ascend ladders. Median times from first pool entry to exit a pool into a ladder were 3.40 to 8.03 h at the B Branch, Cascade Island and WA-shore pools and 16.01 h through the A Branch pool. Median times from first entry to exit from the top of a ladder were 14.16 to 21.32 at the four pools (Table 4).

Of the 357 chinook salmon that exited transition pools into the tailrace at Bonneville Dam, 182 (51%) reentered the same fishway and passed the dam via the transition pool they first entered. Forty-nine percent (175) exited a transition pool into the tailrace and then passed the dam via a different transition pool than the one first entered. Median times from first fishway entry to first transition pool entry and to ascend ladders were similar for fish that passed via the pool they first entered and for those that passed via a different pool (Figure 34). Chinook salmon that exited a transition pool into the fishway and then passed the dam via a different pool took a median of 17.22 h to pass from first transition pool entry to exit a pool into a ladder; almost six times as long as fish that exited to the tailrace and then reentered and passed through the same transition pool (2.95 h). Fish that passed the dam via a different transition pool than they first entered took 23.13 h to pass from first fishway entry to exit from the top of a ladder compared to 10.96 h for chinook salmon that passed via the same transition pool they first entered (Figure 34).

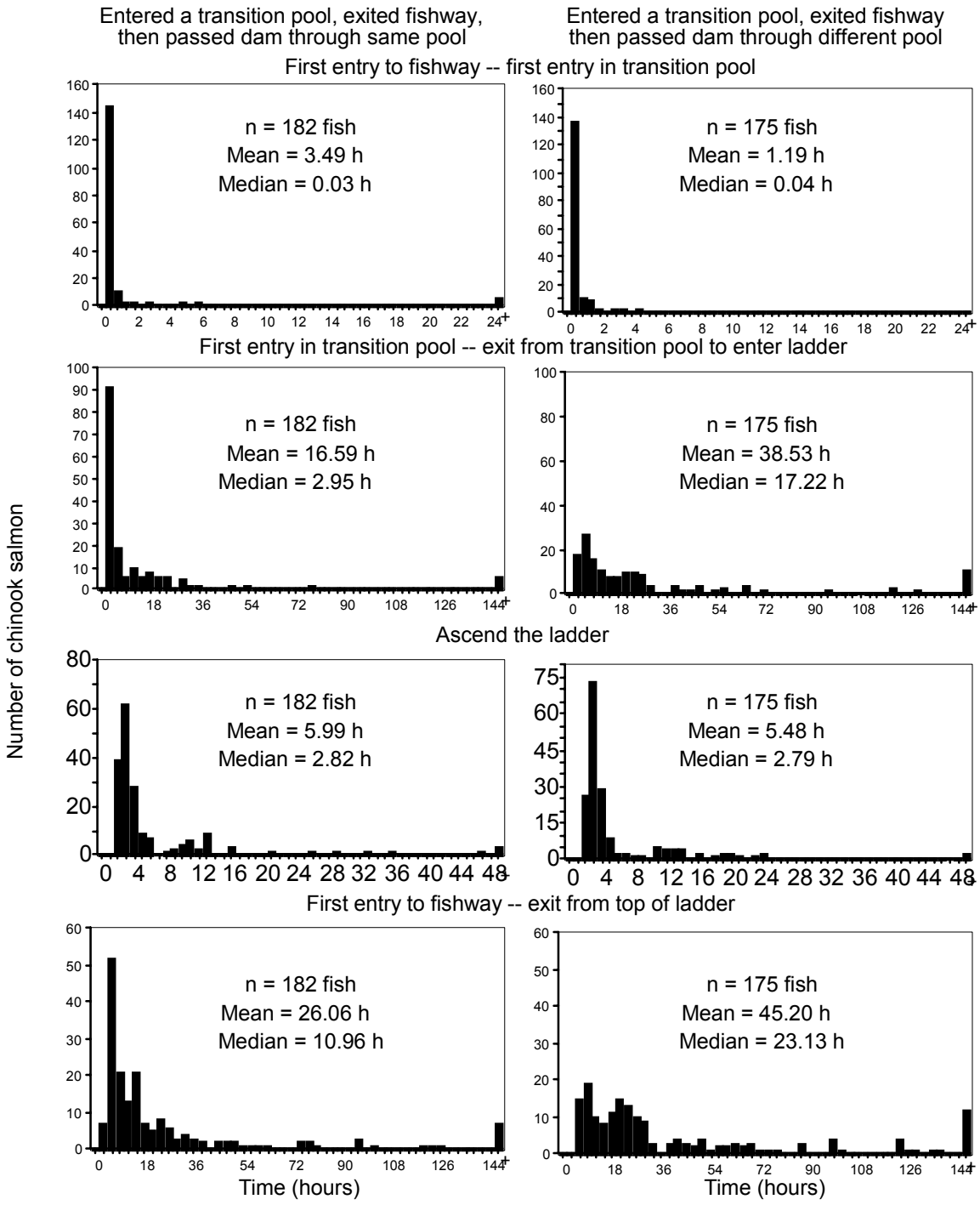


Figure 34. Median time to first enter and to pass through a transition pool, to ascend a ladder, and to exit from the top of a ladder at Bonneville Dam in 1996 by chinook salmon that exited a transition pool into the tailrace and either did or did not pass the dam via the same transition pool they first entered.

Of the 93 fish that exited the A Branch transition pool into the tailrace, 39 (42%) reentered and passed there, the remaining fish eventually passed the dam via one of the other three transition pools (Table 5). Median passage times from first entry at the A Branch pool to exit a pool into a ladder ranged from 7.16 h for fish that reentered and passed the A Branch pool to 27.84 h for fish that passed via the WA-shore pool. Of the fish that exited from the A Branch transition pool, the longest median passage time from first fishway entry to exit from the top of a ladder (36.10 h) was also for fish that passed via the WA-shore pool (Table 5).

Of the 75 chinook salmon that exited from the B Branch transition pool, 37 (48%) reentered and passed there, 8 (11%) passed via the A Branch pool, 11 (15%) passed via the Cascades Island pool, and 19 (25%) passed via the WA-shore pool (Table 5). Median passage times from first transition pool entry to exit a pool into a ladder were shorter for fish that passed via the B Branch and Cascades Island pools than for fish that exited the B Branch pool and then passed the dam via the WA-shore pool and A Branch pools and this was reflected in the median passage times from first fishway entry to exit from the top of a ladder for the four passage routes (Table 5).

Of the 23 fish that exited the Cascades Island transition pool into the tailrace, 12 (52%) reentered and passed via the same pool, 3 (13%) passed via the A Branch pool, 7 (30%) passed via the B Branch pool, and 1 (4%) passed via the WA-shore pool (Table 4). The small number of fish that exited from the Cascades Island pool precluded meaningful comparisons of passage times for those fish.

At the WA-shore transition pool, 108 chinook salmon were first recorded after entering NSE1, and 58 were first recorded in the pool after entering via NSE2,3 or the collection channel (Table 5). Of the 108 fish that entered via the downstream shoreline entrance, 63 (57%) exited to the tailrace and then reentered and passed via the WA-shore pool; 31 (65%) of the 58 fish that entered via the upstream shoreline entrances or the collection channel exited to the tailrace and then reentered and passed via the WA-shore pool. Median passage times from first transition pool entry to exit the pool into the ladder for all fish that exited the WA-shore pool to the tailrace and then reentered and passed there were less than 4.0 h. Fish that exited the WA-shore pool into the tailrace and then passed the dam via the spillway pools had median passage times from first pool entry to exit into a spillway ladder that ranged from 6.94 to 11.76 h. Fish that exited the WA-shore pool into the tailrace and then passed the dam via the A Branch pool had median passage times from 20.81 to 68.54 h. The latter time was for 12 chinook salmon that first entered the WA-shore pool via the NSE1 and then exited to the tailrace and passed via the A Branch pool (Table 5). In general, passage times of fish moving through transition pools increased as the distance between the location of first and last pool records increased.

Fishway entrances used by chinook salmon to exit a fishway after leaving a transition pool were similar to those used to subsequently reenter the fishway (Figure 35). Most exits

Table 5. Median passage times (h) from first fishway entry to first transition pool entry, from first pool to last pool, from last pool to ascend a ladder, and from first fishway entry to the top of a ladder for chinook salmon that exited a fishway between first and last records in a transition pool at Bonneville Dam.

			Median passage time (h) from:			
			First entry	First pool	Ascend	First entry
First pool	Last pool	N	To first pool	To last pool	Ladder	To exit ladder
A Branch	A Branch	39	0.37	7.16	2.59	14.73
	B Branch	18	0.23	17.82	2.54	21.16
	Cascade Is.	14	0.41	14.25	3.48	20.85
	WA-shore	22	0.26	27.84	2.71	36.10
B Branch	A Branch	8	0.01	23.16	6.45	36.14
	B Branch	37	0.01	1.87	2.18	10.86
	Cascade Is.	11	0.02	3.03	3.16	10.96
	WA-shore	19	0.02	20.60	2.67	23.21
Cascade Is.	A Branch	3	0.02	41.80	2.09	44.60
	B Branch	7	0.01	20.58	1.97	23.33
	Cascade Is.	12	0.01	1.27	4.27	9.99
	WA-shore	1	--	--	--	--
WA-shore	A Branch	20	0.03	26.61	2.64	29.36
	B Branch	24	0.03	8.56	2.34	15.12
	Cascade Is.	28	0.14	8.41	3.26	19.30
	WA-shore	94	0.03	3.93	3.01	10.53
*WA-shore^{L}	A Branch	12	0.02	68.54	2.78	76.01
	B Branch	17	0.02	7.55	2.29	15.63
	Cascade Is.	16	0.03	6.94	3.63	19.45
	WA-shore	63	0.02	3.24	3.11	10.32
*WA-shore^{M}	A Branch	8	0.31	20.81	2.48	23.69
	B Branch	7	0.24	11.76	2.83	14.60
	Cascade Is.	12	0.21	10.42	2.80	17.82
	WA-shore	31	0.34	4.00	2.83	13.20

* At the WA-shore transition pool, the ‘L’ designation was for the fish that entered the pool via the downstream shoreline entrance and the ‘M’ designation was for fish that entered via the upstream shoreline entrance or through the powerhouse collection channel.

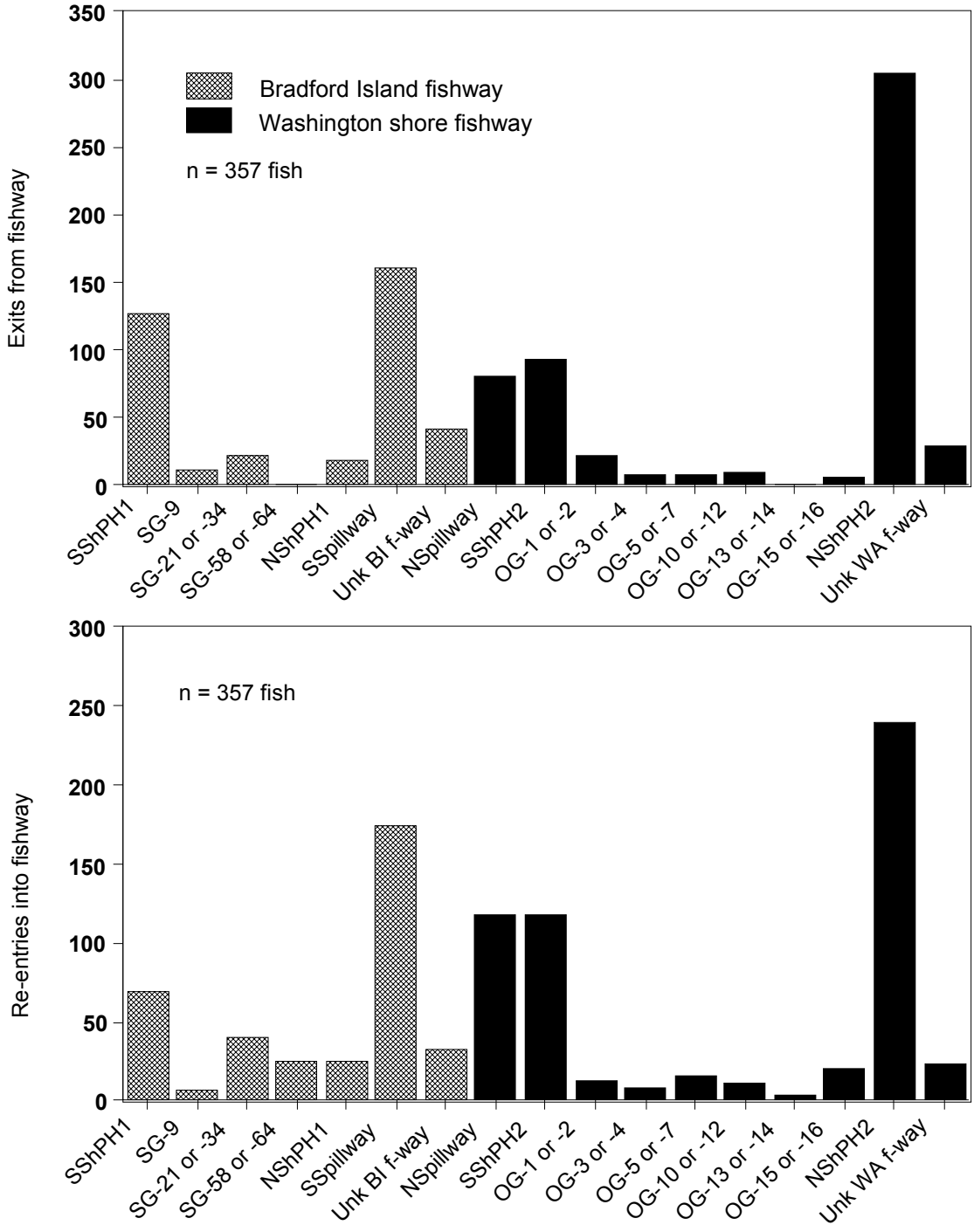


Figure 35. Entrances used to exit and reenter the fishways by chinook salmon that entered a transition pool, exited to the tailrace, and then reentered a pool and passed over Bonneville Dam in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

and reentries occurred at shoreline and spillway entrances and the highest number were from entrances at the Washington-shore and B Branch fishways. The 94 chinook salmon that first exited the WA-shore transition pool, exited to the tailrace, and ultimately passed the dam via the WA-shore ladder, made 67% of their 137 exits at the Washington-shore entrances and 12% from the south-shore entrances at Powerhouse 2 (Figure 36). The remaining exits were primarily from orifice-gate entrances. Seventy-four percent of reentries by the 94 fish were at north- and south-shore entrances at Powerhouse 2.

The 39 fish that first entered the A Branch transition pool, exited to the tailrace and ultimately passed the dam via the A Branch ladder, made 41% of their 94 exits at the south-shore entrance (Figure 36). Approximately 47% of the exits were from other entrances to the Bradford Island fishway and 13% were distributed among entrances to the Washington-shore fishway. Reentries were distributed more evenly between fishway entrances, but approximately 87% were at entrances to the Bradford Island fishway. The highest numbers of reentries were at the south-shore entrance and at unknown entrances to the Bradford Island fishway (Figure 36).

Sixty-seven chinook salmon exited from a spillway transition pool to the tailrace and then reentered and passed Bonneville Dam via either the Cascades Island or B Branch pool and ladder. The 67 fish made 82% of their exits and 84% of their reentries at entrances to the ladders adjacent to the spillway (Figure 37).

The remaining 157 fish that exited transition pools into the tailrace eventually passed Bonneville Dam via a different transition pool than they first entered. These chinook salmon exited and reentered the fishways mostly at shoreline and spillway entrances (Figure 37).

***Transition Pool Movements by Fish that Fell Back*:** In 1996, 89 chinook salmon with transmitters passed Bonneville Dam, fell back over the dam, and were recorded in transition pools while passing the dam a second time. Of the 89 fish, 47 (53%) re-passed Bonneville Dam via the Bradford Island fishway and 42 (47%) re-passed via the Washington-shore fishway. After they fell back, about 60% of the chinook salmon first approached the dam at entrances to the Bradford Island fishway (Figure 38). Another 22% first approached at shoreline entrances to the Washington-shore fishway. After they fell back, most chinook salmon first entered fishways at Washington-shore entrances, at spillway entrances, or at south-shore entrances at Powerhouse 1 (Figure 38).

Median passage times from first fishway entry to first transition pool entry, first pool entry to enter a ladder, to ascend a ladder, and from first fishway entry to exit from the top of a ladder were shorter for the second passage of the 89 fish that fell back than for the sample of 679 fish on their first passage (Figure 39). Eighty-one fish had complete transition pool records on their first and second passage of the dam, and median times for these fish were also shorter on the second passage than on their first (Figure 39). Differences in median

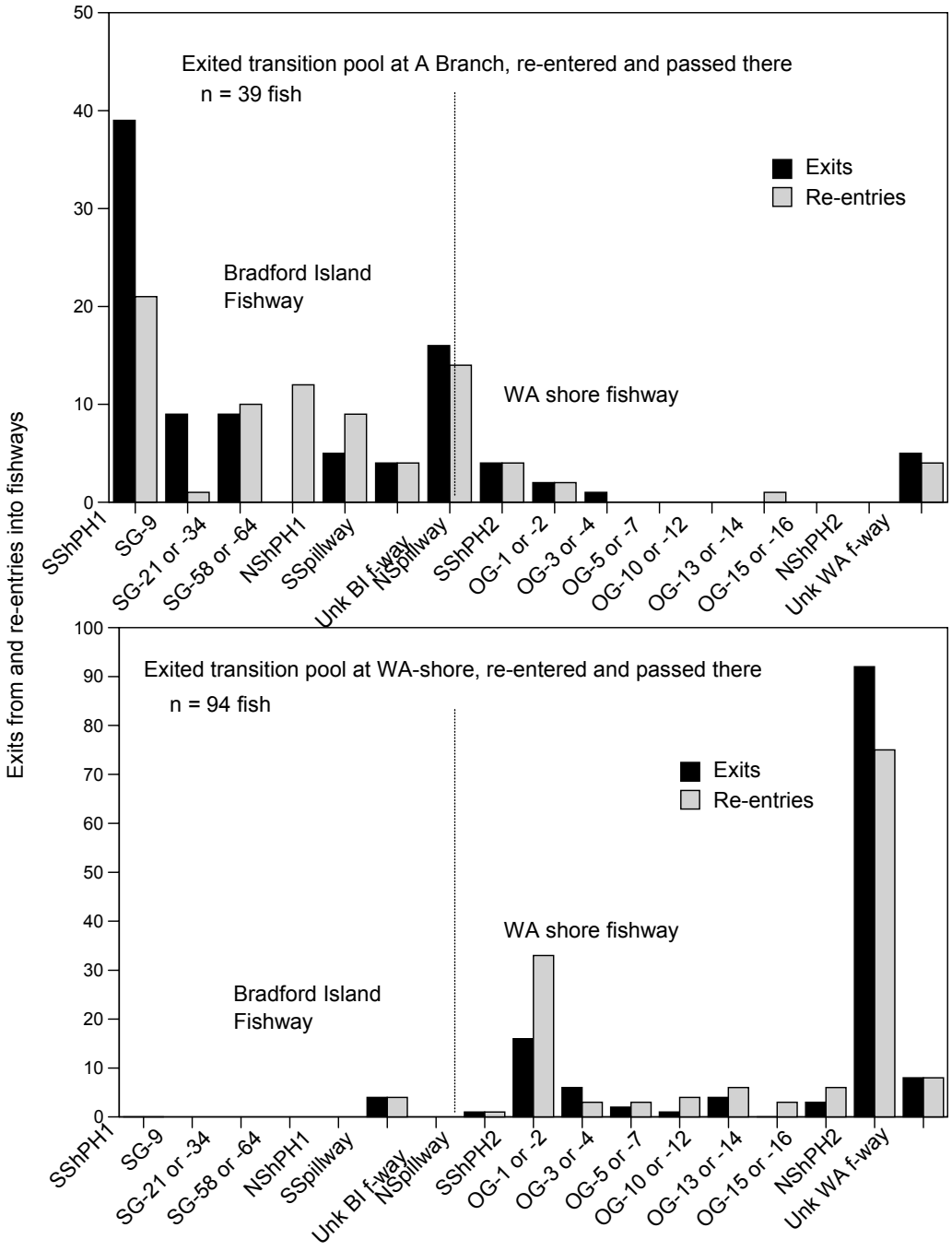


Figure 36. Entrances used to exit and reenter the fishways by chinook salmon that entered the A Branch or WA-shore transition pool, exited to the tailrace, and then reentered the same pool and passed over Bonneville Dam in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

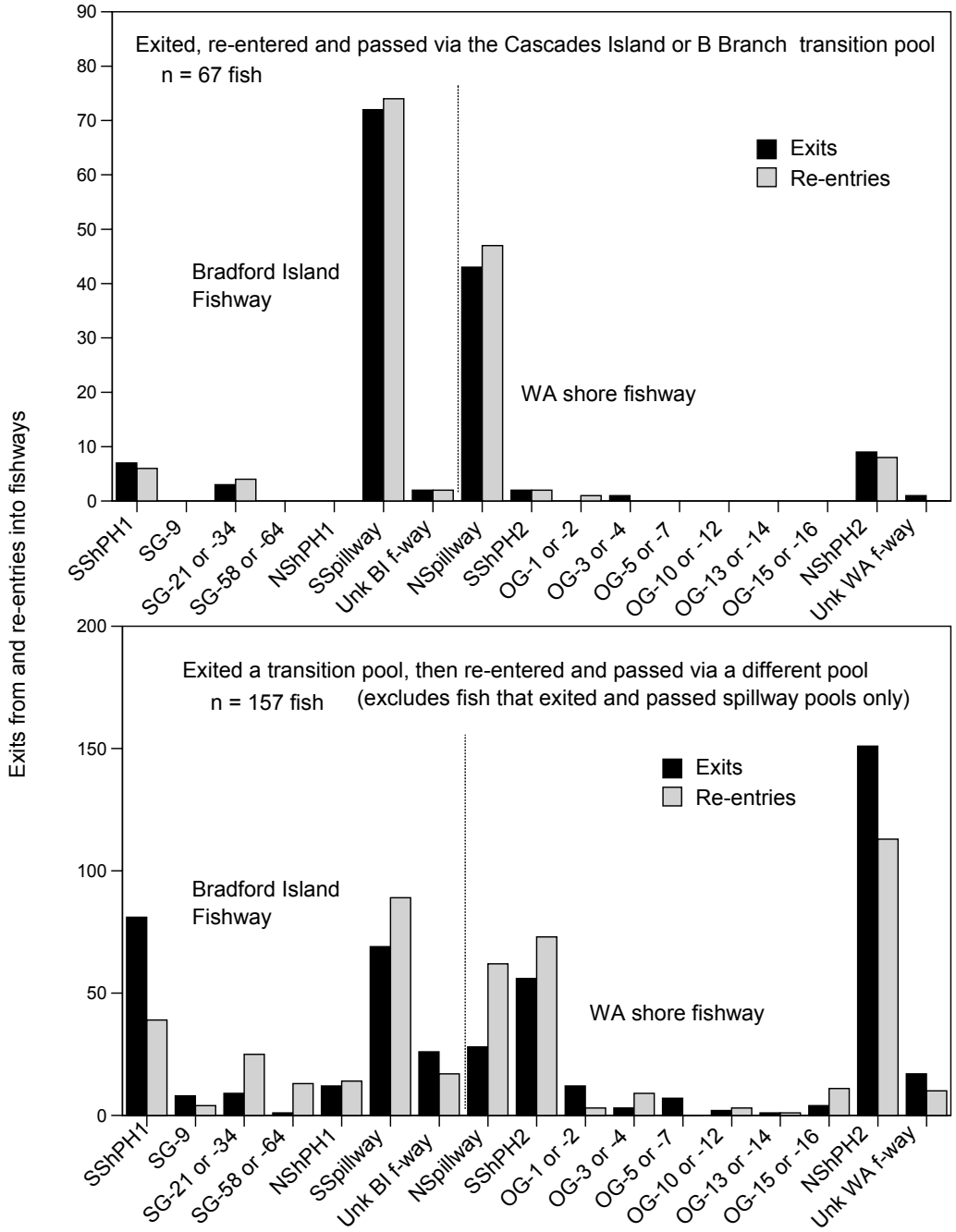


Figure 37. Entrances used to exit and reenter the fishways by chinook salmon that exited a spillway transition pool, exited to the tailrace, and then reentered a spillway pool and passed over Bonneville Dam and fish that exited a transition pool into the tailrace and passed the dam via a different pool in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

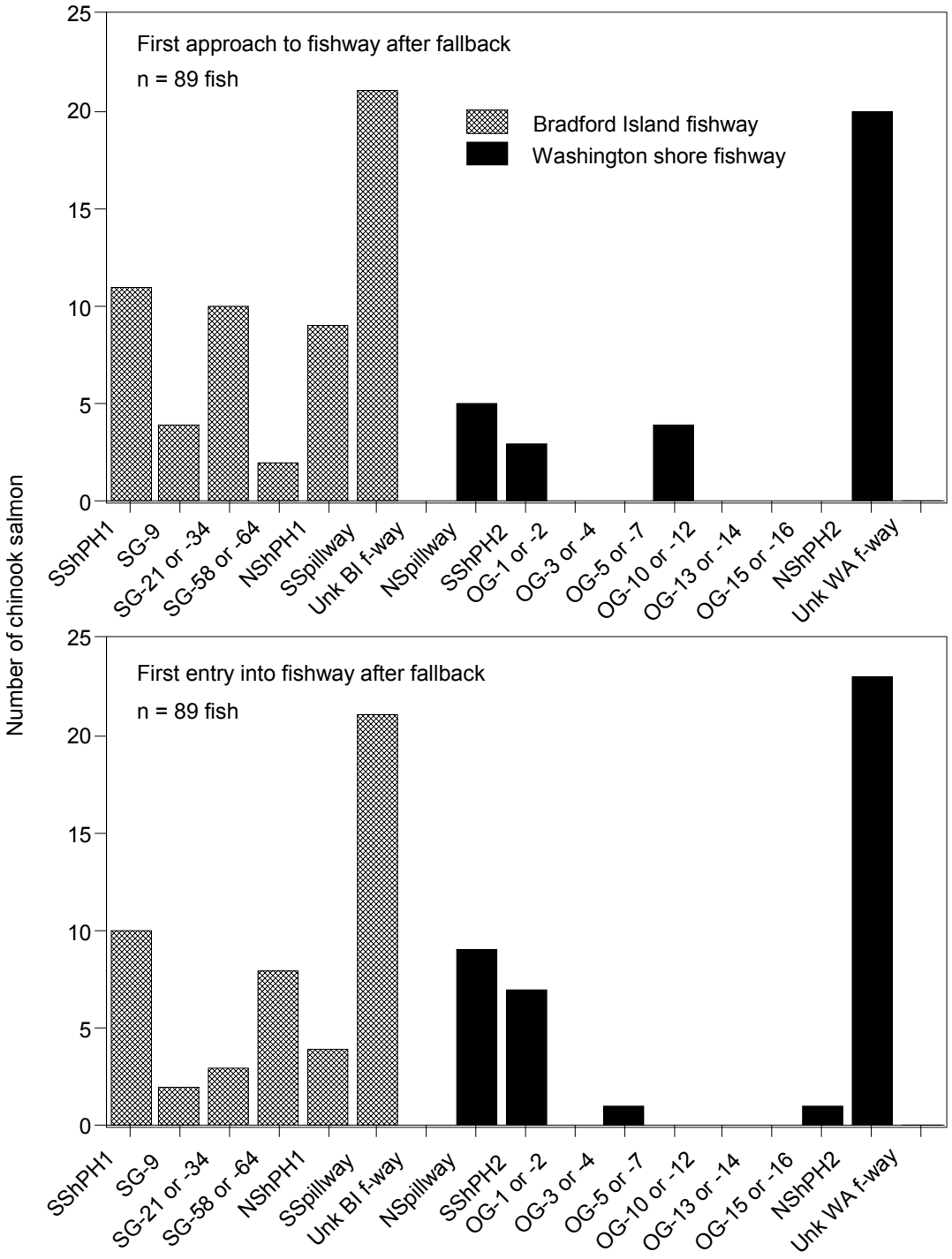


Figure 38. Locations of first approaches and first entries into the fishways on their second passage by chinook salmon that fell back over Bonneville Dam in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

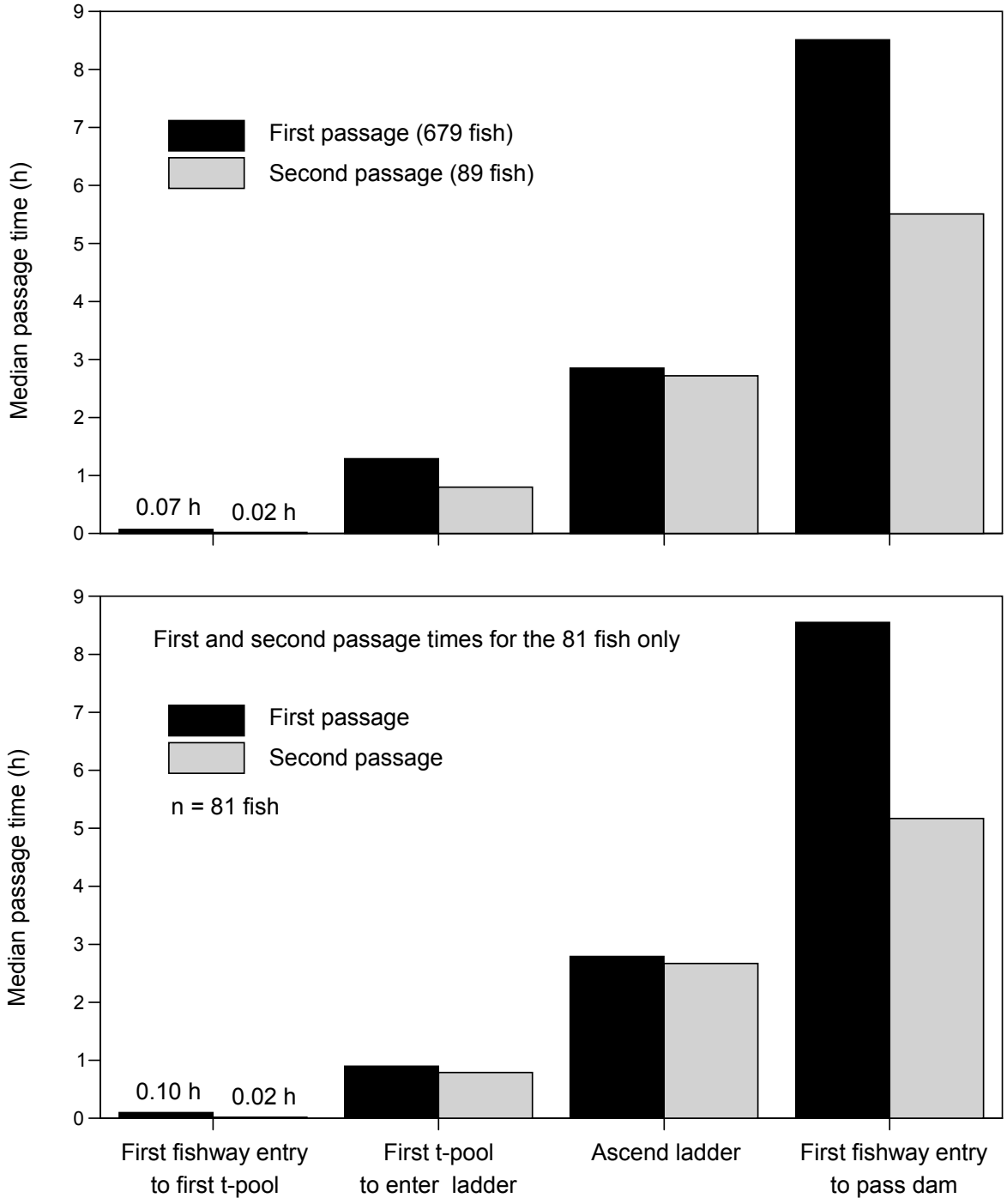


Figure 39. Median passage times from first fishway entry to first transition pool entry, first pool entry to enter a ladder, to ascend a ladder, and first fishway entry to exit from the top of a ladder for fish that fell back over Bonneville Dam in 1996 and reascended.

passage times between first and second passage of the dam were greatest from first fishway entry to exit from the top of a ladder; the 81 fish that fell back passed in 8.55 h (median) on the first passage and 5.17 h on the second. By comparison, median first passage for the 679 chinook salmon was 8.51 h from first fishway entry to exit from the top of a ladder.

The 81 chinook salmon with complete transition pool records before and after they fell back over Bonneville Dam made similar types of movements in transition pools on each passage of the dam. However, more fish moved through a pool on the first attempt on their second passage (55%) than on their first (29%), fewer fish exited a pool into a collection channel on the second passage (9%) than on the first (28%), and fewer fish exited into the tailrace on the second passage (36%) than on the first (43%) (Figure 40).

Median time of second passage from the first fishway entry to first transition pool entry for the 89 fish that fell back and then reascended was less than 2 min (0.02 h) (Table 6). Of the 89 fish, 9 (10%) exited a pool into a collection channel and passed from first fishway entry to first pool entry in a median time of 28 min (0.46 h). Median time from first pool entry to exit a pool into a ladder was 48 min (0.80 h) for all 89 fish and ranged from 10 m (0.17 h) for fish that moved through a pool with no downstream movement to 18.64 h for fish that exited a pool into the tailrace (Table 6). On their second passage, median time for chinook salmon to ascend ladders ranged from 2.21 to 2.83 h. Median times from first fishway entry to exit from the top of a ladder were 2.81 h for fish that moved straight through a pool, 3.67 h for fish that moved downstream in a pool but did not exit before passing into a ladder, 4.80 h for fish that exited a pool into a collection channel, and 22.94 h for fish that exited a pool into the tailrace (Table 6).

Distributions of second passage times through transition pools for 89 chinook salmon that fell back and reascended the ladders at Bonneville Dam in 1996 were all skewed to the right, and many fish took more than 24 h to pass through pools and over the dam. Although median passage time from first pool entry to exit a pool into a ladder was 48 min (0.80 h), 15 fish took more than 24 h to pass through a pool. Median time from first fishway entry to pass over the dam was 5.51 h, but 20 (22%) chinook salmon took more than 24 h to pass the dam the second time.

After they fell back, 23 (26%) chinook salmon reentered a fishway and transition pool and passed straight through a transition pool into a ladder. Median passage times for these fish were 1 min (0.02 h) from first fishway entry to first entry in a transition pool, 10 min (0.17 h) from first entry in a transition pool to exit a pool into a ladder, 2.36 h to ascend a ladder, and 2.81 h from first fishway entry to exit from the top of a ladder (Table 6). Another 24 (27%) moved downstream in a transition pool but did not exit before entering a ladder. Median times for those fish from first entry to first pool and to ascend a ladder were similar to those for fish that moved straight through a pool; the 24 fish took a median of 34 min (0.56 h) from first pool to exit a pool into a ladder and 3.67 h from first fishway entry to exit from the top of a ladder (Table 6).

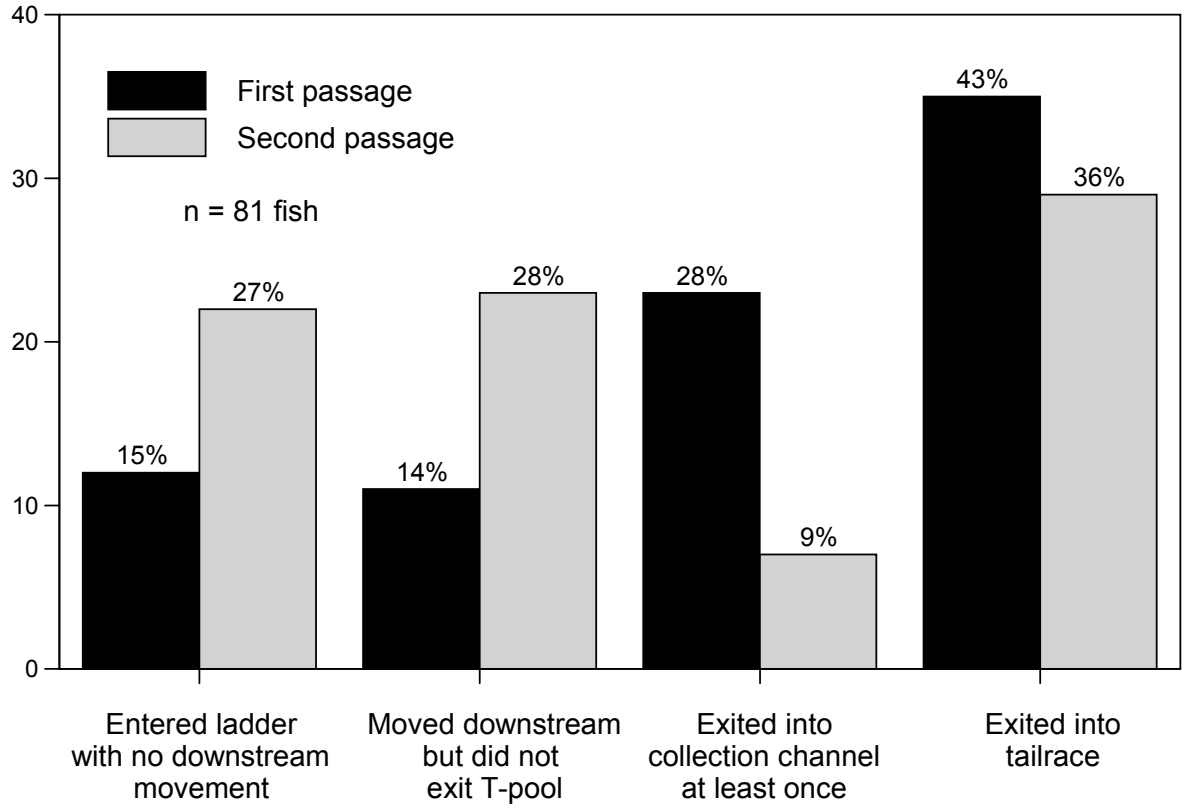


Figure 40. Percentage of chinook salmon that passed straight through a Bonneville transition pool into a ladder, moved downstream in a pool before entering the ladder, exited a pool into a collection channel, or exited a pool into the tailrace on their first and second passage of the dam in 1996.

Nine chinook salmon (11%) fell back, reentered a fishway and transition pool, and then exited to a collection channel. The 9 fish had median times that were longer for each migration segment than those for fish that moved through a pool on the first attempt (Table 6). The remaining 33 (37%) fish exited a transition pool into the tailrace. Median times for those fish were 18.64 h from first pool entry to exit a pool into a ladder, 2.83 h to ascend a ladder, and 22.94 h from first fishway entry to exit from the top of a ladder (Table 6). Seven (21%) of the 33 fish passed the dam in less than 6 h on the second passage, and 16 (48%) took more than 24 h to pass the dam.

Overall, the 89 fish that fell back and reascended passed the dam more quickly on their second passage (median = 5.51 h) than all 679 fish on their first passage (median = 8.51 h). The shorter second passage was likely because on the second passage 53% passed through transition pools on their first attempt, compared to 36% for the 679 fish on their first passage (see Table 3) and 53% of the fish exited transition pools to the tailrace on their first passage, compared to 37% on the second passage.

Table 6. Median and mean passage times for chinook salmon that moved through a transition pool at Bonneville Dam with no downstream movement, moved downstream in a transition pool but did not exit before passing into a ladder, exited a transition pool into a collection channel but not into the tailrace, or exited into the tailrace in 1996.

		Median passage time (h) from:			
		First entry	First pool	Ascend	First entry
Transition pool behavior	N	To first pool	To last pool	Ladder	To exit ladder
All behaviors	89	0.02	0.80	2.72	5.51
Moved straight through	23	0.02	0.17	2.36	2.81
Moved downstream, but didn't exit	24	0.02	0.56	2.21	3.67
Exited pool to collection channel	9	0.46	1.07	2.46	4.80
Exited pool to tailrace	33	0.02	18.64	2.83	22.94
		Mean passage time (h):			
All behaviors	89	2.06	12.18	4.82	19.06
Moved straight through	23	0.07	0.25	4.84	5.16
Moved downstream, but didn't exit	24	0.75	6.88	8.43	16.05
Exited pool to collection channel	9	13.86	1.03	2.74	17.63
Exited pool to tailrace	33	1.42	29.47	5.30	36.18

After they fell back, reentered a fishway and transition pool, and then exited into the tailrace, chinook salmon used similar fishway entrances to exit and subsequently reenter the fishways. The 33 fish that exited a transition pool into the tailrace made 70 exits and reentries before passing Bonneville Dam; 29% of the exits were from entrances to the Bradford Island fishway, and 71% were from entrances to the Washington-shore fishway and were primarily at north-shore entrances (Figure 41). Reentries were distributed among more fishway entrances than entries made during the first passage. Approximately 69% of the reentries were at entrances to the Washington-shore fishway and 19% were at entrances to the B Branch pool (Figure 41).

Results – McNary Dam

Passage times

Fishway entrance use and movements within the fishway at McNary Dam (Figure 42) in 1996 were monitored by recording movements of 307 chinook salmon outfitted with transmitters. Median passage time of chinook salmon from release downstream from Bonneville Dam to the McNary tailrace was 11.1 d and was 12.9 d from release to passage over the dam (Figure 43). Median passage times of chinook salmon from the

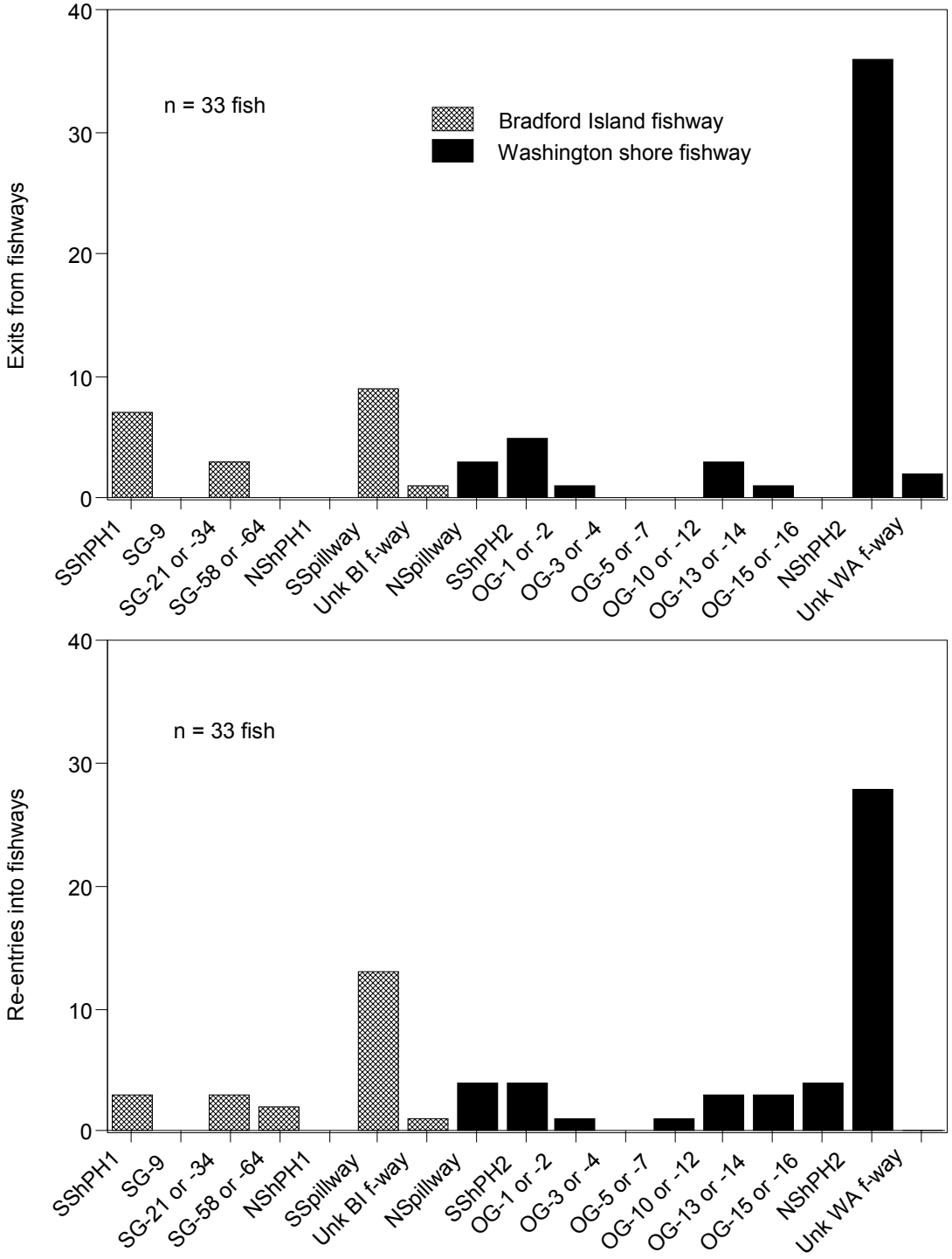


Figure 41. Entrances used to exit and reenter the fishway by chinook salmon in 1996 that exited a transition pool to the tailrace on their second passage of Bonneville Dam.

tailrace receiver (about 2 km downstream from McNary Dam)to first recorded approach at an entrance, first entry into the fishway, and passage from the top of a ladder were 2.49 h, 9.70 h, and 1.06 d (Figure 44). Median time from first approach at a fishway to first entry into the fishway at McNary Dam was 3.02 h, and median time from first entry into a fishway to exit from the top of a ladder was 5.55 h (Figure 45). Most fish entered the fishway within 24 h after passing the tailrace receiver, but several took more than 10 d to pass the dam because they spent a day or more in the fishway or spent time exiting and reentering the fishway. Some fish were in the fishway at nightfall and usually stayed there until morning, and some migrated up and down the powerhouse collection channel during daylight (Figure 46). Passage times of chinook salmon between the tailrace and passage from the top of the ladder also included time spent making multiple entries into the ladder.

Fishway Use

Approaches to fishways: Chinook salmon had a tendency to first approach McNary Dam at orifice gate 14 and the north-shore entrance, although many first approached at orifice gates 3 and 26, and at least one fish first approached at each entrance (Figure 47). When all approaches at fishway entrances made by chinook salmon in 1996 were considered, approaches were most frequent at orifice gates 14, 3, 26, and 21. Shoreline and north-powerhouse entrances were approached less frequently than most orifice gates (Figure 47). The large number of approaches to entrances (averaged 25.1 per fish; 7,522 total) is an indication that chinook salmon wandered in the tailrace and moved back and forth along the dam before making their final entry to the fishway. Of 307 chinook salmon monitored at McNary Dam, 7 (2.3%) did not have a recorded approach at the dam, 21 (7%) approached the dam only once, 127 (42%) approached the dam 1 to 10 times, 159 (52%) approached 11 to 99 times and 11 (4%) approached various entrances from 100 to 331 times (Figure 48). The time between first approach and first entry into the fishway was about 7 h (based on median passage times; Figure 44).

Entries to and exits from fishways: The majority of first and subsequent entries into the fishway occurred at the north-shore entrance and south-shore entrance 2 (Figure 49). North-powerhouse entrances and the south-shore entrance 1 were used less frequently and, although fish approached orifice-gate entrances, few entered the fishway through these openings. Orifice-gate entrances at McNary Dam are 0.61 m high and 1.83 m wide, with the center of the opening 1.22 m below the surface and have a designed flow capacity of 60-80 cfs each. Powerhouse and shoreline entrances were 4.58 m wide and 2.44 to 2.74 m deep with a discharge of approximately 800 cfs.

Of the 307 chinook salmon monitored at McNary Dam, 10 did not enter the fishway. Of the chinook salmon that entered, 135 (45%) entered the fishway at McNary Dam only once and the rest exited and reentered 1 to 21 times (Figure 50). Chinook salmon entered the McNary fishway 2.3 times on average (median of 2 entries).

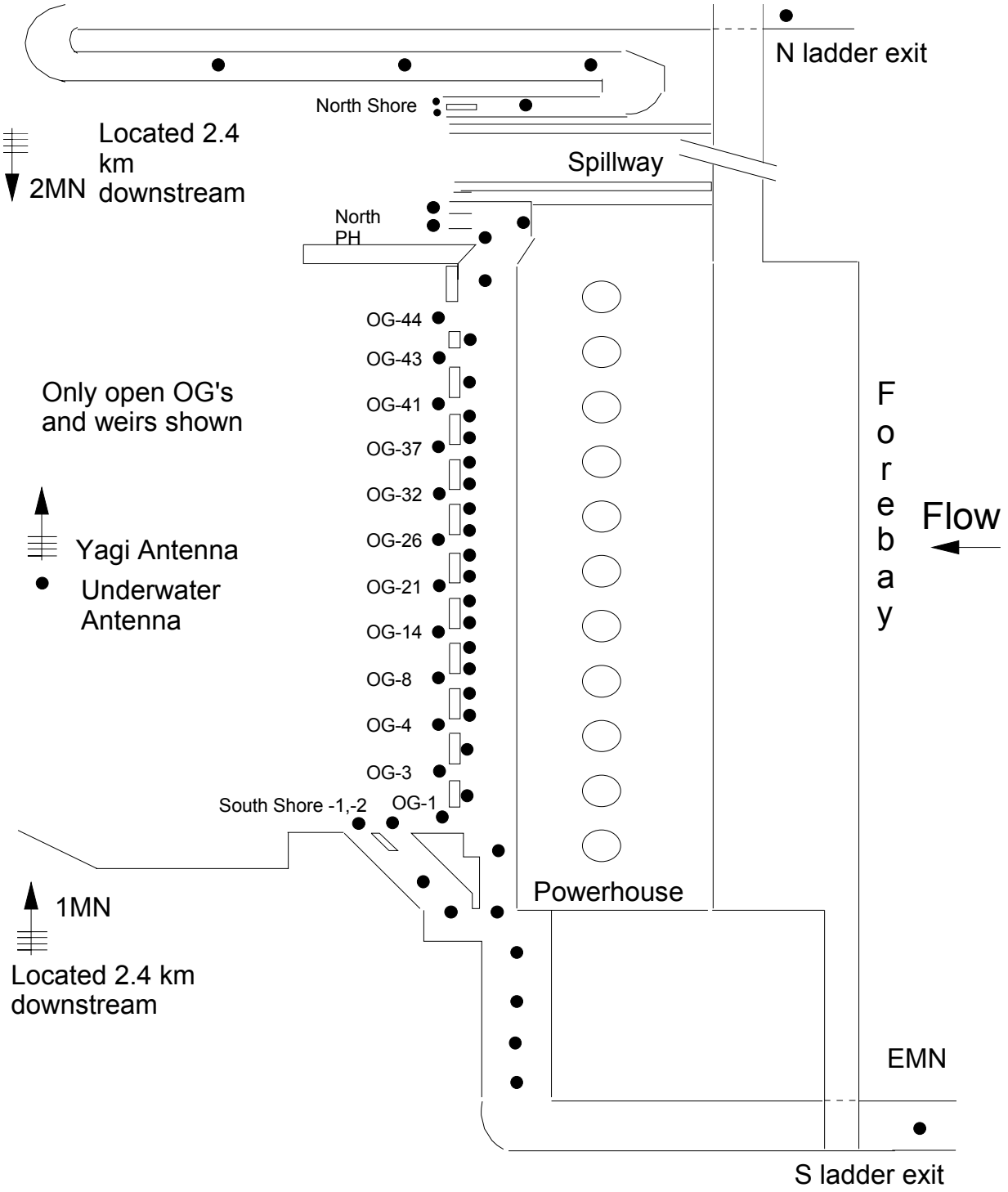


Figure 42. Location of antennas and fishway entrances at McNary Dam in 1996 when chinook salmon were passing the dam.

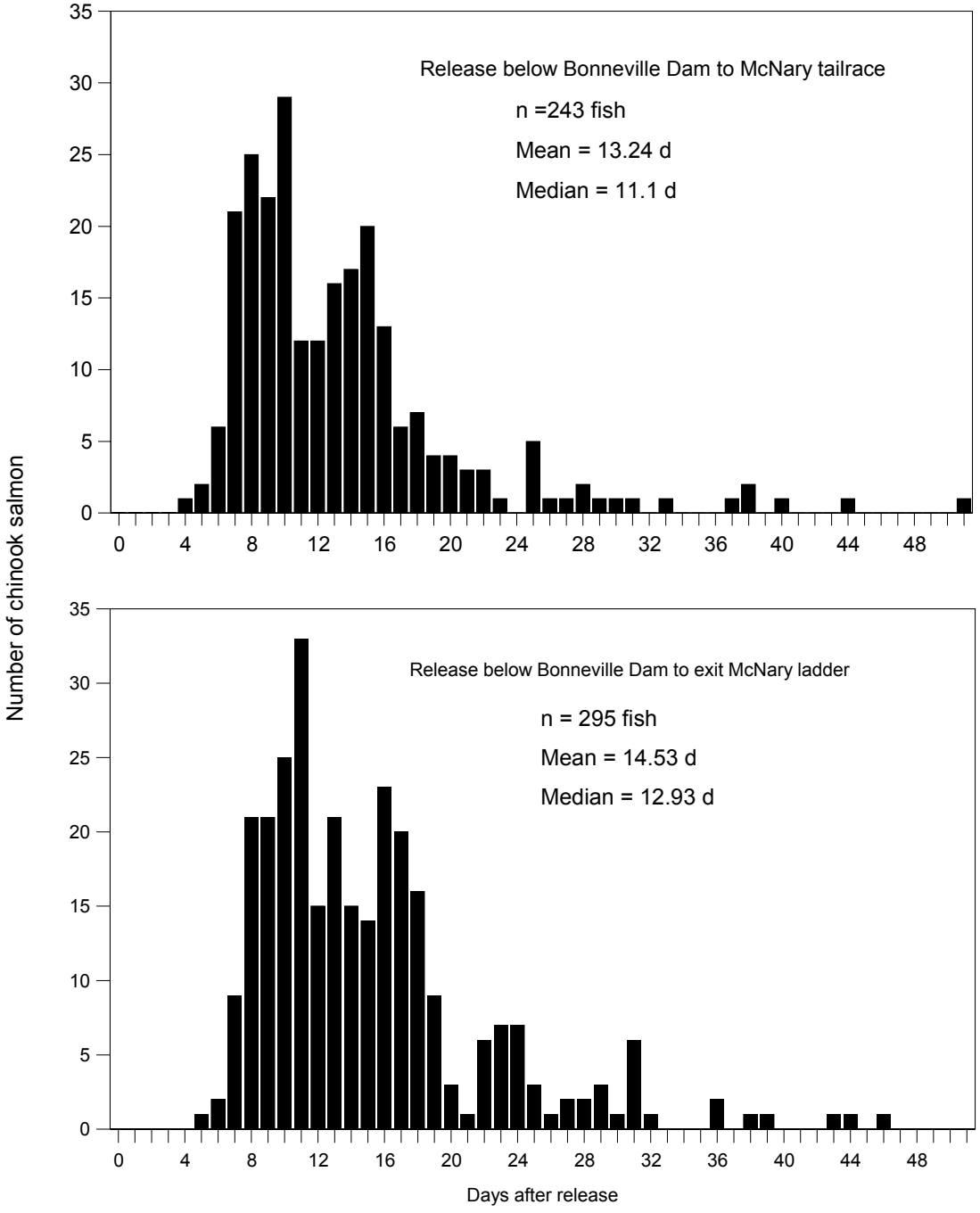


Figure 43. Number of chinook salmon and days to migrate from the release site below Bonneville Dam to the tailrace and to exit from the top of the ladder at McNary Dam in 1996.

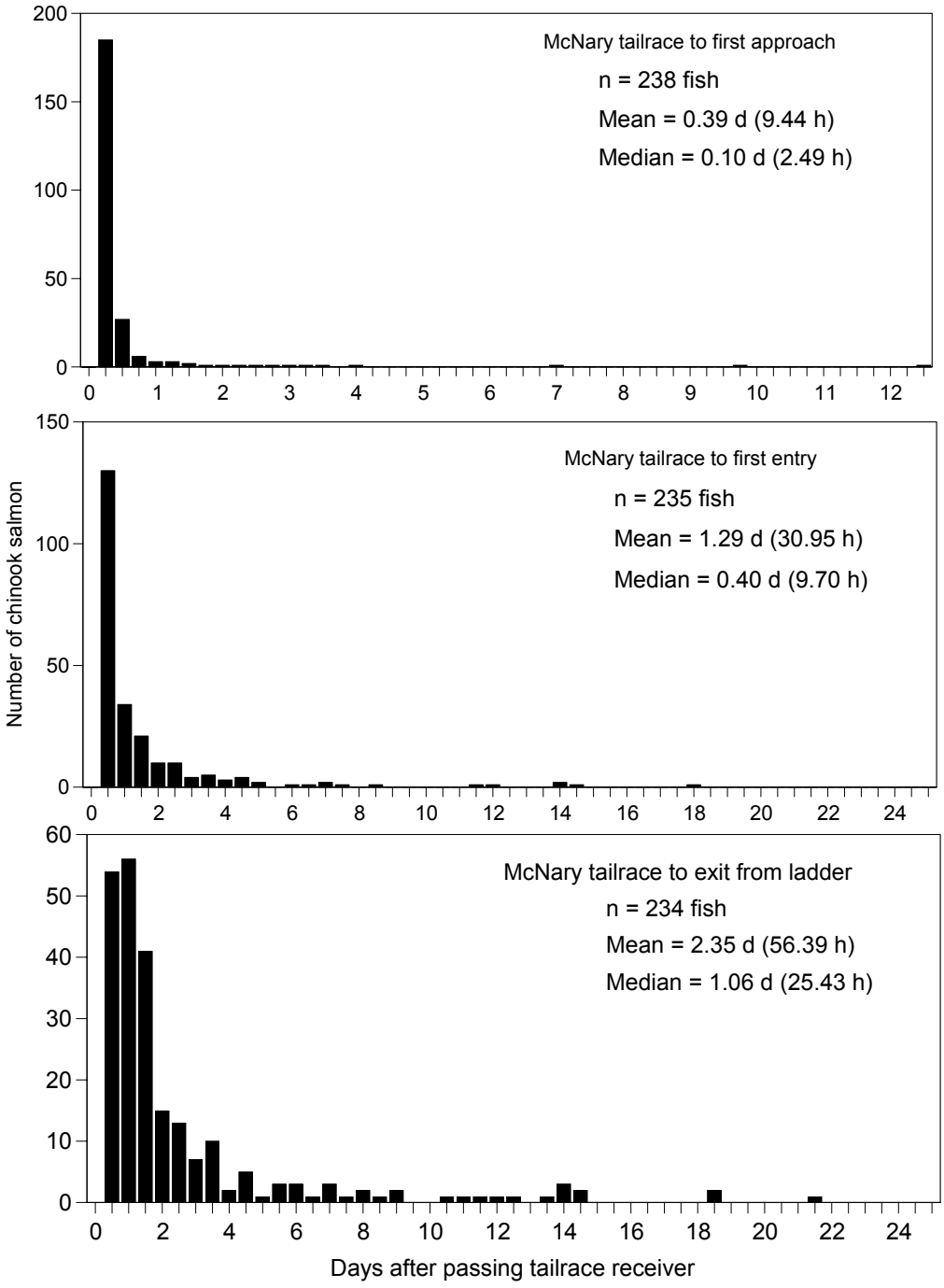


Figure 44. Number of chinook salmon and time to pass from the McNary tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladders in 1996.

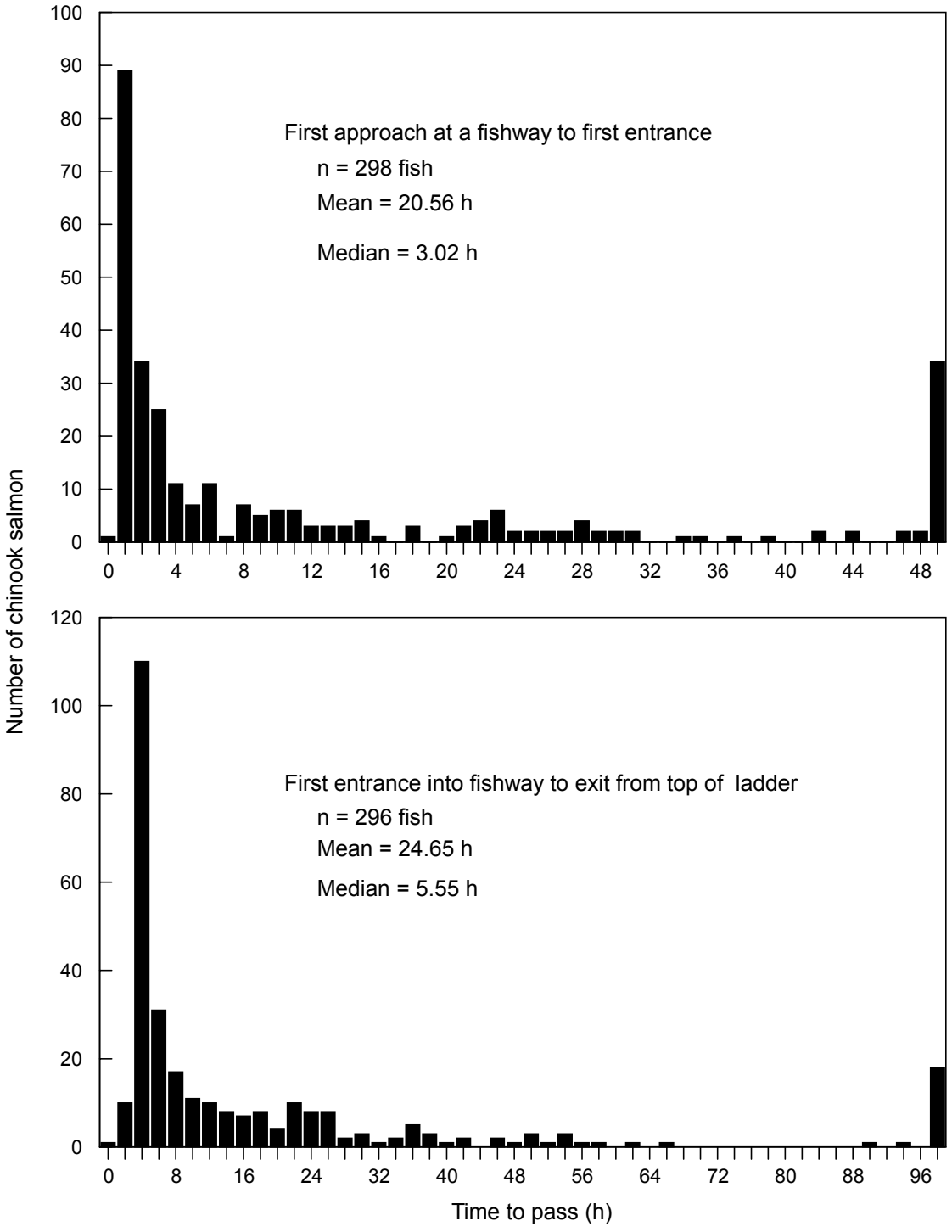


Figure 45. Number of chinook salmon and time to pass from first approach at a fishway entrance to first entry into a fishway to exit from the top of the ladder at McNary Dam in 1996.

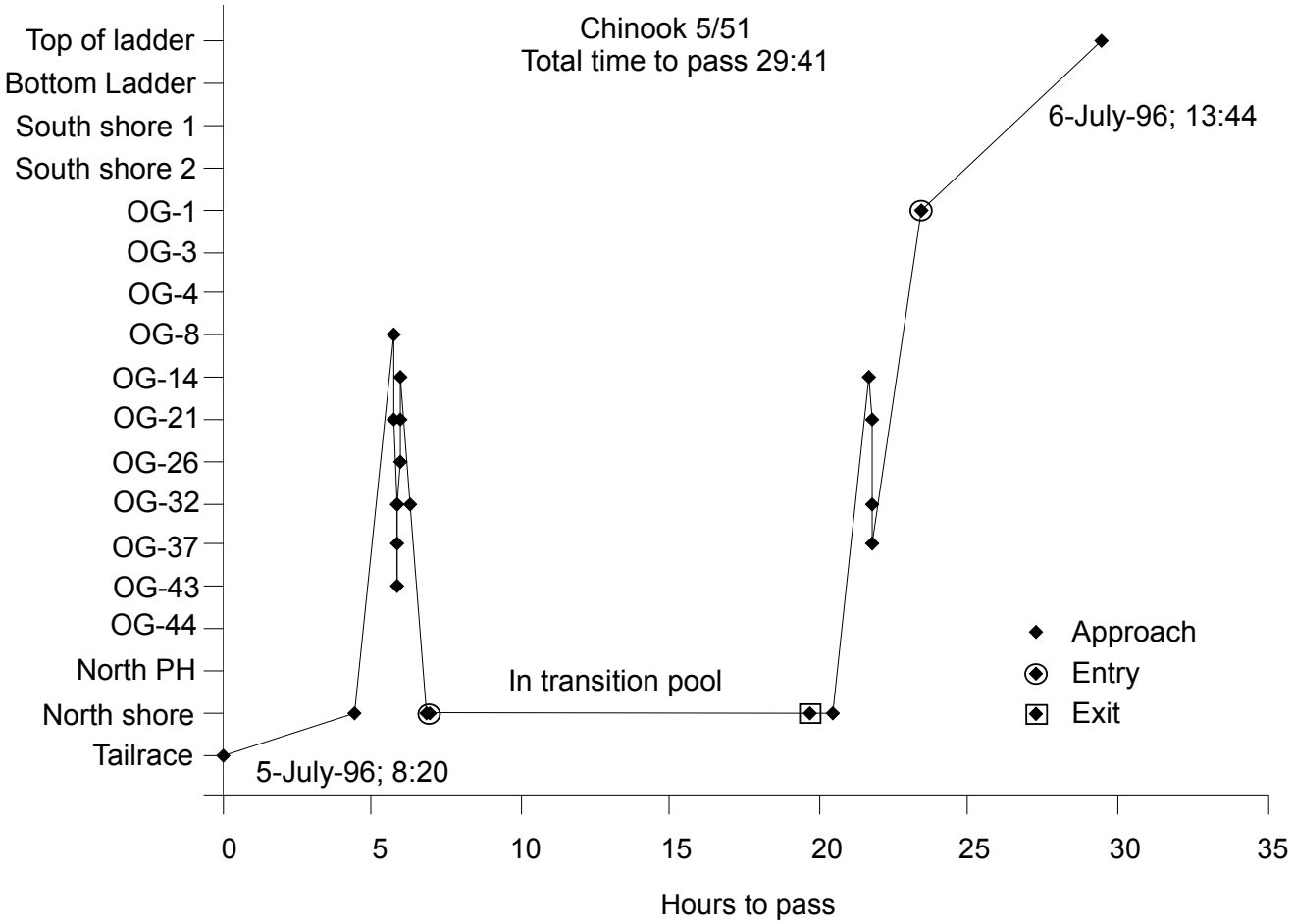


Figure 46. Illustration of the types of movements made by some chinook salmon in 1996 when approaching McNary Dam, entering and exiting the fishway, and passing through the fishway.

Chinook salmon exited the fishway via many entrances, but most did so at the north-shore and north-powerhouse entrances and entrance 2 at the south shore (Figure 51). Few fish exited at orifice gates. Of the 297 chinook salmon that entered a McNary fishway in 1996, 136 (46%) did not exit the fishway, 159 (54%) exited from 1 to 10 times, and 2 (0.7%) exited more than 10 times (Figure 50). Chinook salmon exited the McNary fishway 1.3 times on average (median of 1 exit). Many fish moved up the collection channel to the transition pool located at the bottom of the ladder and then returned down the channel and exited the fishway one or more times (Table 2). The median time from the first entry to and first exit from fishways at McNary Dam was 0.22 h.

Net entry rates (known entries minus exits) for fishway entrances ranged from -11 to 62 for first entries and exits, and -56 to 135 for all entries and exits (Figure 52). The north-shore entrance was the most effective (more entries than exits) followed by south-shore

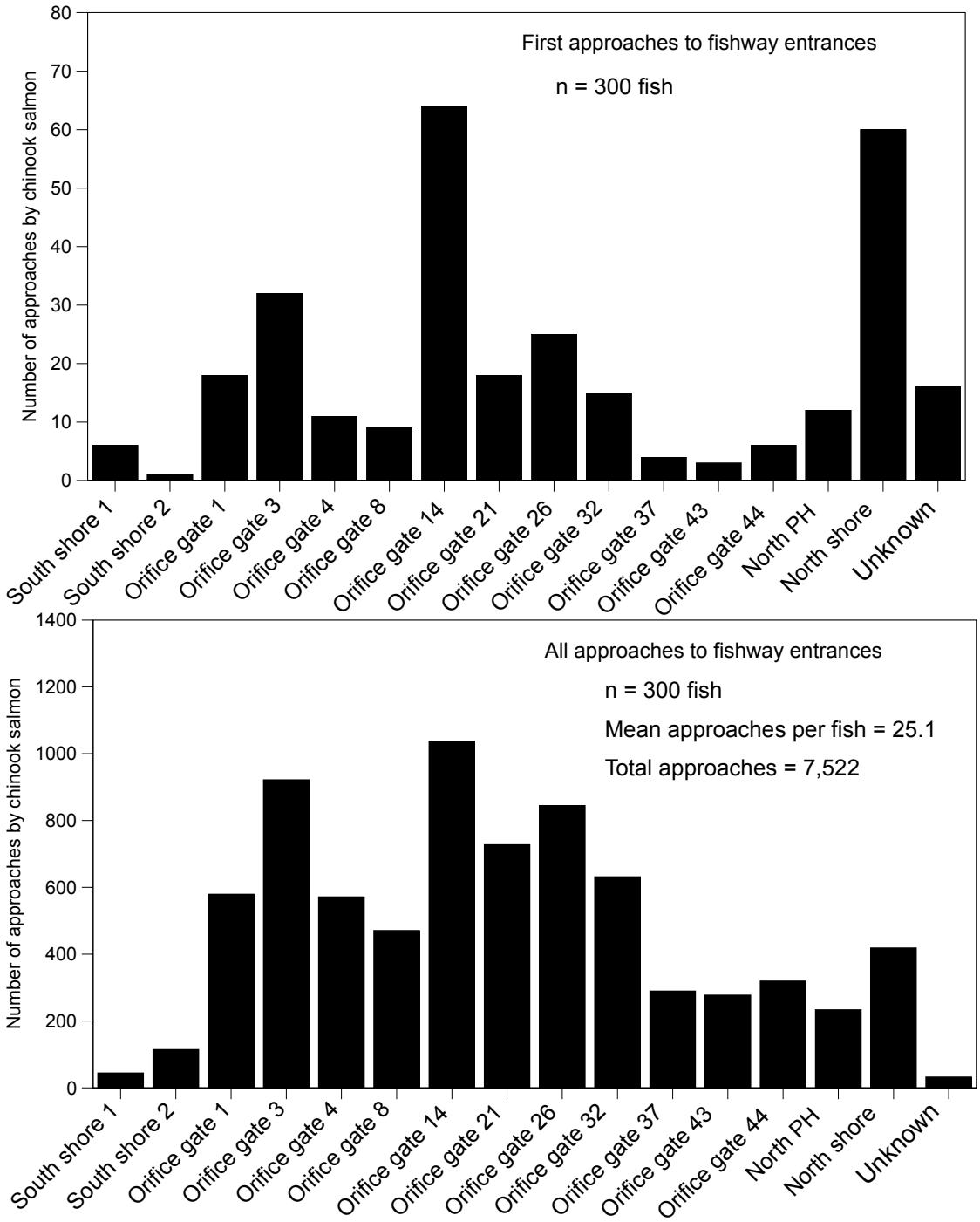


Figure 47. Number of first and total approaches at McNary Dam fishway entrances by chinook salmon in 1996.

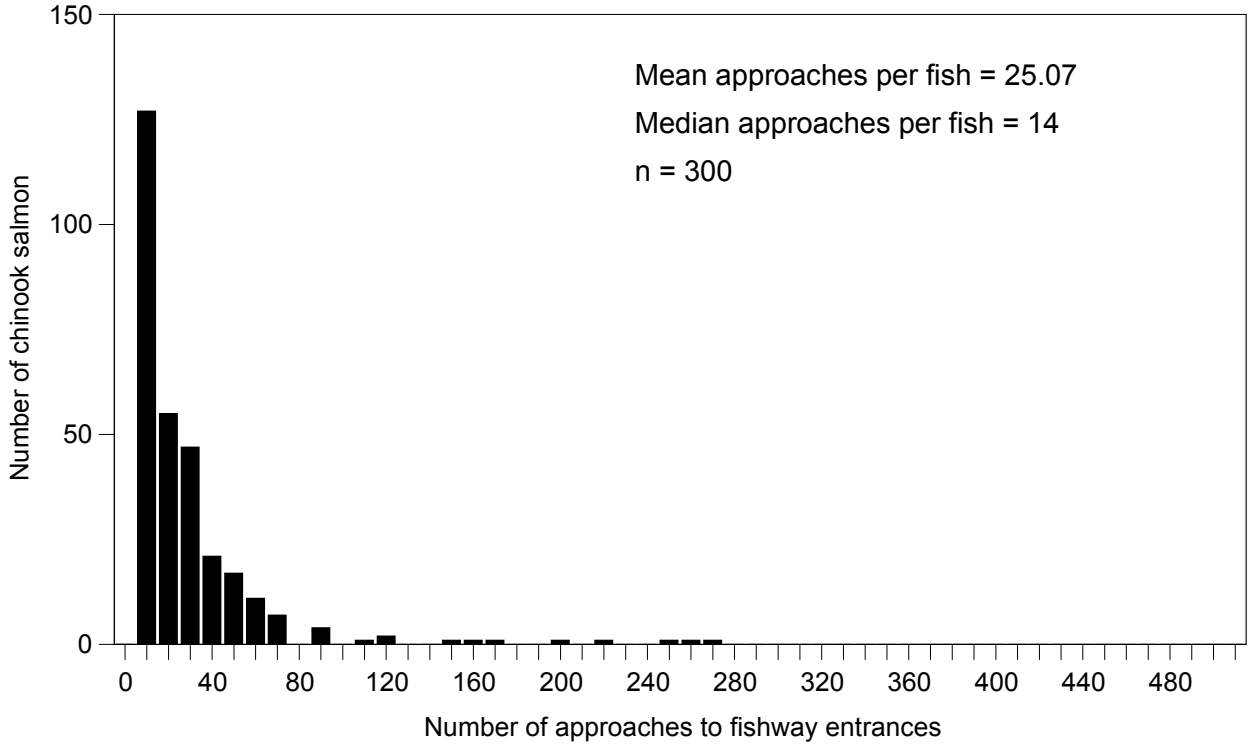


Figure 48. Number of chinook salmon that approached McNary Dam fishway entrances one or more times in 1996.

entrance 2. There were more first and total exits than entries by chinook salmon at the north-powerhouse entrance.

The furthest upstream fish reached before making their first exits at McNary Dam were spread between the powerhouse collection channel (20.5% of 161 fish), south-shore entrance and transition pool (39.1%), and north-shore entrance and transition pool (39.7%). Only 2 fish (~1%) exited to the tailrace after reaching the top-of-ladder receivers (Table 2).

Nine salmon did not pass after reaching McNary Dam. One fish was caught in a fishery, 4 fish entered a tributary or downstream hatchery and the remaining 4 fish were not accounted for. Five of the nine fish were only recorded at tailrace receiver sites, 2 fish approached a fishway entrance and the remaining two fish entered a fishway but were not recorded in a transition pool.

Movements Through Transition Pools

We analyzed behavior of 294 chinook salmon as they moved through transition pools at McNary Dam in 1996. Forty-three percent (128) of the chinook salmon outfitted with

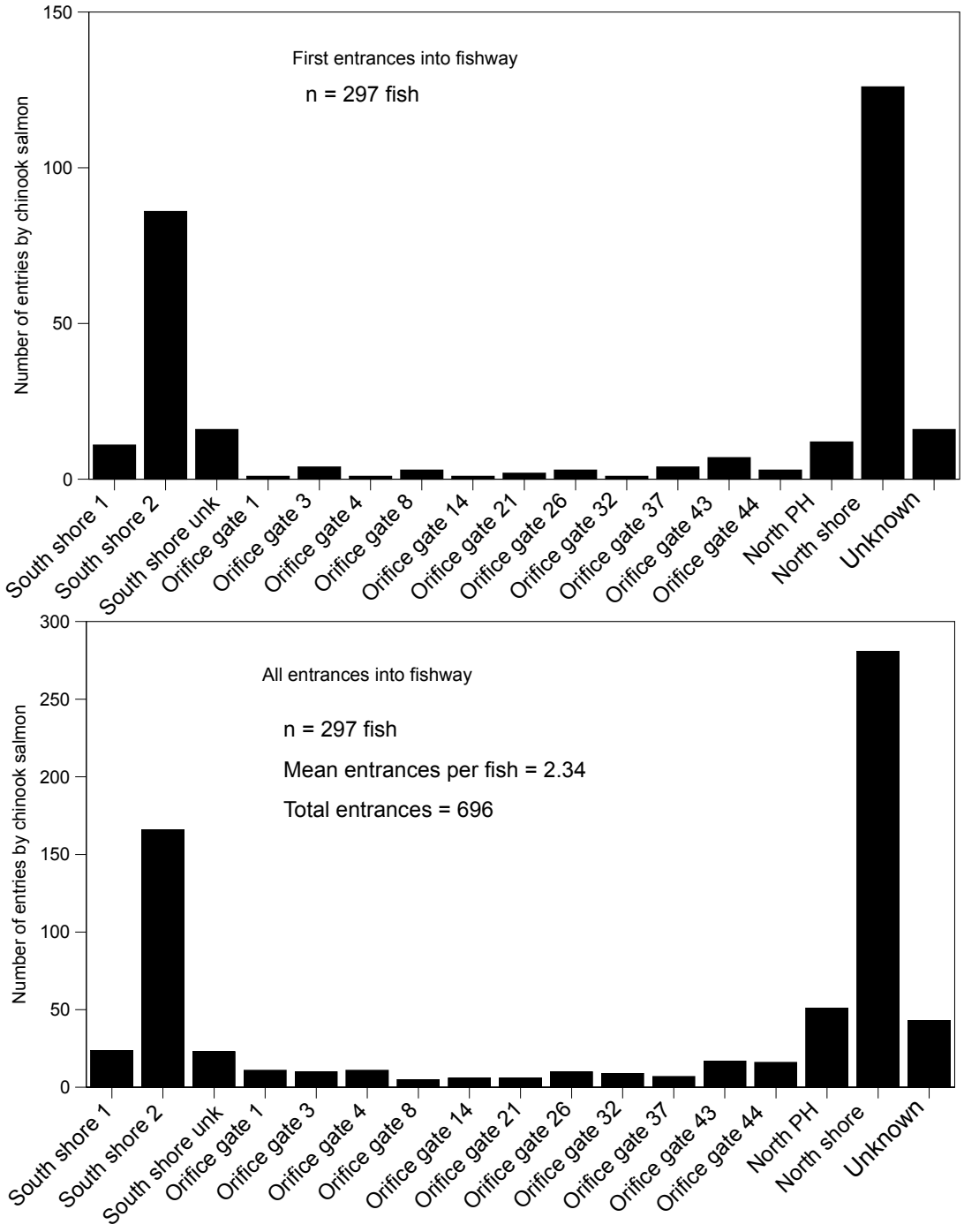


Figure 49. Number of first and total entries at McNary fishway entrances by chinook salmon in 1996.

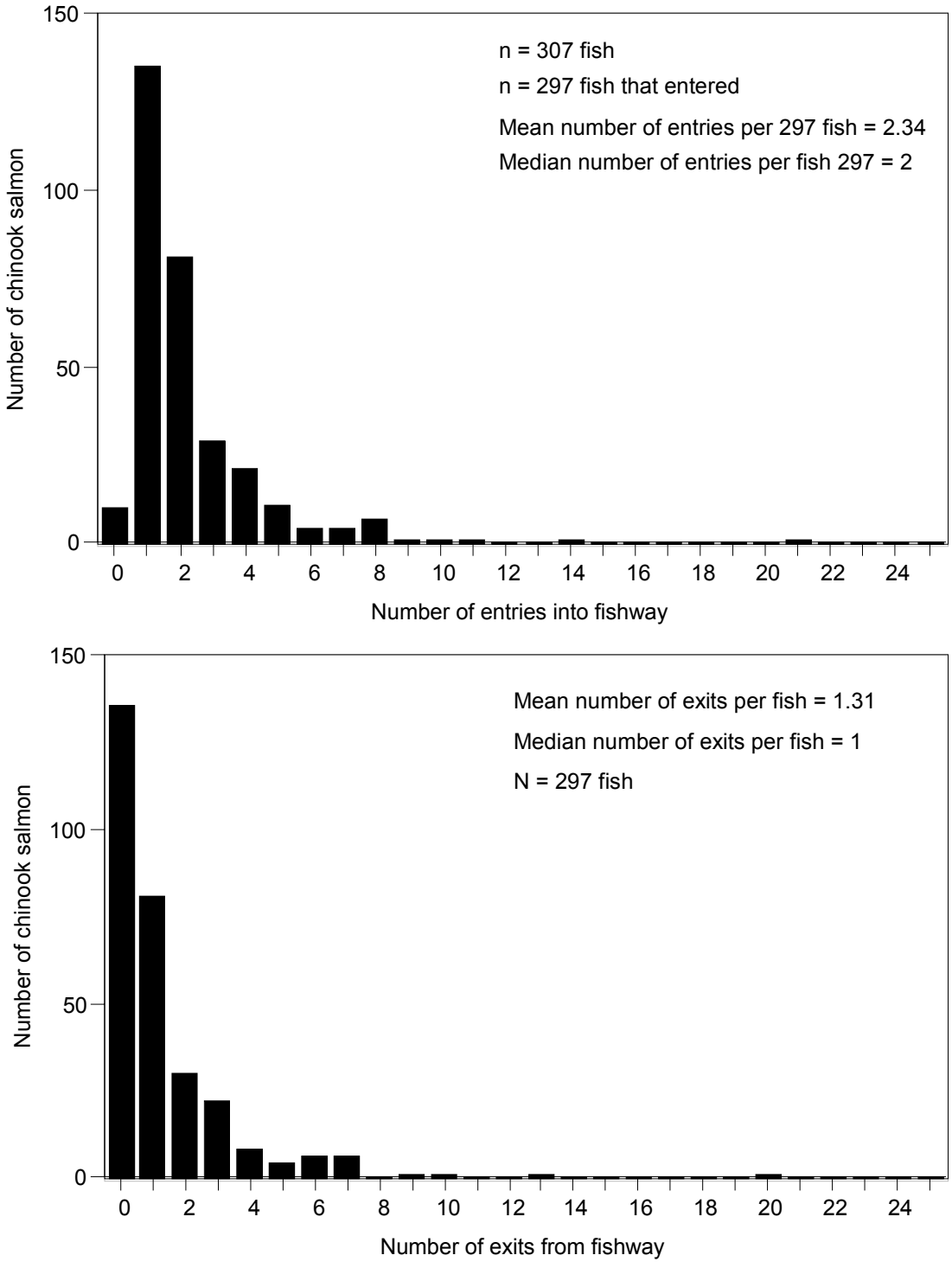


Figure 50. Number of chinook salmon that entered or exited fishway, and those with multiple entries and exits into or from the fishway at McNary Dam via the entrances in 1996.

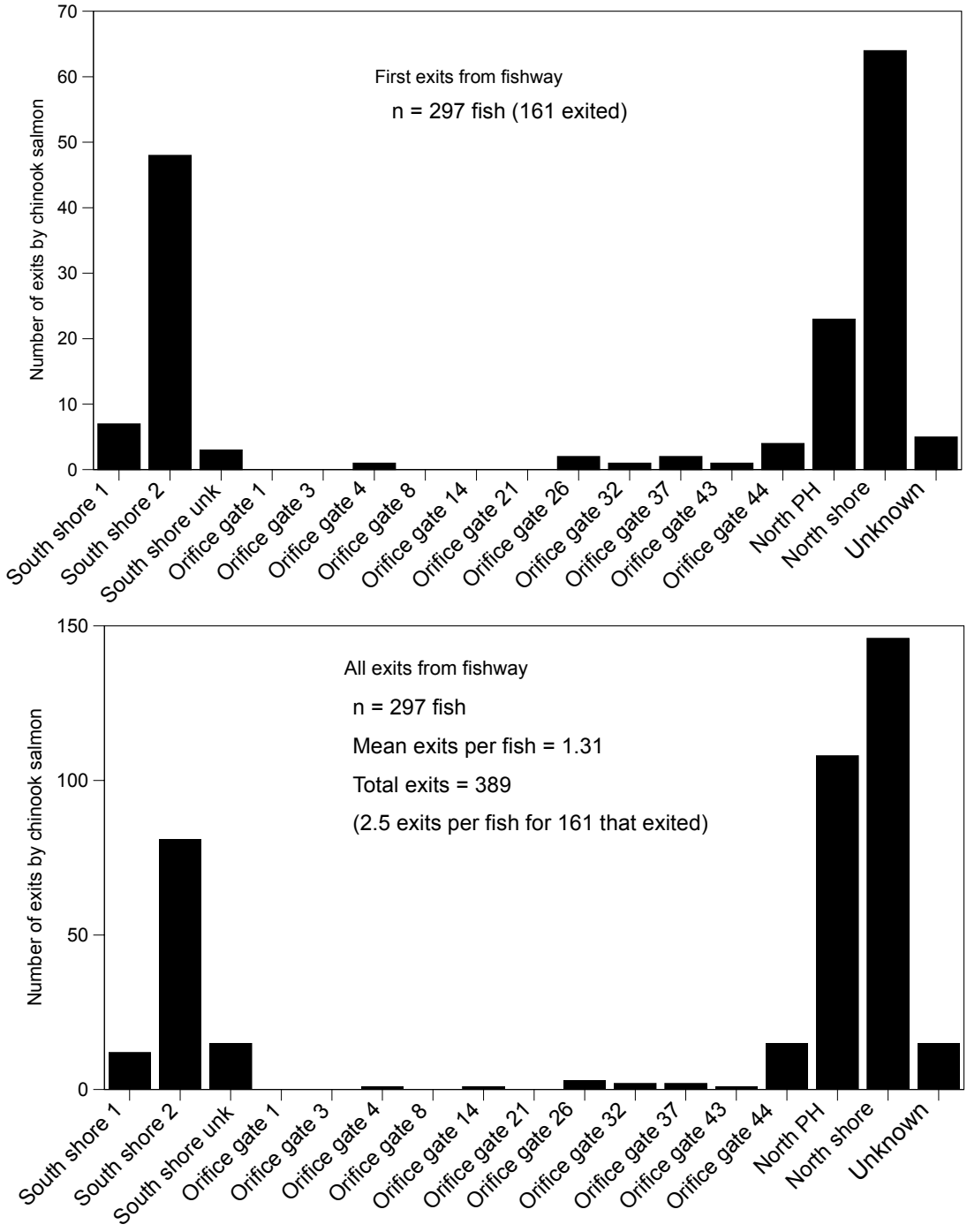


Figure 51. Number of first and total exits from fishway for each entrance by chinook salmon at McNary Dam in 1996.

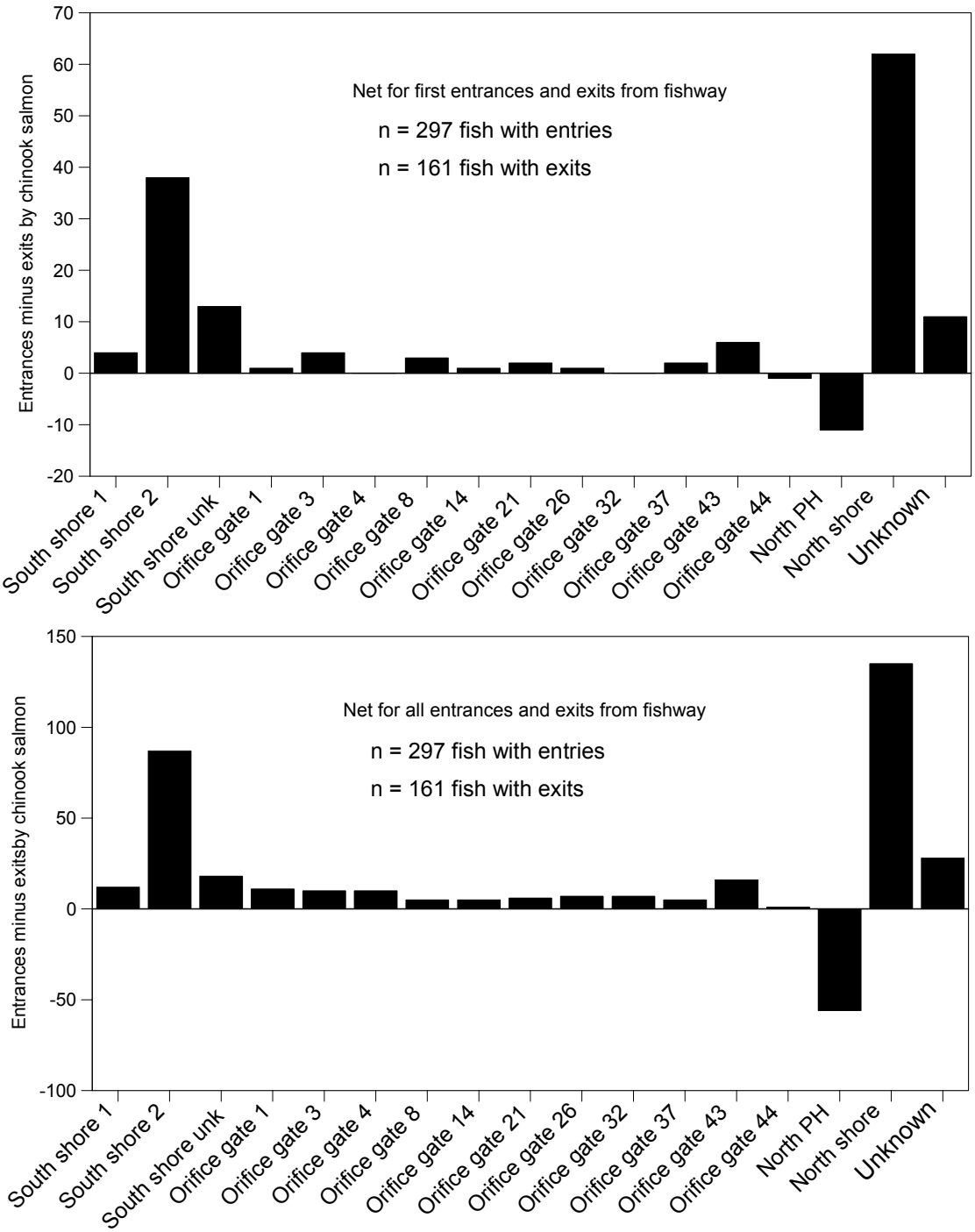


Figure 52. Net number of first and total exits from fishway for each entrance by chinook salmon at McNary Dam in 1996.

transmitters entered the transition pool at the bottom of the south-shore ladder first and then passed over the dam via the south-shore ladder (Figure 53). Forty-two percent (123) entered the transition pool at the bottom of the north-shore ladder first and then passed the dam via the north-shore ladder. Of the remaining 15%, 3% (9) entered the south-shore transition pool but then turned around and exited the fishway, crossed the tailrace, and passed the dam via the north-shore ladder and 12% (34) entered the north-shore transition pool, turned around and exited the fishway, and passed via the south-shore ladder.

Of the 128 chinook salmon that first entered the south-shore transition pool and passed the dam via the south-shore ladder, 20% (26) moved straight through the transition pool and entered the ladder; 55% (70) turned around in the transition pool, moved downstream, and remained in the pool before entering the ladder (Table 7). A total of 32 (25%) turned around, moved downstream, and exited the transition pool. Nineteen fish (15% of 128) traveled downstream into the collection channel after first entering the pool, exited and reentered the fishway and pool before passing the dam. The remaining 13 fish (10% of 128) exited the transition pool into the collection channel and did not exit into the tailrace.

The north-shore transition pool at McNary Dam was configured differently than the south-shore pool, in that fish entered the north-shore pool shortly after entering the fishway and without passing through a collection channel. Of the 123 chinook salmon that first entered the north-shore pool and passed the dam via the north-shore ladder, 30 (24%) moved straight through the transition pool and entered the ladder, 51 (41%) moved downstream in the transition pool before entering the ladder, and 42 (34%) moved downstream in the fishway and exited into the tailrace at least once before returning and entering the ladder (Table 7).

Chinook salmon used similar fishway entrances to exit and subsequently reenter the fishways at McNary Dam after leaving a transition pool. The 128 fish that first entered the south-shore transition pool, exited and reentered the fishway, and ultimately passed the dam via the south-shore ladder, made 50% of their 34 exits to the tailrace from south-shore entrances (Figure 54). Approximately 41% of the exits made by chinook salmon were from the north-powerhouse and north-shore entrances. Reentries of chinook salmon were distributed among more fishway entrances, but 51% were at shoreline entrances.

The nine fish that first entered the transition pool in the south-shore fishway and passed the dam via the north-shore ladder, exited the fishways 24 times, 6 times each at south-shore entrance-2 and at the north-powerhouse entrance and 5 times at the north-shore entrance (Figure 54). The nine fish made 58% of their reentries at the north-shore entrance; the remaining reentries were distributed between orifice gates and the north-powerhouse entrances. The 123 chinook salmon that first entered the north-shore transition pool, exited and reentered the fishway, and ultimately passed the dam via the north-shore ladder, made 61% of their 131 exits and reentries at the north-shore entrance (Figure 55). The 123 fish also made 40 exits from the north-powerhouse entrances and made reentries at almost

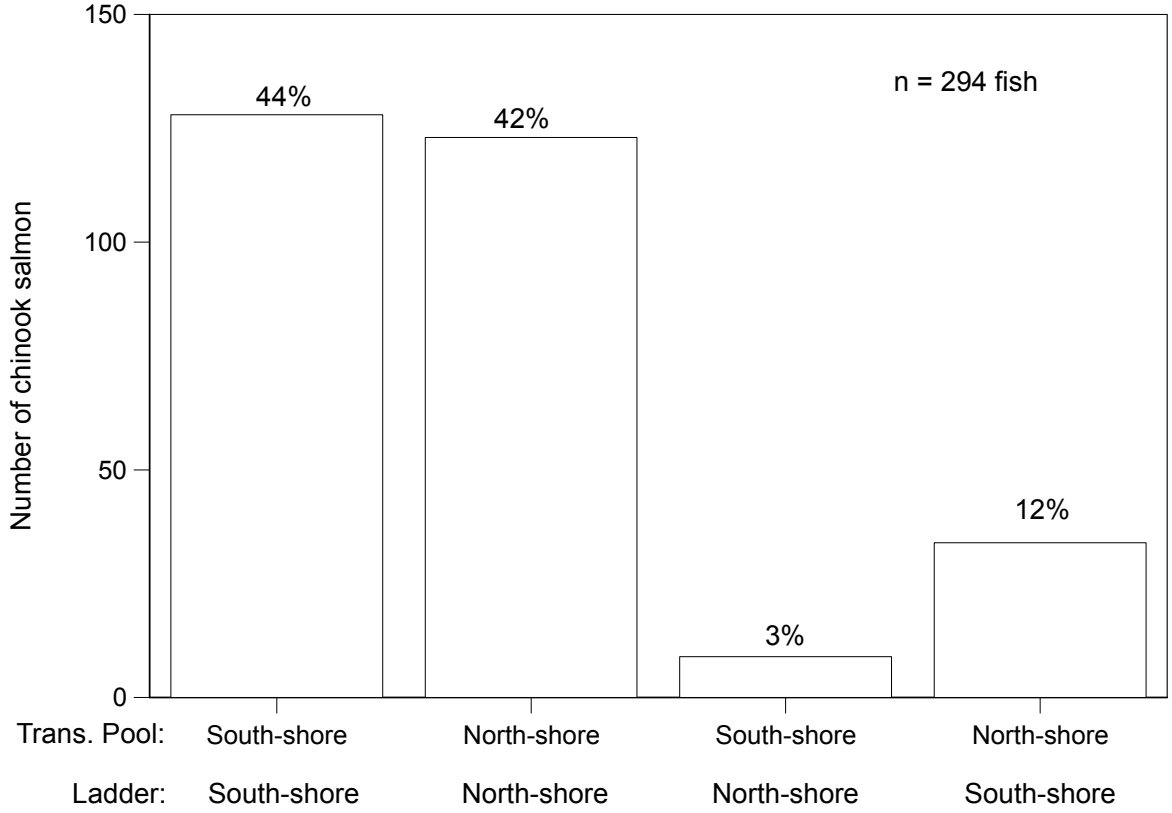


Figure 53. Number of chinook salmon that passed McNary Dam in 1996, the transition pool first entered, and the ladder used to pass the dam.

Table 7. Number and proportions of chinook salmon that first entered the North- or South-shore transition pools at McNary Dam and either passed through with no downstream movement, moved downstream in the pool but did not exit before passing into at ladder, exited the pool into the collection channel but not into the tailrace, or exited into the tailrace in 1996. Includes only fish that passed the dam via the same pool they first entered.

	First entered South transition pool: Passed South ladder		First entered North transition pool: Passed North ladder	
Transition pool behavior	N	Percent of 128	N	Percent of 123
Moved straight through	26	20%	30	24%
Moved downstream, but didn't exit	70	55%	51	41%
Exited pool to collection channel	13	10%	N/A	N/A
Exited pool to tailrace	19	15%	42	34%

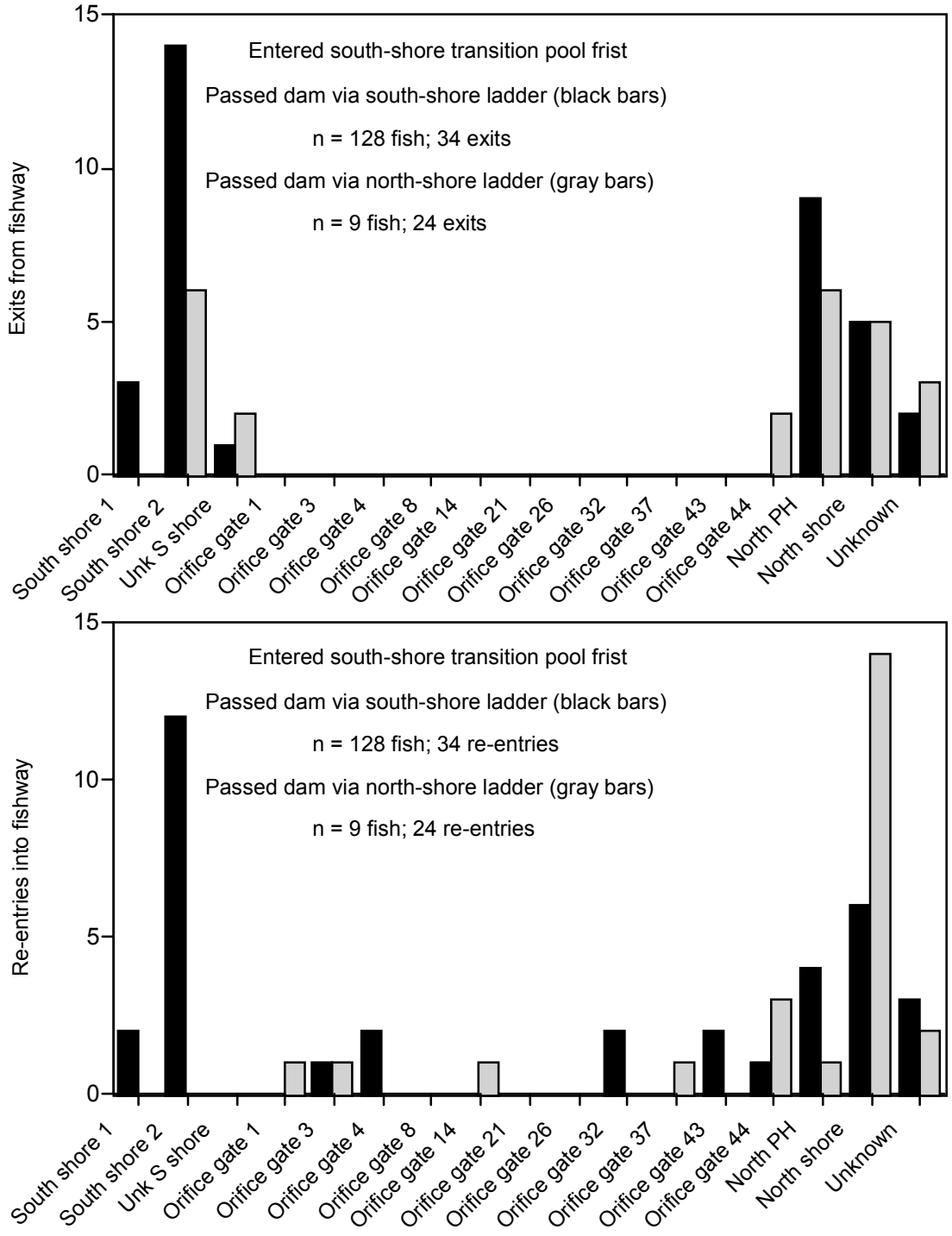


Figure 54. Entrances used to exit and reenter the fishway by chinook salmon that first entered the south-shore transition pool, exited to the tailrace, and passed over McNary Dam by either the south- or north-shore fishways in 1996.

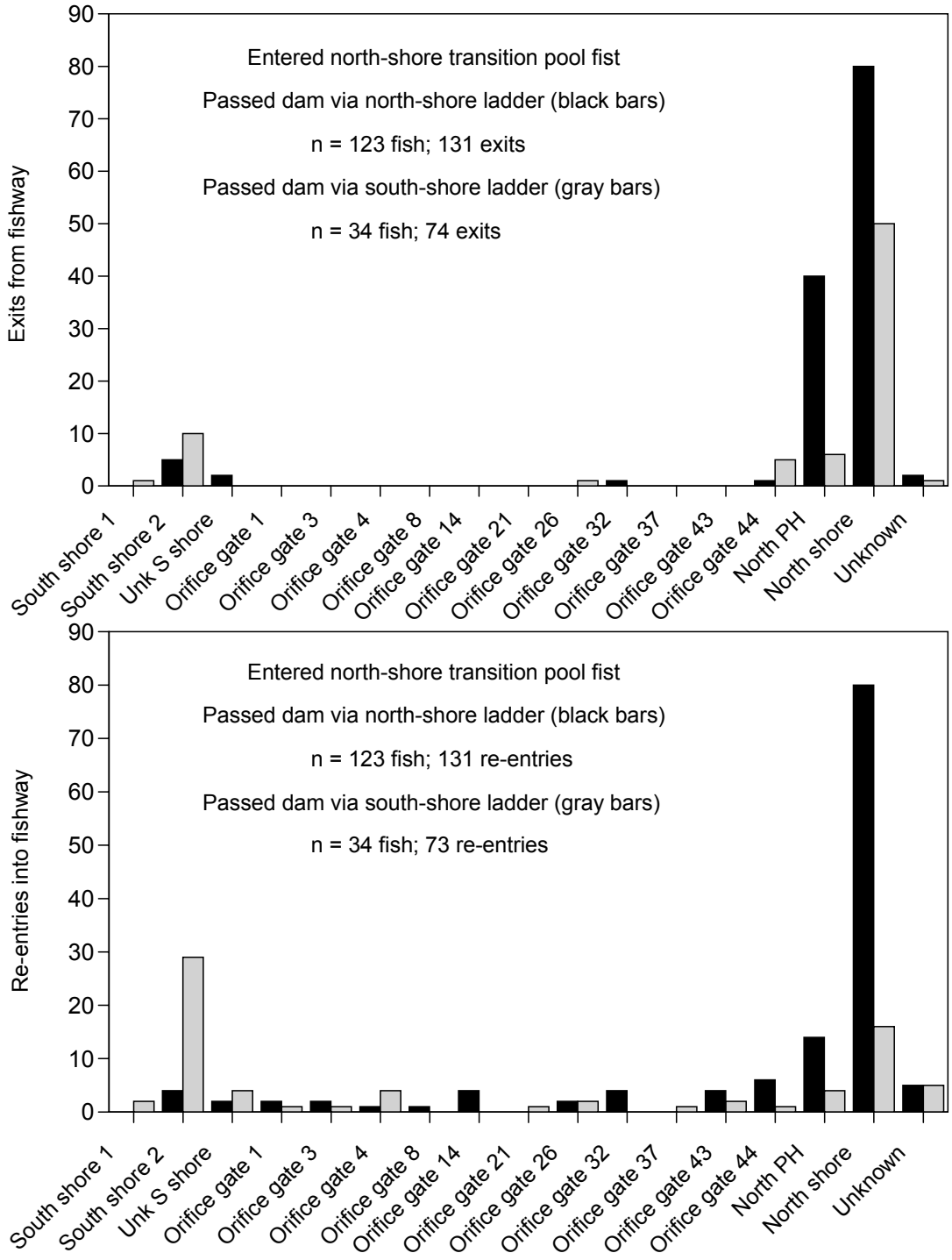


Figure 55. Entrances used to exit and reenter the fishway by chinook salmon that first entered the north-shore transition pool, exited to the tailrace, and passed over McNary Dam by either the south-shore or north-shore fishways in 1996.

all fishway entrances. Thirty-four chinook salmon first entered the north-shore transition pool, exited, and then passed McNary Dam via the south-shore ladder. The 34 fish made 74 exits, 68% of which were from the north-shore entrance; 42% of reentries by the 34 fish were at south-shore entrances, 22% were at the north-shore entrance, and the remaining were distributed among all fishway entrances (Figure 55).

Passage times through transition pools and over McNary Dam were affected by chinook salmon behavior in the pools and whether or not fish exited a pool into a collection channel or the tailrace. For the following analyses, fish that passed straight through the transition pools and those that moved downstream but did not exit a pool before they passed into a ladder were grouped together as 'fish that passed through a pool on the first attempt' and fish that exited the pool to the collection channel or tailrace were grouped together as 'fish that exited the pool one or more times.' Passage times from first fishway entry to first transition pool entry, from pool entry to exit into a ladder, to ascend the ladders, and from first fishway entry to exit the top of the ladders were skewed to the right (Figure 56); as a result, median values for passage time were more representative indicators of overall chinook salmon behavior than mean values.

Median passage times for all 294 fish that passed through transition pools at McNary Dam were 0.06 h from first fishway entry to first transition pool entry, 0.76h from first pool to exit into a ladder, 2.38h to ascend a ladder, and 5.62 h from fish fishway entry to exit from the top of a ladder (Table 8). Median times to first enter a pool and to ascend ladders were similar for all groups of fish, while fish that exited a pool into a collection channel had longer passage times through pools and from first entry to exit from a ladder; chinook salmon that exited from a pool into the tailrace at McNary Dam had median times to pass the dam that were 4.6 to 6.8 times longer than fish that did not exit pools (Table 8).

For the 177 chinook salmon that moved through a McNary transition pool and entered a ladder on the first attempt, median passage time from first fishway entry to first entry in a transition pool was 8 min (0.11 h); the 117 fish that made more than one attempt to pass a transition pool took a median of 2 min (0.03 h) to first enter a pool (Table 8). Median times from first entry in a transition pool to exit into a ladder were 19 min (0.32 h) for fish that moved through a pool on the first attempt and 16.35 h for fish that made more than one attempt to pass. Median time to ascend a ladder was about 2.4 h for each group. Median times from first fishway entry to exit from the top of a ladder were 3.43 h for fish that moved through a pool on the first attempt and 21.14 h for fish that made more than one attempt (Figure 56).

For the 128 chinook salmon that first entered the south-shore transition pool and passed the dam via that ladder, median times to first enter the transition pool after first entering the fishway (7 to 16 min), and to ascend a ladder (2.33 to 2.35 h) were similar for fish that passed through the pool into the ladder on the first attempt and for those that exited the pool one or more times before entering the ladder (Table 9). For the 32 fish that made more than one attempt to pass through the south-shore transition pool, median time from first fishway

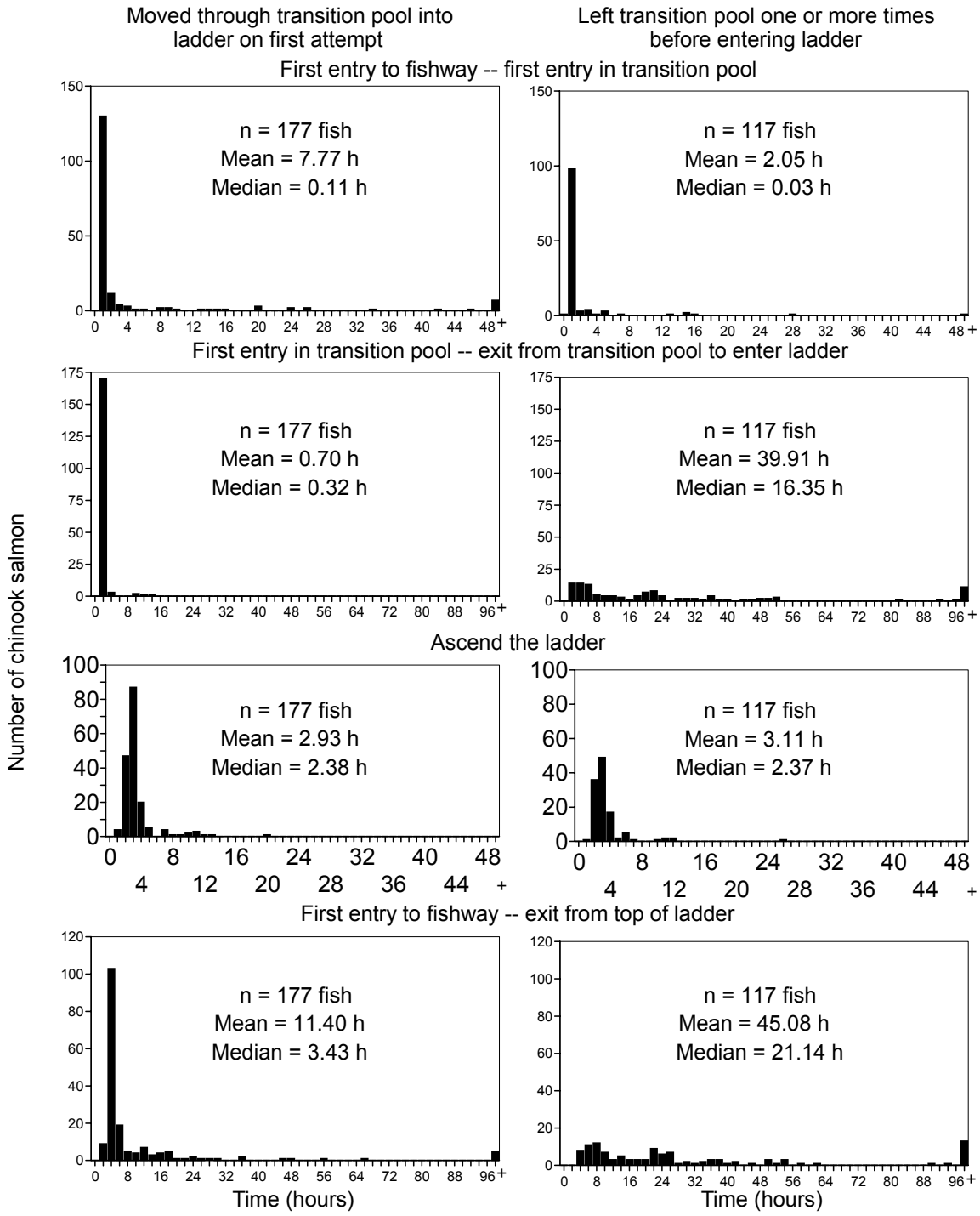


Figure 56. Time to first enter and to pass through a transition pool, to ascend a ladder, and to exit from the top of a ladder at McNary Dam in 1996 by chinook salmon that passed through the pool on the first attempt and by those that made more than one attempt.

Table 8. Median and mean passage times for chinook salmon that moved through a transition pool at McNary Dam with no downstream movement, moved downstream in a transition pool but did not exit before passing into a ladder, exited a transition pool into a collection channel but not into the tailrace, or exited into the tailrace in 1996.

		Median passage time (h) from:			
		First entry	First pool	Ascend	First entry
Transition pool behavior	N	To first pool	To last pool	Ladder	To exit ladder
All behaviors	294	0.06	0.76	2.38	5.62
Moved straight through	56	0.10	0.14	2.38	3.29
Moved downstream, but didn't exit	121	0.13	0.43	2.33	3.50
Exited pool to collection channel	13	0.19	2.22	2.38	4.81
Exited pool to tailrace	104	0.02	18.85	2.36	22.29
		Mean passage time (h):			
All behaviors	294	5.49	16.31	3.00	24.80
Moved straight through	56	6.05	8.56	1.54	2.11
Moved downstream, but didn't exit	121	0.28	0.90	2.36	44.61
Exited pool to collection channel	13	2.98	2.91	3.03	3.12
Exited pool to tailrace	104	9.31	12.37	6.93	49.84

entry to first transition pool entry was 3.19 h, compared to 13 min (0.22 h) for the 96 fish that passed through the pool into the ladder on the first attempt. Passage time for fish that made more than one attempt to pass through the south-shore transition pool was 8.36 h to pass the dam after first fishway entry, compared to 3.19 h for fish that passed through the pool on the first attempt. Most fish that made multiple attempts to pass through the south-shore pool entered the ladder in less than 8 h, but 31% took more than 12 h.

The 13 fish that turned around in the south-shore transition pool and traveled downstream in the collection channel but did not exit the fishway had median times of 11 min (0.19 h) from first fishway entry to first transition pool entry, 2.22 h from first transition pool entry to exit the pool and enter the ladder, 2.38 h to ascend the ladder, and 4.81 h from first fishway entry to exit from the top of the ladder (Table 9). Nineteen chinook salmon exited the fishway into the tailrace after exiting the south-shore pool; these fish had median passage times of 5 min (0.08 h) from first fishway entry to first pool entry, 13.07 h from first pool entry to exit the pool into the ladder, 2.29 h to ascend the ladder, and 22.45 h to exit the top of the ladder after first entering the fishway (Table 9).

Of 123 chinook salmon that first entered the north-shore transition pool and passed the dam via the north ladder, 81 passed the pool on their first attempt and had median times of 2

Table 9. Median and mean passage times for chinook salmon that moved through the North- and South-shore transition pools at McNary Dam by fish that passed through a transition pool on their first attempt or exited a transition pool into a collection channel or the tailrace, by the first pool entered and the ladder eventually passed in 1996.

Transition pool behavior	First pool	Ladder passed	N	Median passage time (h) from: First entry to first pool	First pool to last pool	Ascend ladder	First entry to exit ladder
Passed through pool on first attempt	South	South	96	0.26	0.22	2.35	3.19
	North	North	81	0.03	0.46	2.47	3.57
	All fish[1]		177	0.11	0.32	2.38	3.43
Exited pool to Collection channel	South	South	13	0.19	2.22	2.38	4.81
Exited pool to tailrace	South	South	19	0.08	13.07	2.29	22.45
	South	North	9	0.26	10.61	2.42	13.20
	North	North	42	0.02	16.81	2.47	21.52
	North	South	34	0.02	23.74	2.06	26.67
Exited pool one or more times	All fish[1]		117	0.03	16.35	2.37	21.14
				Mean passage time (h):			
Passed through pool on first attempt	South	South	96	6.15	0.71	2.80	9.66
	North	North	81	9.68	0.69	3.09	13.46
	All fish[1]		177	7.77	0.70	2.93	11.40
Exited pool to Collection channel	South	South	13	1.54	2.36	3.03	6.93
Exited pool to tailrace	South	South	19	0.47	36.95	4.37	41.79
	South	North	9	0.53	60.88	2.32	63.73
	North	North	42	3.82	45.01	3.14	51.97
	North	South	34	1.34	44.08	2.62	48.04
Exited pool one or more times	All fish[1]		117	2.05	39.91	3.11	45.08

[1] See Figure 56 for passage time distributions

min (0.03 h) from first fishway entry to first transition pool entry, 28 min (0.46 h) from first transition pool entry to exit the pool into the ladder, 2.47 h to ascend the ladder, and 3.57 h from first fishway entry to exit from the top of the ladder (Table 9). By comparison, the 42 fish that made more than one attempt to pass through the north-shore pool had median times of 1 min (0.02 h) from first fishway entry to first pool entry, 16.81 h from first pool entry to exit into the ladder, 2.47 h to ascend the ladder, and 21.52 h from first fishway entry to exit from the top of the ladder (Table 9).

Forty-three chinook salmon passed McNary Dam via a different transition pool than the one they first entered. Nine fish first entered the south-shore pool, exited into the tailrace,

and then passed the dam via the north-shore pool; 34 fish first entered the north-shore pool, exited to the tailrace, and then passed via the south-shore pool (Table 9). The nine chinook salmon that first entered the south-shore transition pool but passed the dam via the north-shore ladder had median passage times of 10.61 h from first entry in the south-shore transition pool to exit the north-shore pool into the ladder, 2.42 h to ascend the ladder, and 13.20 h from first fishway entry to exit from the top of the ladder. The 34 chinook salmon that first entered the north-shore transition pool but passed the dam via the south-shore ladder had median passage times of 23.74 h from first entry in the north-shore transition pool to exit the south-shore pool into the ladder, 2.06 h to ascend the ladder, and 26.67 h from first fishway entry to exit from the top of the ladder (Table 9).

Results - Ice Harbor Dam

Passage times

Fishway entrance use and movements within the fishway at Ice Harbor Dam (Figure 57) in 1996 were monitored by recording movements of 127 chinook salmon outfitted with transmitters. Median passage time of chinook salmon from release below Bonneville Dam to the Ice Harbor tailrace was 16.2 d, and was 17.8 d from release to passage over the dam (Figure 58). Median passage times from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into the fishway, and passage from the top of the ladder were 2.61 h, 10.53 h, and 17.46 h (Figure 59). Median time from first approach at a fishway to first entry into the fishway at Ice Harbor Dam was 4.48 h, and median time from first entry into a fishway to exit from the top of the ladder was 3.88 h (Figure 60). Distributions of passage times were skewed to the right, with a few fish taking several days to approach the entrances, enter the fishway, or pass over the dam. Consequently, mean passage times were longer than median times.

Most fish entered fishways within 1 to 6 h after passing the tailrace receiver, but several fish took up to 7 d to pass the dam because they spent a day or more in the fishways or spent time exiting and reentering fishways. Some fish were in the fishways at nightfall and usually stayed there until morning. Others spent time migrating up and down the powerhouse collection channel during daylight (Figure 61). Passage times between the tailrace and passage from the top of the ladders also included time used by fish that exited a fishway via one of the entrances, moved out into the tailrace, and then reentered a fishway.

Fishway Use

Approaches to fishways: Chinook salmon first approached Ice Harbor Dam at all entrances, with a tendency to enter shoreline and southern powerhouse entrances. Thirty-eight of 119 fish recorded approached either the south-shore or north-shore ladder entrances (Figure 62). When all approaches at fishway entrances made by chinook salmon in 1996 were considered, most were at the south-shore ladder and at southern powerhouse entrances; relatively few were at the north-shore or north-powerhouse entrances (Figure 62).

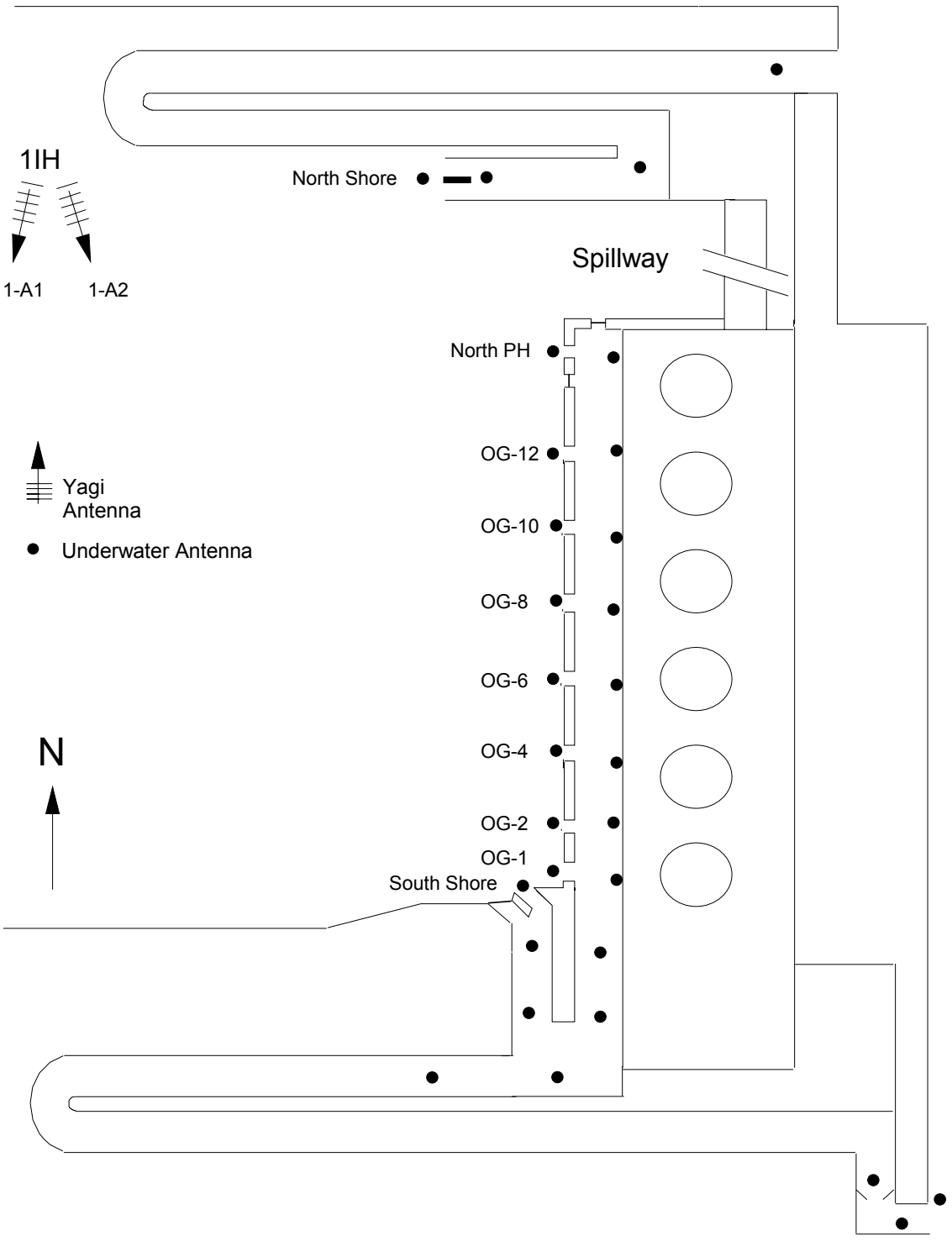


Figure 57. Location of antennas and fishway entrances at Ice Harbor Dam in 1996 when chinook salmon were passing the dam.

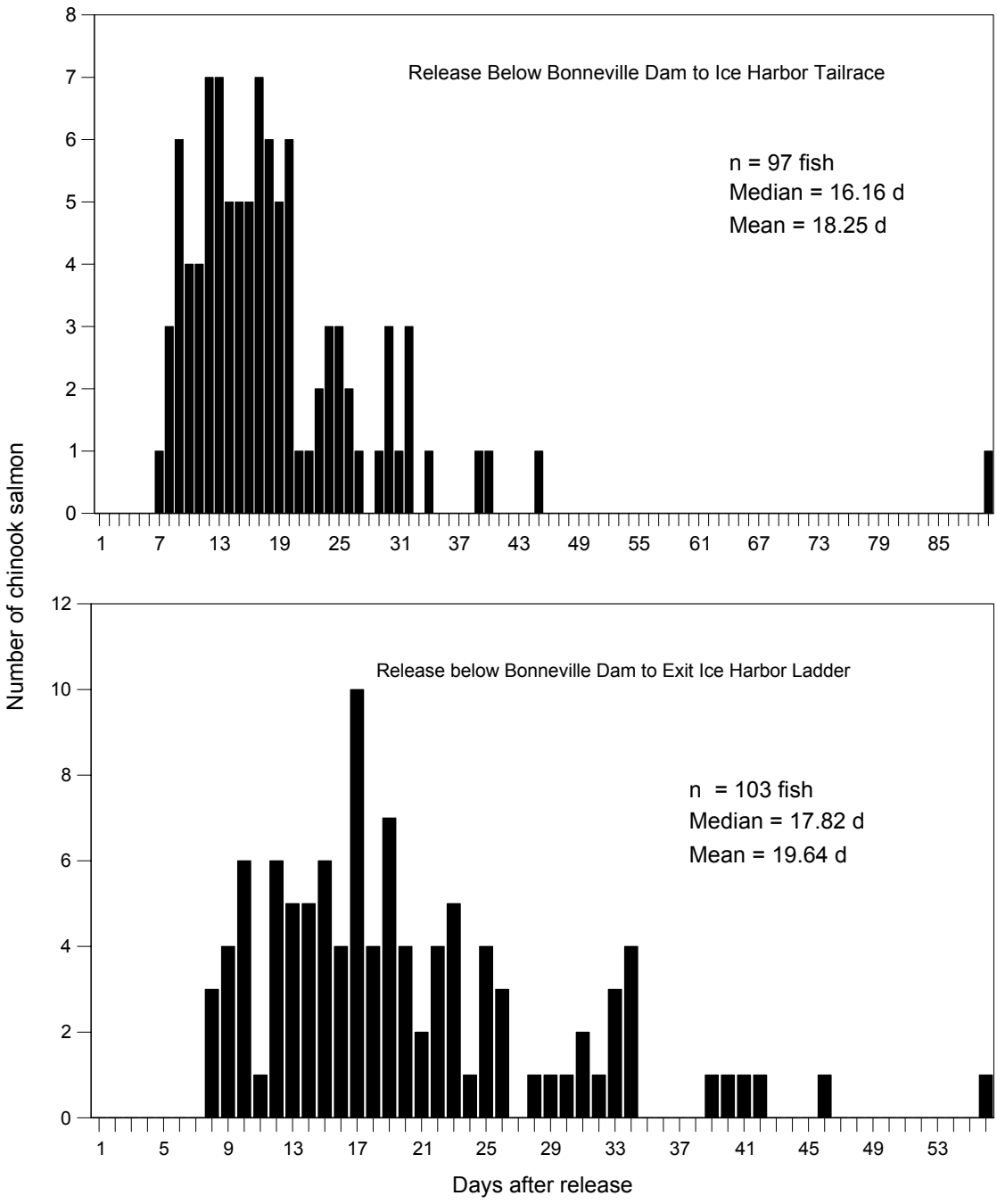


Figure 58. Number of chinook salmon and days to migrate from the release site below Bonneville Dam to the tailrace and to exit from the top of the ladder at Ice Harbor Dam in 1996.

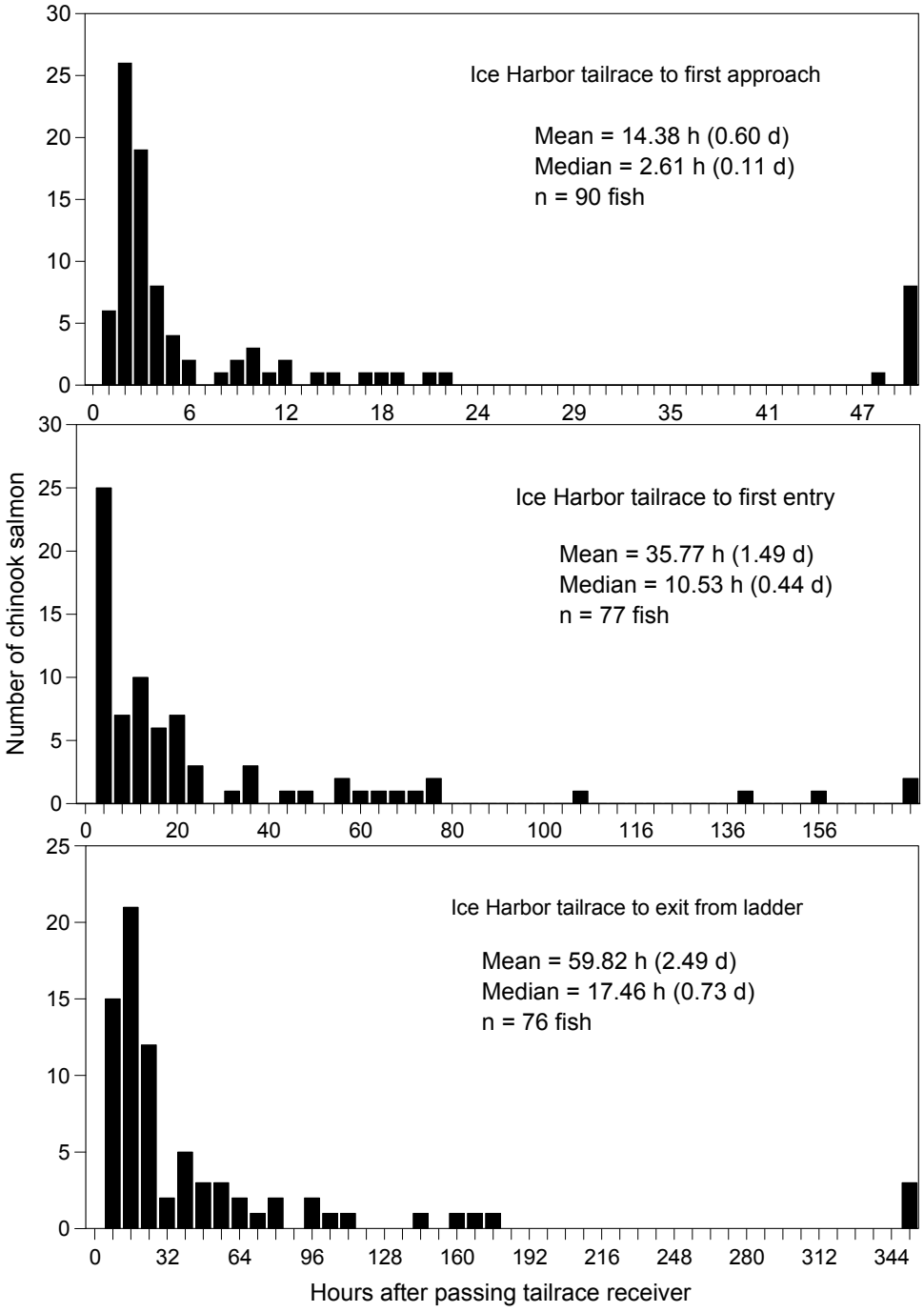


Figure 59. Number of chinook salmon and time to pass from the Ice Harbor Dam tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladders in 1996.

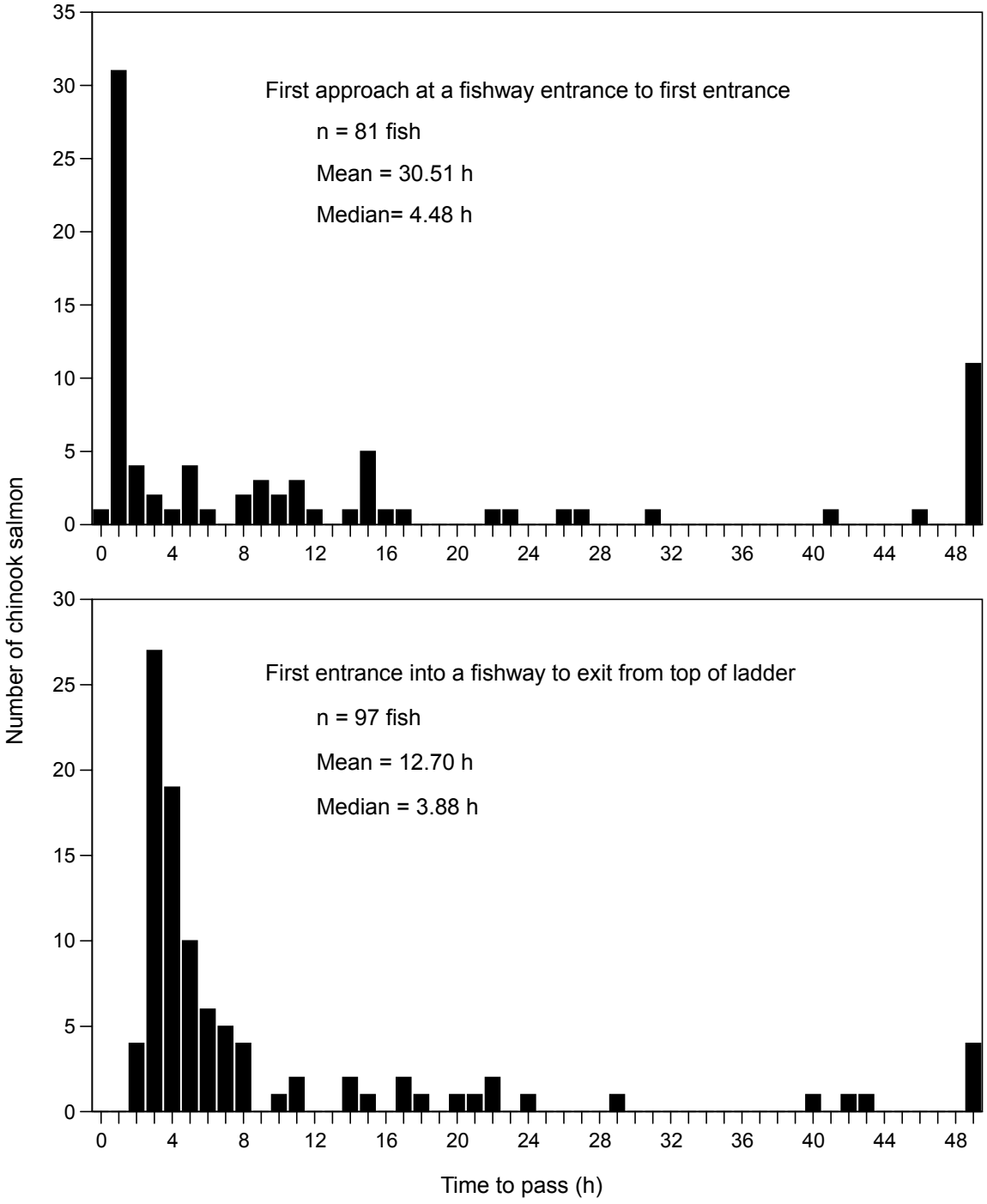


Figure 60. Number of chinook salmon and time to pass from first approach at a fishway entrance to first entry into a fishway and from first fishway entry to exit from the top of the ladder at Ice Harbor Dam in 1996.

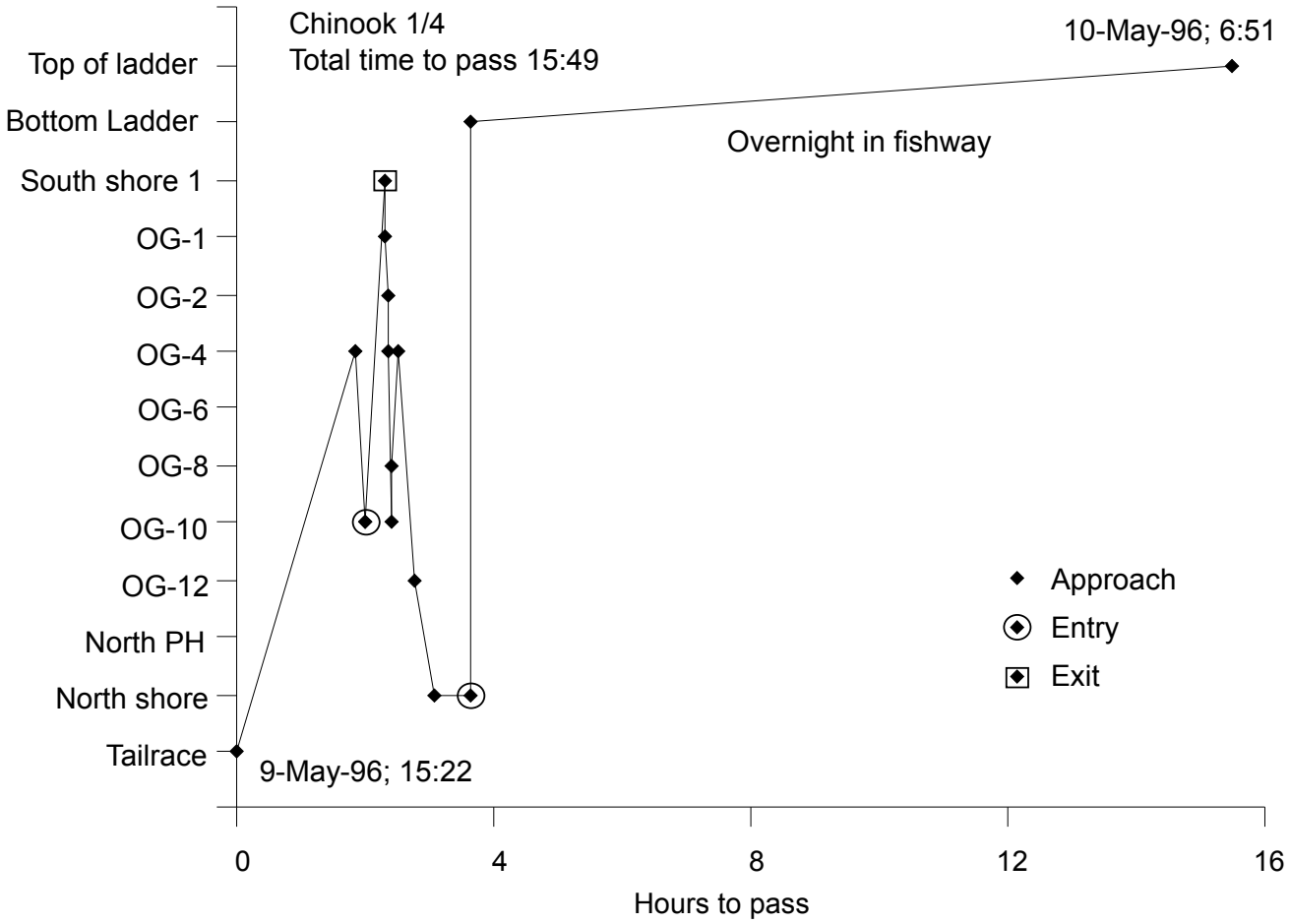


Figure 61. Illustration of the types of movements made by some chinook salmon in 1996 when approaching Ice Harbor Dam and entering, exiting, and passing through the fishway.

The large number of approaches (mean 18.9 per fish, median 11.0 per fish , 2,396 total), most of which (mean = 14, median = 9) occurred prior to the first entry, is an indication that many chinook salmon moved about the tailrace of the dam before making their final entry and passing the dam.

The 127 chinook salmon monitored at Ice Harbor Dam had a median of 11 approaches each (Figure 63). Ten chinook salmon approached the dam only once and 62 (49%) approached the dam 1 to 10 times; several fish approached various entrances 50 or more times. Most chinook salmon moved back and forth along the dam and approached entrances several times.

Entries to and exits from fishways: Entrances used by chinook salmon in 1996 for first entries were more restricted than entrances approached. The highest number of first and subsequent entries into the fishway occurred at the north-shore entrance as well as at the south-shore and north-powerhouse entrances (Figure 64). Where fish approached the dam

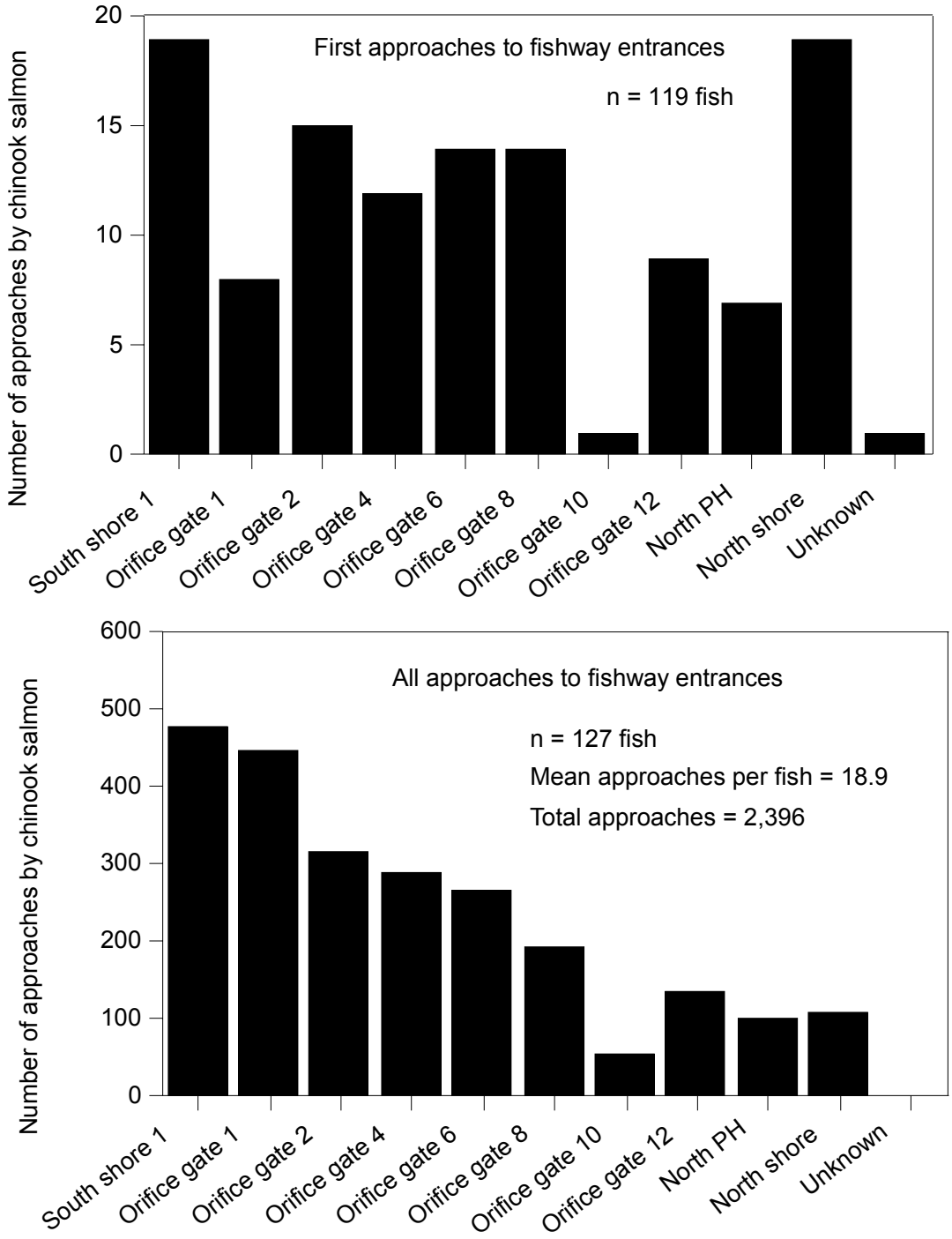


Figure 62. Number of first and total approaches at Ice Harbor Dam fishway entrances by chinook salmon in 1996.

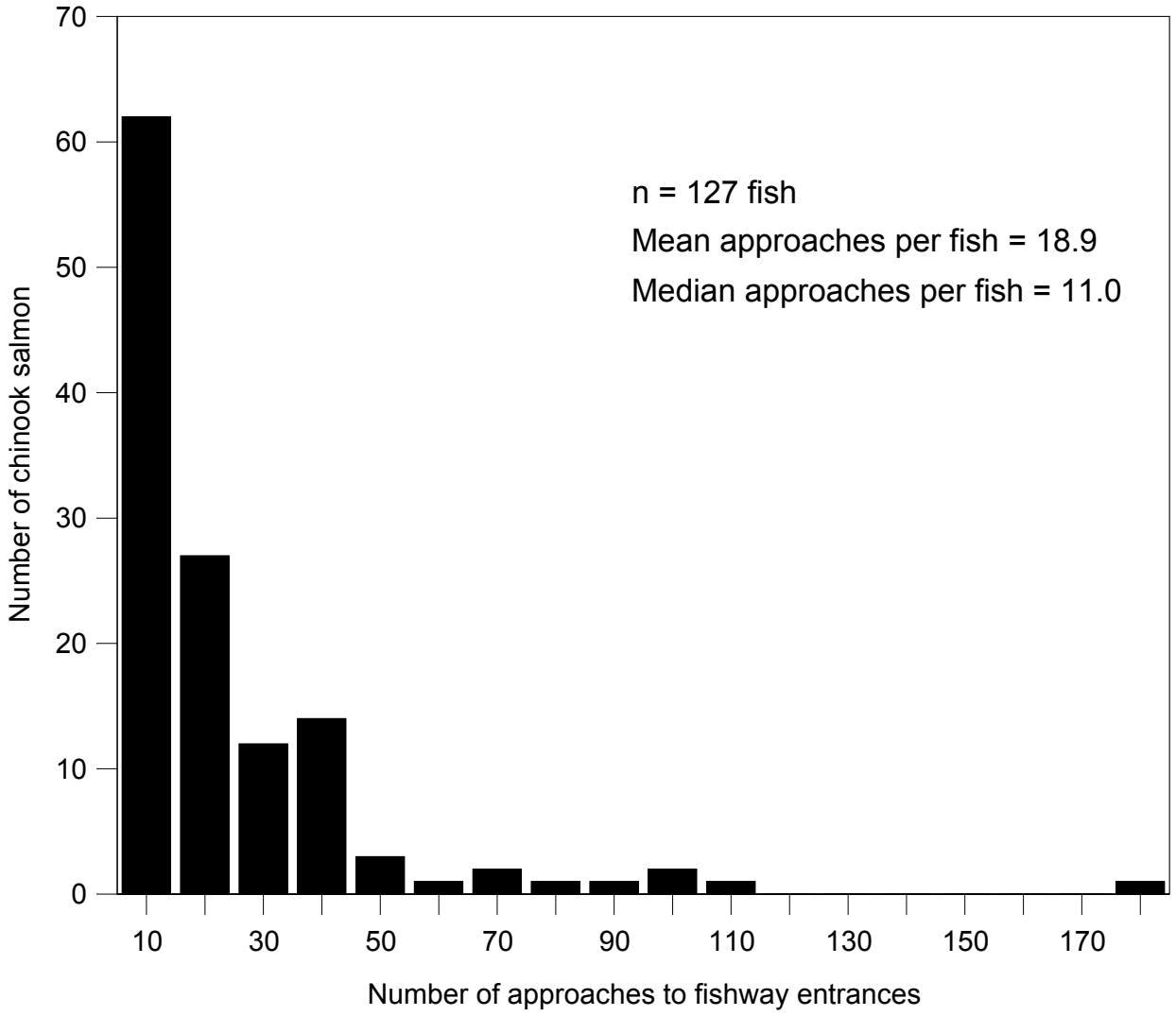


Figure 63. Number of chinook salmon that approached Ice Harbor Dam fishway entrances one or more times in 1996.

was probably related to amount and location of discharges. Ease of following attractive flow to the opening was probably also an important factor. Most entries occurred at the largest fishway entrances on the north and south shores and the north-powerhouse. Although many fish approached the orifice-gate entrances, relatively few entered the fishway through those smaller openings. Orifice-gate entrances at Ice Harbor Dam had relatively low attractive flows (design of 60-80 cfs) and their outflow would be mixed with those from turbines, reducing their attractiveness to the adult migrants. By comparison, the north-powerhouse entrance was designed to discharge 700 cfs and the south- and north-shore entrances discharged approximately 650 cfs.

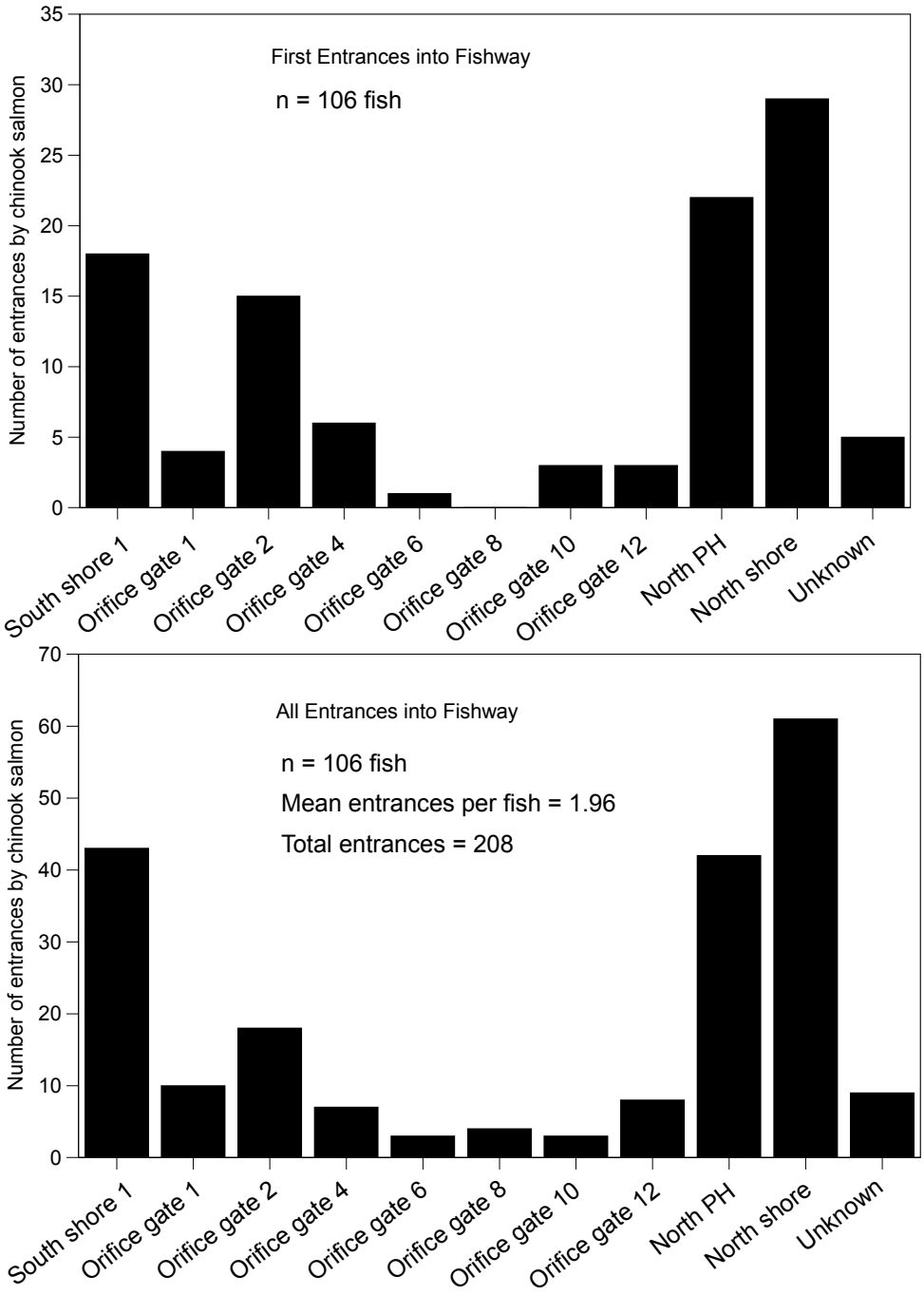


Figure 64. Number of first and total entries at Ice Harbor fishway entrances by chinook salmon in 1996.

Of the 127 chinook salmon monitored at Ice Harbor Dam, 21 did not enter and 5 entered at an unknown location. Of the 106 fish with known entrances, 60 (57%) entered a fishway at Ice Harbor Dam only once and the rest exited and reentered the fishway from 1 to 15 times (Figure 65). Because over half the fish made only a single entry to the fishway at Ice Harbor Dam, the median number of entries was 1.0 per fish, while the mean was 1.96 entries per fish.

Of the 106 fish that entered the Ice Harbor fishway, 64 (60%) did not exit the fishway, 41 (39%) exited from 1 to 8 times, and 1 exited 15 times (Figure 65). Chinook salmon exited the fishways primarily at north-powerhouse and shoreline entrances, with very few fish exiting from orifice-gate entrances (Figure 66). Many fish moved up the collection channel to the transition pool located at the bottom of the ladder and then returned down the channel and exited the fishway one or more times. The median time from the first entry and first exit from fishways at Ice Harbor Dam was 0.31h.

Net entry rates (entries minus exits) for fishway entrances ranged from -4 to 17 for first entries and exits, and 3 to 32 for all entries and exits (Figure 67). The north-shore ladder entrance was the most effective (more entries than exits) followed by orifice gate 2. There were more first exits than first entries of chinook salmon at orifice gate 8. The furthest upstream fish reached before making their first exits at Ice Harbor Dam were spread between the powerhouse collection channel (12.2% of 41 fish), south-shore entrance and transition pool (58.5%), and north-shore entrance and transition pool (29.3%) (Table 2). Fifteen salmon did not pass after reaching Ice Harbor Dam. Seven fish entered a tributary or downstream hatchery and the remaining 8 fish were not accounted for. Eight of the 15 fish were only recorded at tailrace receiver sites, 6 fish approached a fishway entrance and the remaining fish entered a fishway and was recorded in a transition pool.

Movements Through Transition Pools

We analyzed behavior of 86 chinook salmon as they moved through the transition pools at Ice Harbor Dam in 1996. Sixty-two percent (53) of the chinook salmon first entered the transition pool at the bottom of the south-shore ladder and then passed the dam via the south-shore ladder. Thirty-one percent (27) of chinook salmon first entered the north-shore ladder transition pool and passed the dam via the north-shore ladder. The remaining 6 fish entered one transition pool and then turned around and exited the fishway, crossed the tailrace, entered the other fishway and transition pool, and passed over the dam (Figure 68).

Of the 53 chinook salmon that first entered the south-shore transition pool and passed the dam via the south-shore ladder; 21% (11) moved straight through the transition pool and entered the ladder; 26% (14) turned around in the transition pool, moved downstream and remained in the pool before they entered the ladder (Table 10). A total of 53% (28 fish) turned around, moved downstream, and exited the transition pool. Twelve fish (23% of 53) that traveled downstream into the collection channel after first entering the south-shore transition pool exited and reentered the fishway and pool before passing the dam.

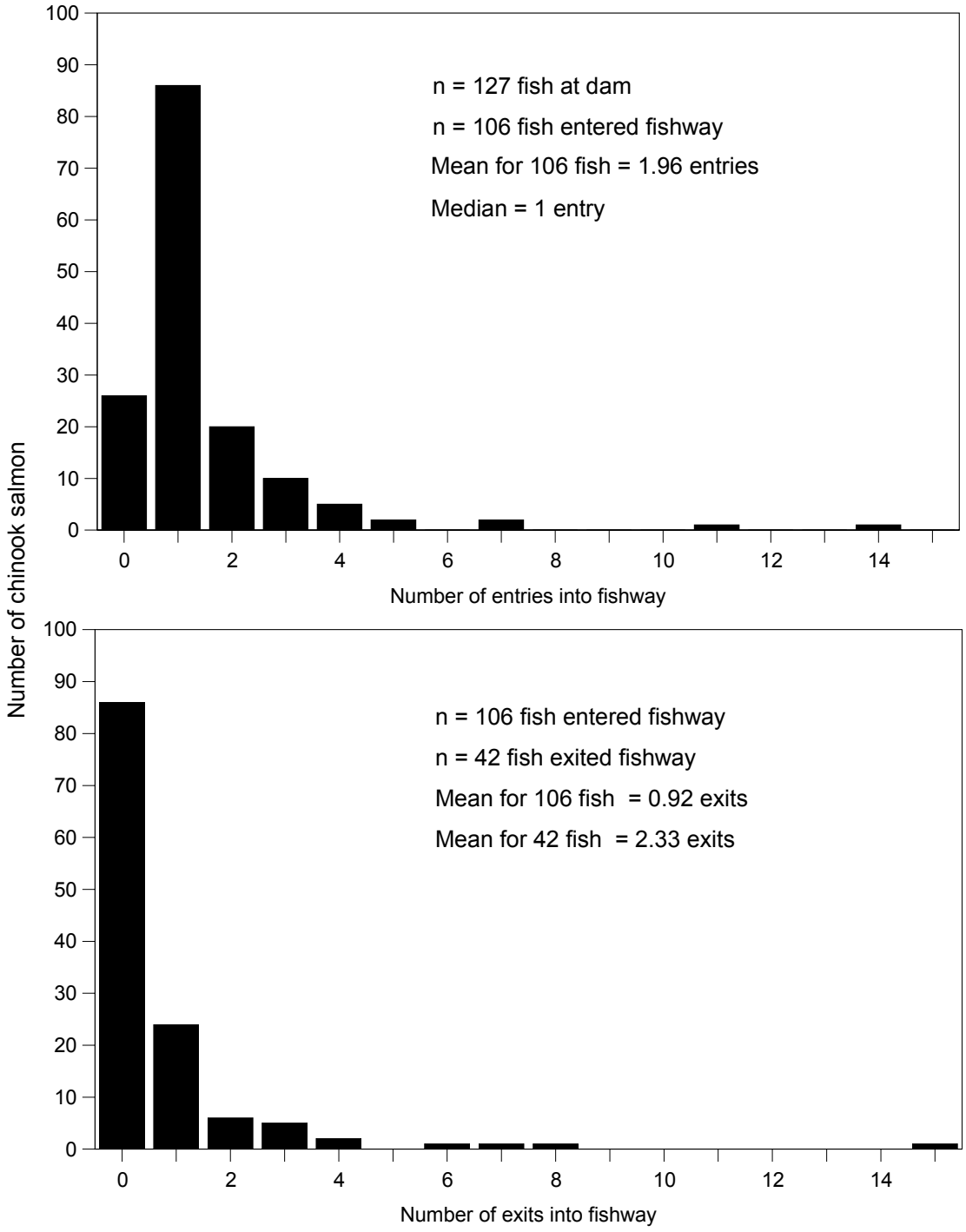


Figure 65. Number of chinook salmon that entered or exited the fishway, and those with multiple entries and exits into or from the fishway at Ice Harbor Dam via the entrances in 1996.

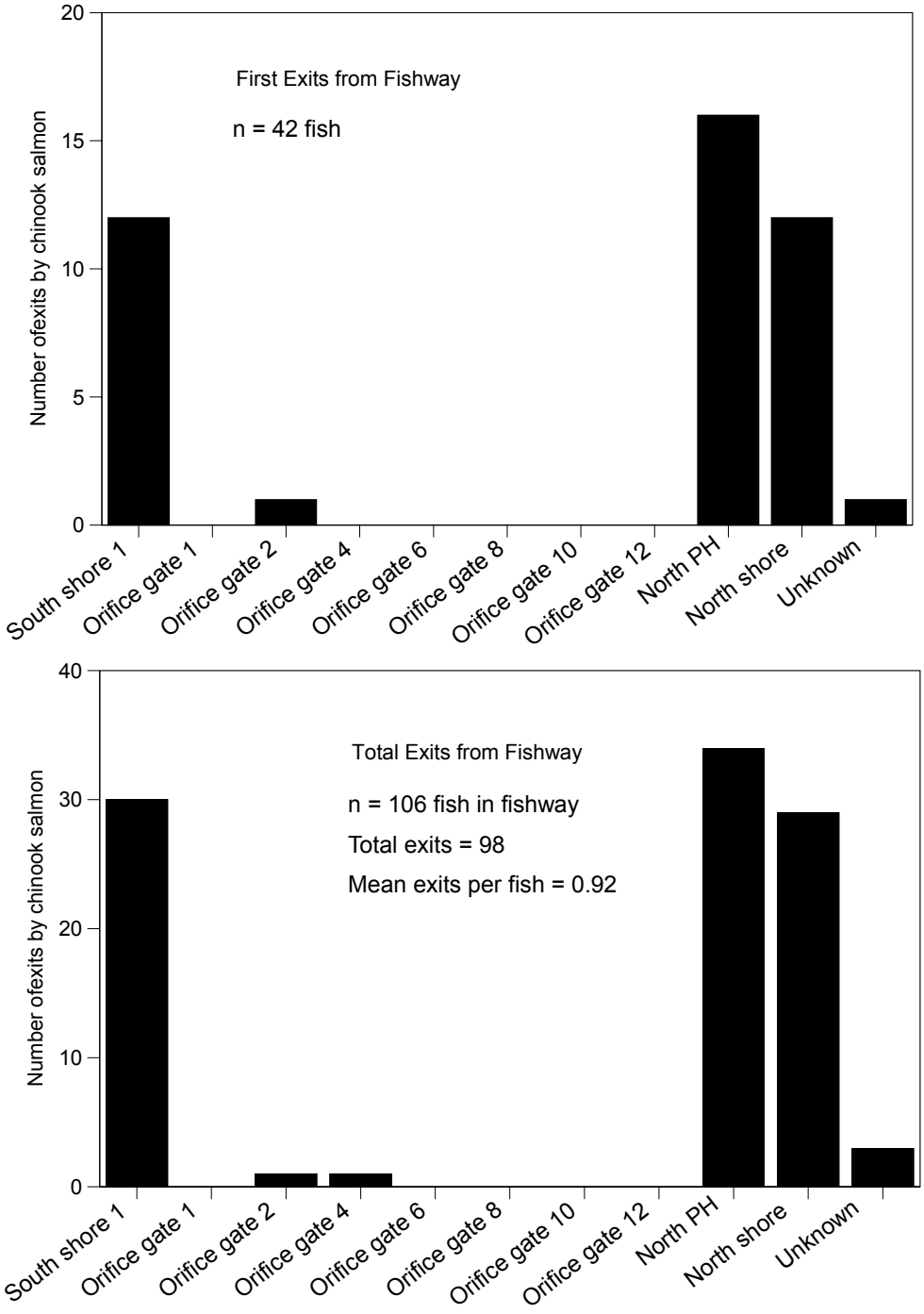


Figure 66. Number of first and total exits from the fishway for each entrance by chinook salmon at Ice Harbor Dam in 1996.

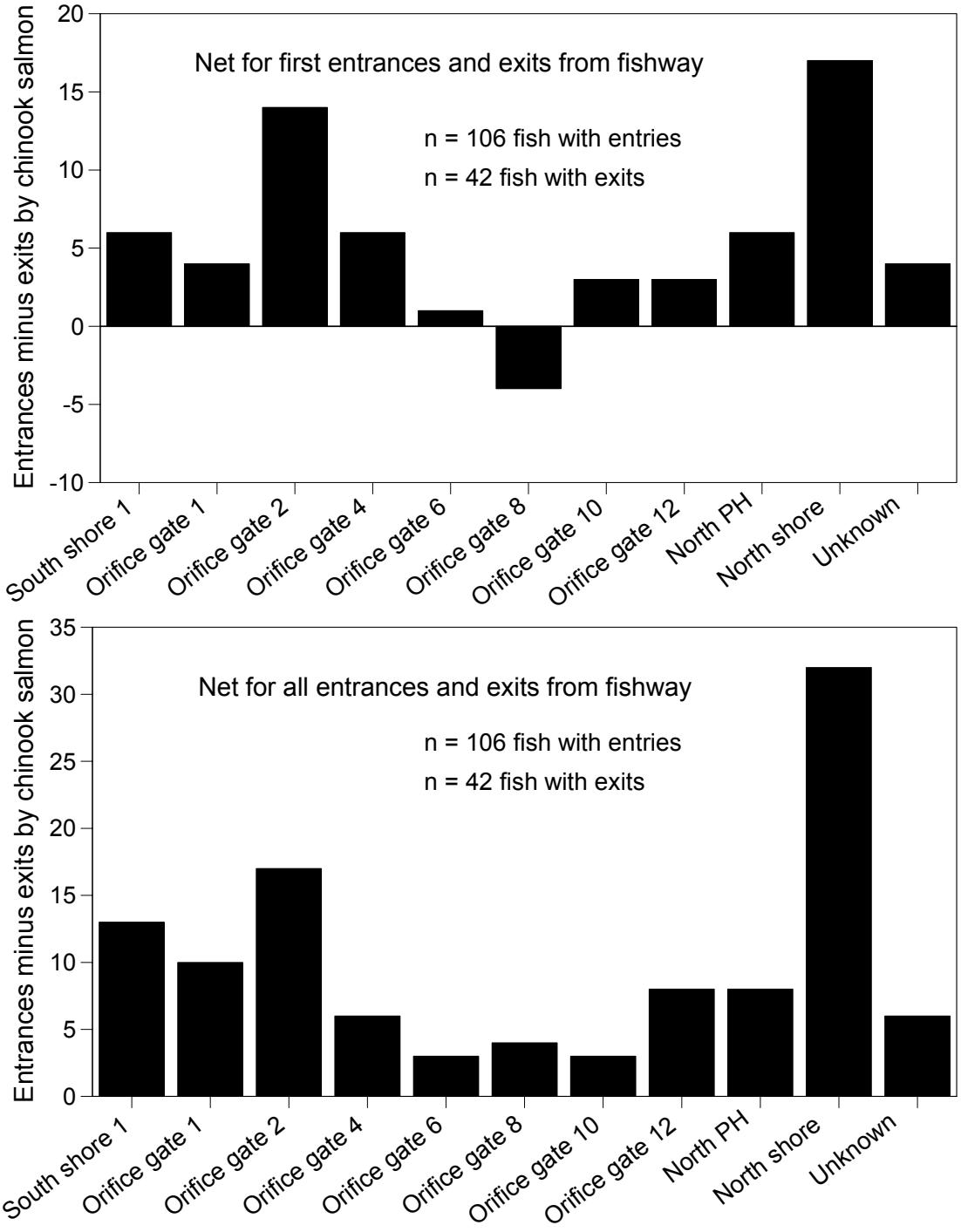


Figure 67. Net number of first and total exits from the fishway for each entrance by chinook salmon at Ice Harbor Dam in 1996.

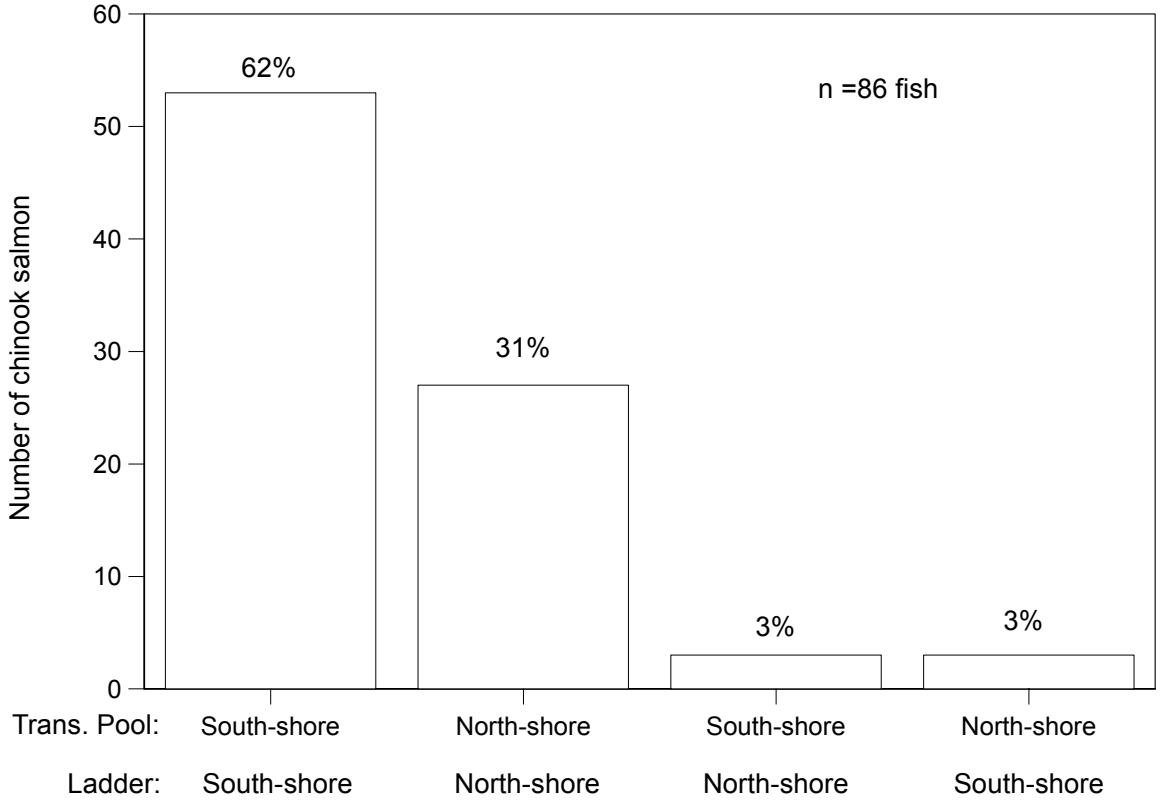


Figure 68. Number of chinook salmon that passed Ice Harbor Dam in 1996, the transition pool first entered, and the ladder used to pass the dam.

The remaining 16 fish (30% of 53) exited the transition pool into the collection channel but did not exit the fishway into the tailrace (Table 10). The north-shore transition pool at Ice Harbor Dam was configured differently than the south-shore pool, in that fish entered the north-shore pool shortly after entering the fishway without passing through a collection channel. Of the 27 chinook salmon that first entered the north-shore pool and passed the dam via the north-shore ladder, 11 (41%) moved straight through the transition pool and entered the ladder, 11 (41%) moved downstream in the transition pool before entering the ladder, and the remaining 5 (19%) moved downstream in the fishway and exited into the tailrace at least once before returning and entering the ladder (Table 9).

Chinook salmon used similar fishway entrances to exit and subsequently reenter a fishway after leaving a transition pool at Ice Harbor Dam. The 12 fish that first entered the south-shore transition pool, exited and reentered the fishway, and ultimately passed the dam via the south-shore ladder, made 57% of their 30 exits to the tailrace from south-shore

Table 10. Number and proportions of chinook salmon that first entered the North- or South-shore transition pools at Ice Harbor Dam and either passed through with no downstream movement, moved downstream in the pool but did not exit before passing into at ladder, exited the pool into the collection channel but not into the tailrace, or exited into the tailrace in 1996. Includes only fish that passed the dam via the same pool they first entered.

	First entered South transition pool: Passed South ladder		First entered North transition pool: Passed North ladder	
Transition pool behavior	N	Percent of 53	N	Percent of 27
Moved straight through	11	21%	11	41%
Moved downstream, but didn't exit	14	26%	11	41%
Exited pool to collection channel	16	30%	N/A	N/A
Exited pool to tailrace	12	23%	5	19%

entrance-1 (Figure 69). Approximately 33% of the exits were from the north-powerhouse entrance, evidence that some fish after first entering the south-shore transition pool, moved down the powerhouse collection channel and exited at the north powerhouse. Reentries of these chinook salmon were distributed among more fishway entrances, but approximately 70% were at south-shore and north-powerhouse entrances. The three fish that first entered the south-shore fishway transition pool and passed the dam via the north-shore ladder, exited the fishways five times, three times at south-shore entrance-1 and twice at the north-powerhouse entrance (Figure 69). The three fish reentered once each at the south-shore and north-powerhouse entrances and three times at the north-shore entrance.

The five fish that first entered the north-shore transition pool, exited and reentered the fishway, and ultimately passed the dam via the north-shore ladder and made exits and reentries only at the north-shore entrance. The three fish that first entered the north-shore transition pool, exited, and then passed the south-shore ladder, made seven exits, all at the north-shore entrance. Seven reentries by the three fish were distributed among shoreline entrances, the north-powerhouse entrance, and an unknown entrance to the south-shore fishway.

Passage times through transition pools and over Ice Harbor Dam were affected by chinook salmon behavior in the pools and whether or not fish exited a pool into a collection channel or the tailrace. For some of the following analyses, fish that passed straight through the transition pools and those that moved downstream but did not exit a pool before passing into a ladder were grouped together as 'fish that passed through a pool on the first attempt.'

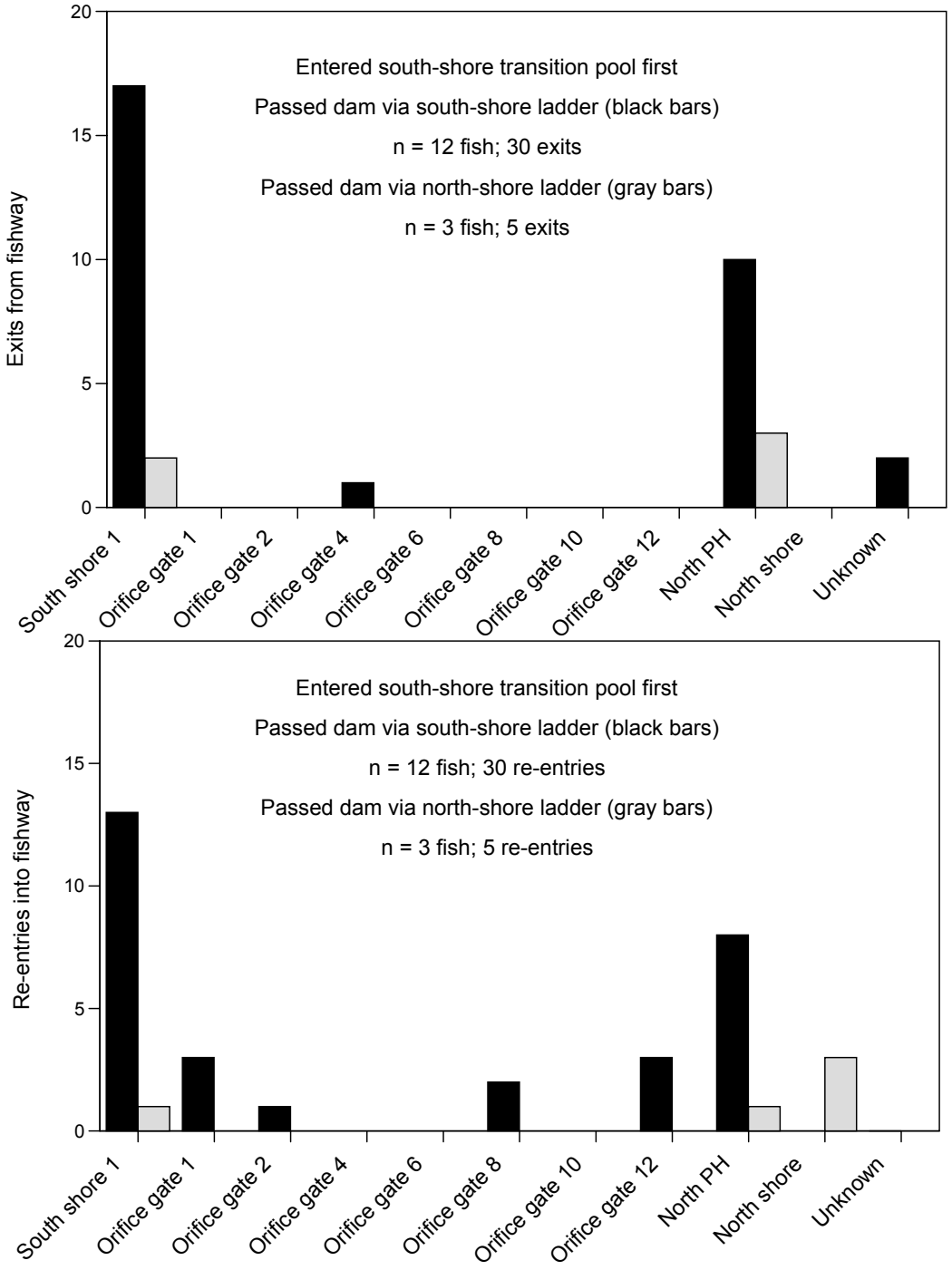


Figure 69. Entrances used to exit and reenter the fishway by chinook salmon that first entered the south-shore transition pool, exited to the tailrace, and passed over Ice Harbor Dam by either the south-shore or north-shore fishways in 1996.

Passage times from first fishway entry to first transition pool entry, from transition pool entry to exit into a ladder, to ascend the ladders, and from first fishway entry to exit the top of the ladders were skewed to the right (Figure 70); as a result, median values for passage time were more representative indicators of overall chinook salmon behavior than mean values.

Median passage times for all 86 fish that passed through transition pools at Ice Harbor Dam were 0.19 h from first fishway entry to first transition pool entry, 0.58 h from first pool to exit into a ladder, 2.11 h to ascend a ladder, and 3.75 h from fish fishway entry to exit from the top of a ladder (Table 11). Median times to first enter a pool and to ascend ladders were similar for all groups of fish, while fish that exited a pool into a collection channel had longer passage times through pools and from first entry to exit from a ladder; chinook salmon that exited from a pool into the tailrace at Ice Harbor Dam had median times to pass the dam that were 1.9 to 3.1 times longer than fish that did not exit pools (Table 11).

For the 47 chinook salmon that moved through an Ice Harbor transition pool and entered a ladder on the first attempt, median passage time from first fishway entry to first entry in a transition pool was 8 min (0.14 h); the 39 fish that made more than one attempt to pass a transition pool took a median of 19 min (0.32 h) to first enter a pool (Table 12). Median times from first entry in a transition pool to exit into a ladder were 13 min (0.22 h) for fish that moved through a pool on the first attempt and 1.71 h for fish that made more than one attempt to pass. Median time to ascend a ladder was about 2 h for the two groups. Median times from first fishway entry to exit from the top of a ladder were 2.62 h for fish that moved through a pool on the first attempt and 6.31 h for fish that made more than one attempt (Figure 70, Table 12).

The 16 fish that turned around in the south-shore transition pool and traveled downstream to the collection channel but did not exit the fishway had median times of 17 min (0.29 h) h from first fishway entry to first transition pool entry, 1.56 h from first transition pool entry to exit the pool and enter the ladder, 2.01 h to ascend the ladder, and 4.11 h from first fishway entry to exit from the top of the ladder (Table 12). Twelve chinook salmon exited the fishway into the tailrace after exiting the south-shore pool; these fish had median passage times of 5.05 h from first pool entry to exit the pool into the ladder, 1.67 h to ascend the ladder, and 16.27 h to exit the top of the ladder after first entering the fishway (Table 12).

Of 27 chinook salmon that first entered the north-shore transition pool and passed the dam via the north ladder, 22 (81%) passed the pool on their first attempt and had median times of 2 min (0.04 h) from first fishway entry to first transition pool entry, 10 min (0.16 h) from first transition pool entry to exit the pool into the ladder, 2.33 h to ascend the ladder, and 3.11 h from first fishway entry to exit from the top of the ladder (Table 12). The 5 fish that made more than one attempt to pass through the north-shore pool had median times of 0.81 h from first pool entry to exit into the ladder and 4.10 h from first fishway entry to exit from the top of the ladder (Table 12).

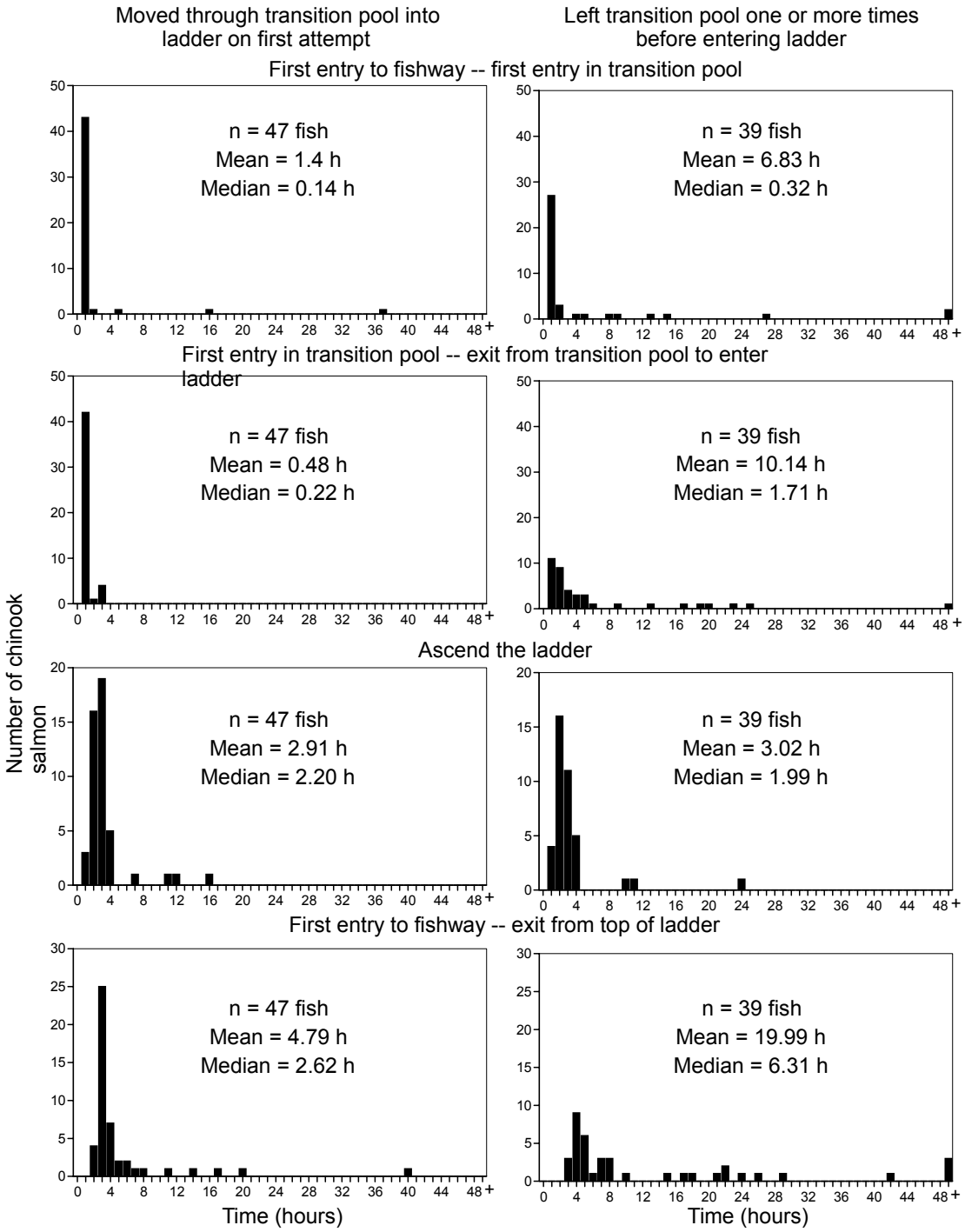


Figure 70. Time to first enter and to pass through a transition pool, to ascend a ladder and to exit from the top of a ladder at Ice Harbor Dam in 1996 by chinook salmon that passed a pool on the first attempt and by those that made more than one attempt.

Table 11. Median and mean passage times for chinook salmon that moved through a transition pool at Ice Harbor Dam with no downstream movement, moved downstream in a transition pool but did not exit before passing into a ladder, exited a transition pool into a collection channel but not into the tailrace, or exited into the tailrace in 1996.

		Median passage time (h) from:			
		First entry	First pool	Ascend	First entry
Transition pool behavior	N	To first pool	To last pool	Ladder	To exit ladder
All behaviors	86	0.19	0.58	2.11	3.75
Moved straight through	22	0.11	0.09	2.29	2.52
Moved downstream, but didn't exit	25	0.17	0.36	2.09	3.08
Exited pool to collection channel	16	0.29	1.56	2.01	4.11
Exited pool to tailrace	23	0.37	2.00	1.99	7.86
			Mean passage time (h):		
All behaviors	86	3.86	4.86	2.96	11.68
Moved straight through	22	0.18	0.26	2.79	3.22
Moved downstream, but didn't exit	25	2.47	0.68	3.02	6.17
Exited pool to collection channel	16	6.73	2.83	3.50	13.06
Exited pool to tailrace	23	6.89	15.22	2.69	24.81

Six fish passed Ice Harbor Dam via a different transition pool than the one first entered. These fish had median times of 3.84 h from first fishway entry to first transition pool entry, 50 min from first pool entry to exit into a ladder, 2.33 h to ascend a ladder, and 7.75 h from first fishway entrance to exit from the top of a ladder.

Results - Lower Granite Dam

Passage times

Fishway entrance use and movements within the fishway at Lower Granite Dam in 1996 were monitored by recording movements of 106 chinook salmon outfitted with transmitters (Figure 71). Median passage times of chinook salmon from release at Bonneville Dam to the Lower Granite tailrace was 25.1 d and was 27.4 d from release to passage over the dam (Figure 72). Median passage times of chinook salmon from the tailrace receiver (about 2 km downstream from Lower Granite Dam) to first recorded approach at an entrance, first entry into the fishway, and passage from top of the ladder were 1.66 h, 6.47 h, and 38.16 h (1.6 d)

Table 12. Median and mean passage times for chinook salmon that moved through the North- and South-shore transition pools at Ice Harbor Dam by fish that passed through a transition pool on their first attempt or exited a transition pool into a collection channel or the tailrace, by the first pool entered and the ladder eventually passed in 1996.

				Median passage time (h) from:			
Transition pool behavior	First pool	Ladder passed	N	First entry to first pool	First pool to last pool	Ascend ladder	First entry to exit ladder
Passed through pool on first attempt	South	South	25	0.19	0.27	1.92	2.62
	North	North	22	0.04	0.16	2.33	3.11
	All fish[1]		47	0.14	0.22	2.20	2.62
Exited pool to Collection channel	South	South	16	0.29	1.56	2.01	4.11
Exited pool to tailrace	South	South	12	0.26	5.05	1.67	16.27
	South	North	3	3.29	0.14	3.27	7.64
	North	North	5	0.03	0.81	2.20	4.10
	North	South	3	4.39	1.55	1.57	7.86
Exited pool one or more times	All fish[1]		39	0.32	1.71	1.99	6.31
				Mean passage time (h):			
Passed through pool on first attempt	South	South	25	0.24	0.57	2.25	3.07
	North	North	22	2.71	0.38	3.66	6.75
	All fish[1]		47	1.40	0.48	2.91	4.79
Exited pool to Collection channel	South	South	16	6.73	2.83	3.50	13.06
Exited pool to tailrace	South	South	12	8.45	26.75	2.37	37.58
	South	North	3	5.72	1.33	5.69	12.73
	North	North	5	1.47	4.36	2.50	8.33
	North	South	3	10.89	1.12	1.25	13.26
Exited pool one or more times	All fish[1]		39	6.83	10.14	3.02	19.99

[1] See Figure 70 for passage time distributions

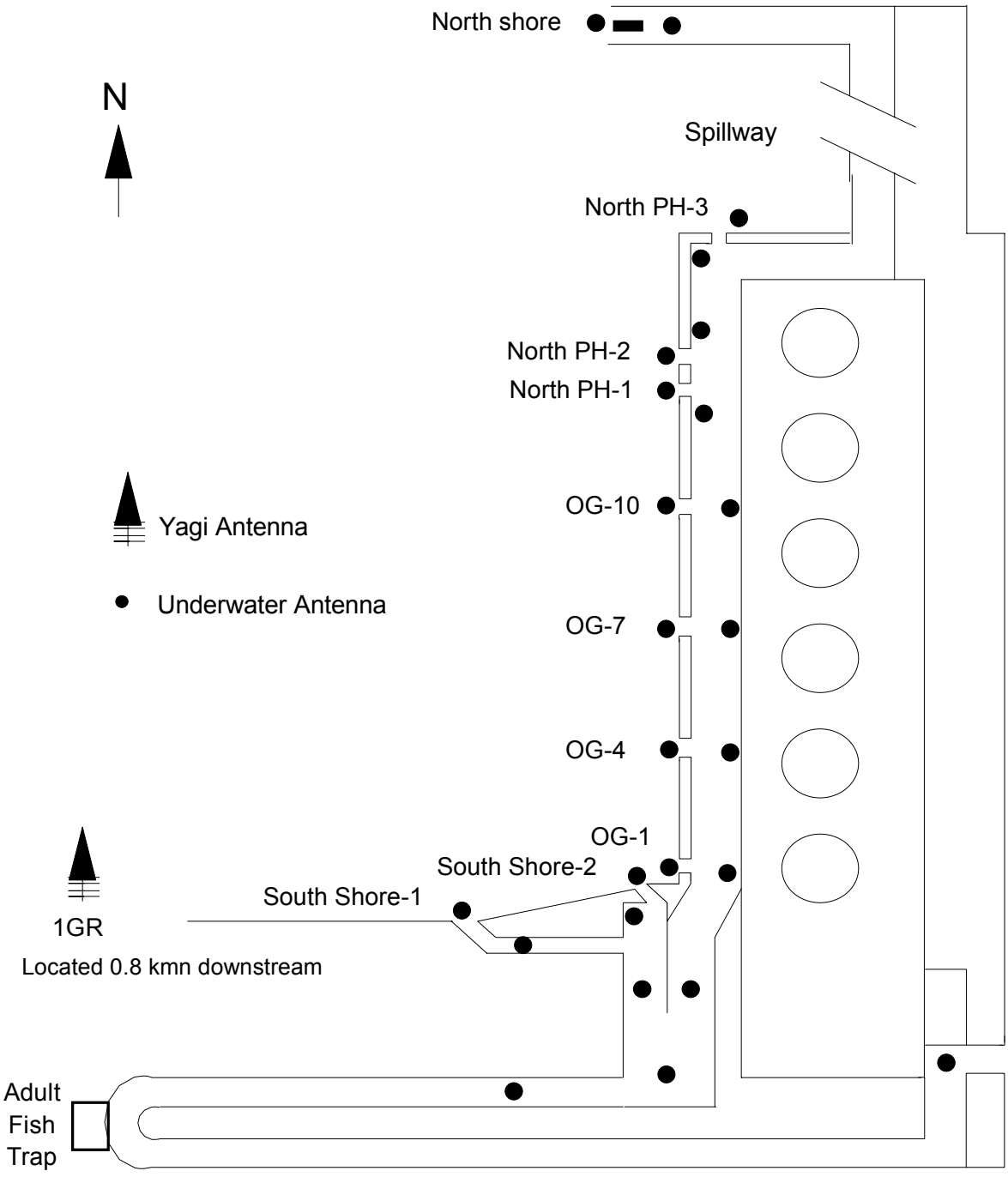


Figure 71. Location of antennas and fishway entrances at Lower Granite Dam in 1996 when chinook salmon were passing the dam.

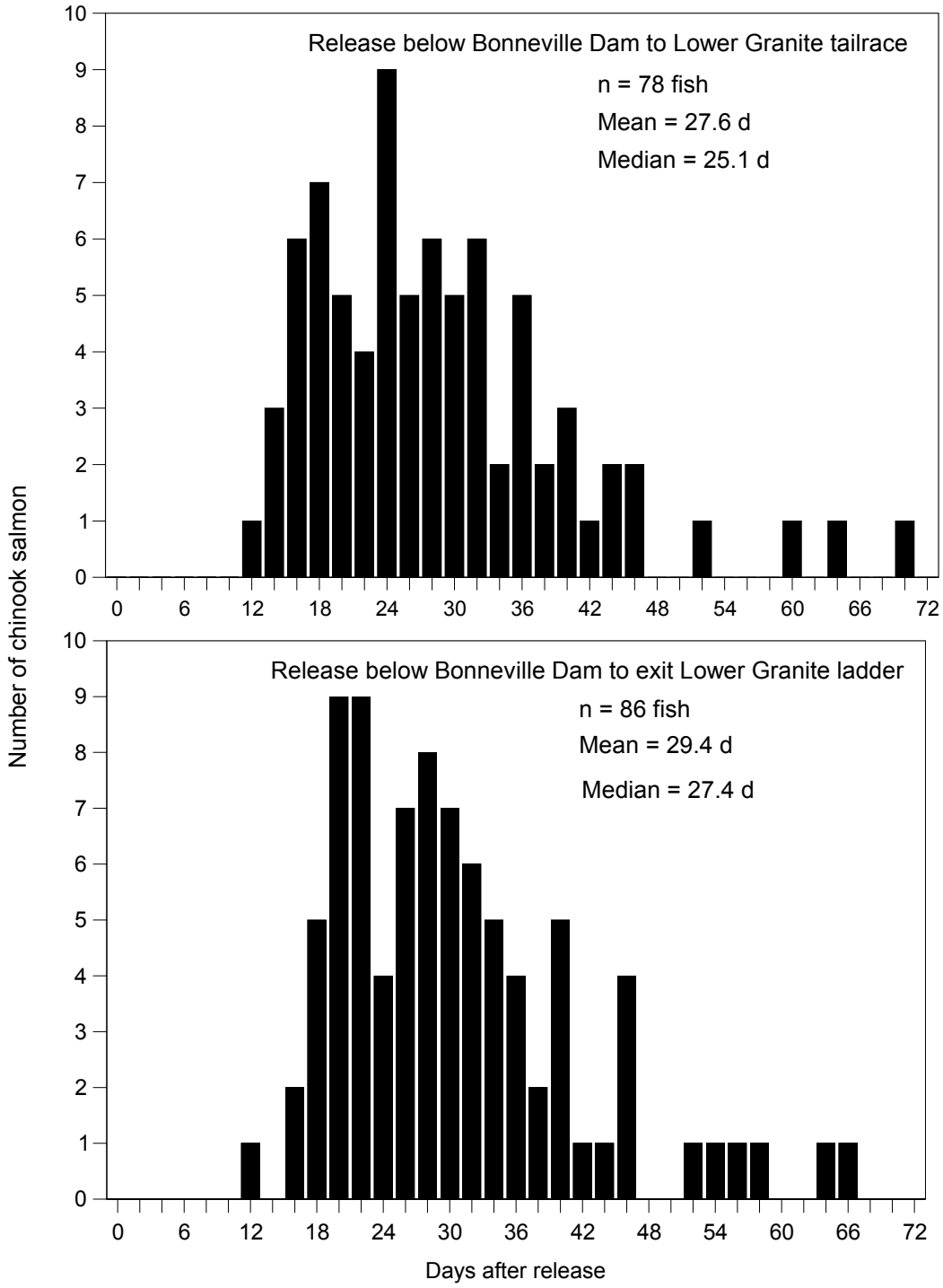


Figure 72. Number of chinook salmon and days to migrate from the release site below Bonneville Dam to the Lower Granite tailrace and to exit from the top of the ladder at Lower Granite Dam in 1996.

(Figure 73). Median time from first approach at a fishway to first entrance into the fishway at Lower Granite Dam was 3.10 h, and median time from first fishway entrance to exit from the top of the ladder was 24.54 h (Figure 74).

Most fish entered the fishway within 4 to 20 h after passing the tailrace receiver, but several fish took more than 10 d to pass the dam because they spent a day or more in the fishway or spent time exiting and reentering the fishway. Some fish were in the fishway at nightfall and usually stayed there until morning; others spent time migrating up and down the powerhouse collection channel (Figure 75).

Passage times between the tailrace and passage from the top of the ladder also included time some fish used when making multiple entries to the ladder and delays resulting from operation of the adult fish trap located in the ladder: most radio-tagged fish were diverted into the trap for inspection.

Fishway Use

Approaches to fishways: Chinook salmon had a tendency to first approach the dam at south- and north-shore entrances, although 13 fish first approached orifice gate 1, and at least one fish first approached at each entrance (Figure 76). When all approaches at fishway entrances made by chinook salmon in 1996 were considered, approaches were most frequent at south-shore entrance-2, and then fairly evenly distributed between orifice-gate entrances, north-powerhouse entrance-1, and south-shore entrance-1 (Figure 76). The large number of approaches to entrances (averaged 50 per fish, median 20.5 per fish, 5,262 total) is an indication that chinook salmon moved back and forth along the dam and wandered in the tailrace before entering the fishway. Of 106 chinook salmon monitored at Lower Granite Dam, 3 approached at unknown locations, 5 approached the dam 1 time, 29 (27%) approached the dam 1 to 10 times, and several fish approached various entrances 100 or more times (Figure 77). Multiple approaches per fish at each fishway entrance is an indication that many chinook salmon moved back and forth along the dam and approached entrances multiple times before making their final entry and passing the dam.

Entries to and exits from fishways: The majority of first entries into the fishway occurred at the north-shore entrance. When total entries were considered, most occurred at north- and south-shore entrances, as well as at orifice gate 1 and the north-powerhouse entrance (Figure 78). Although fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Orifice-gate entrances at Lower Granite Dam were 0.61 m high and 1.83 m wide, with the center of the opening 1.22 m below the surface; orifice gates had lower capacity (design of 60-80 cfs) than other entrances. North-powerhouse entrances were 1.83 m wide and 2.44 m deep and discharged 620 cfs. Each south-shore entrance was 1.22 m wide and 2.44 m deep, with a discharge of 400 cfs total. The north-shore entrance was made up of two openings, 1.83 m wide and 2.14 m deep, with discharges of 560 cfs total. As at other dams, the location, size and discharge of entrances likely influenced use by chinook salmon.

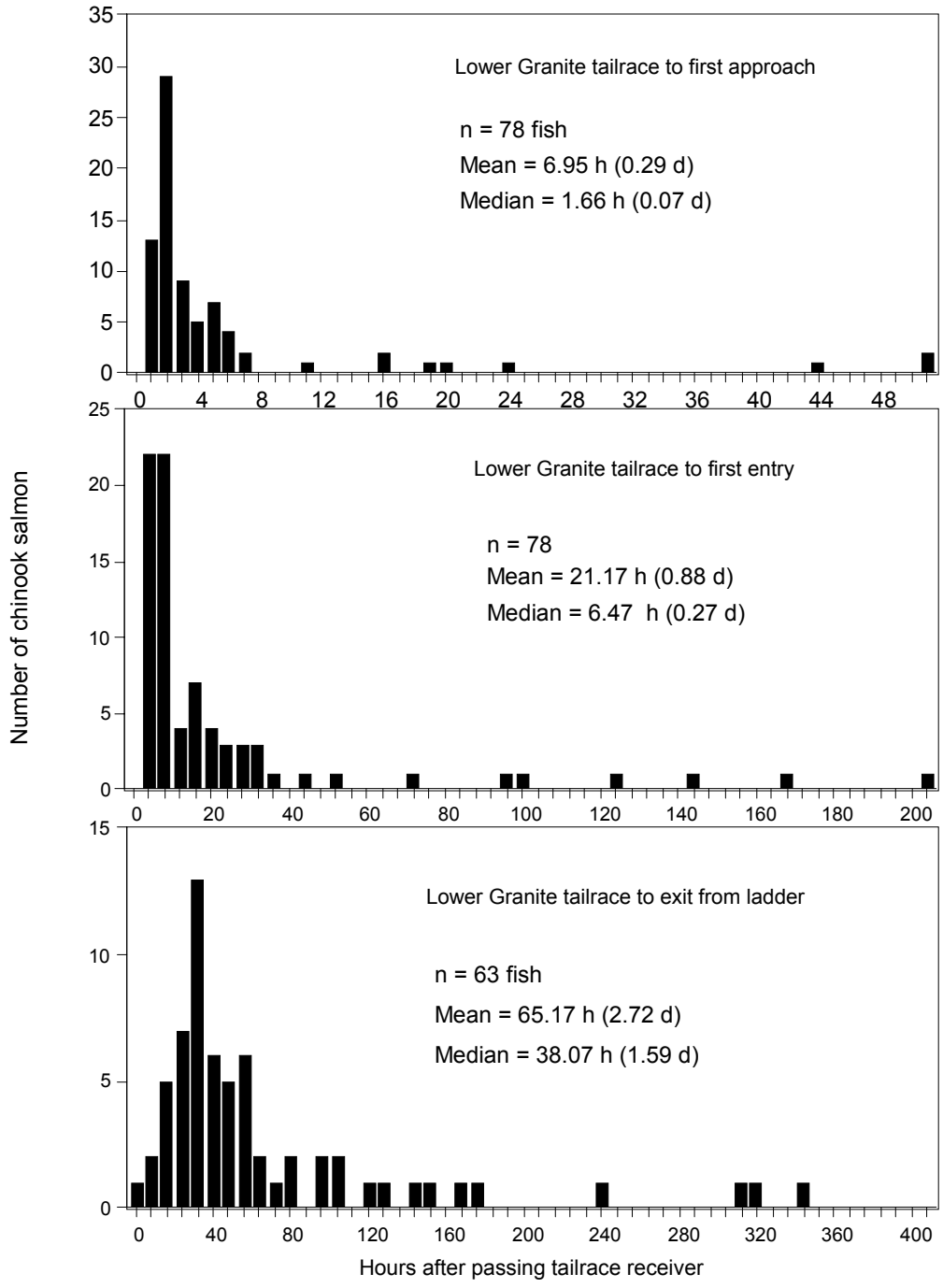


Figure 73. Number of chinook salmon and time to pass from the Lower Granite Dam tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladder in 1996.

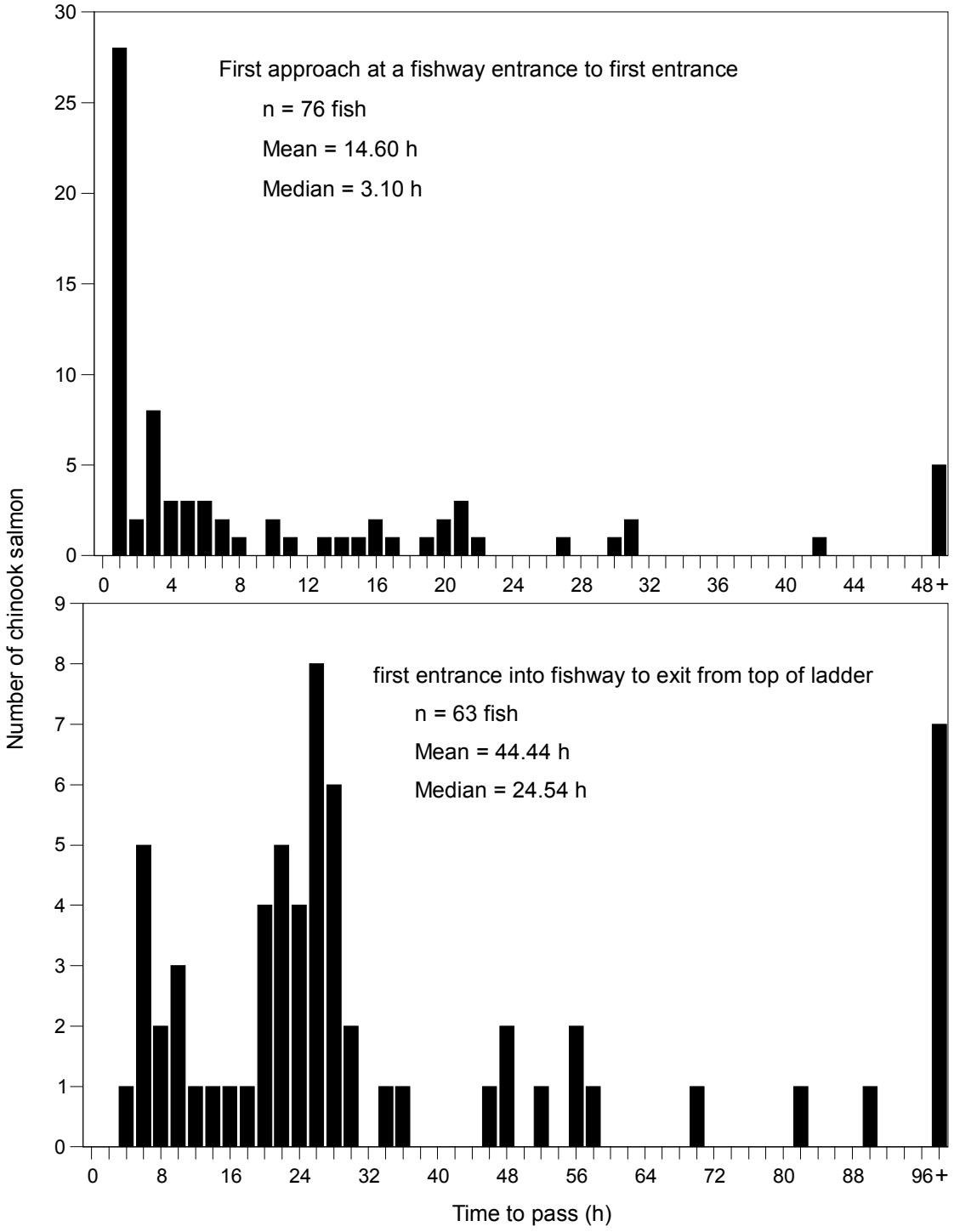


Figure 74. Number of chinook salmon and time to pass from first approach at a fishway entrance to first entry into a fishway and from first fishway entry to exit from the top of the ladder at Lower Granite Dam in 1996.

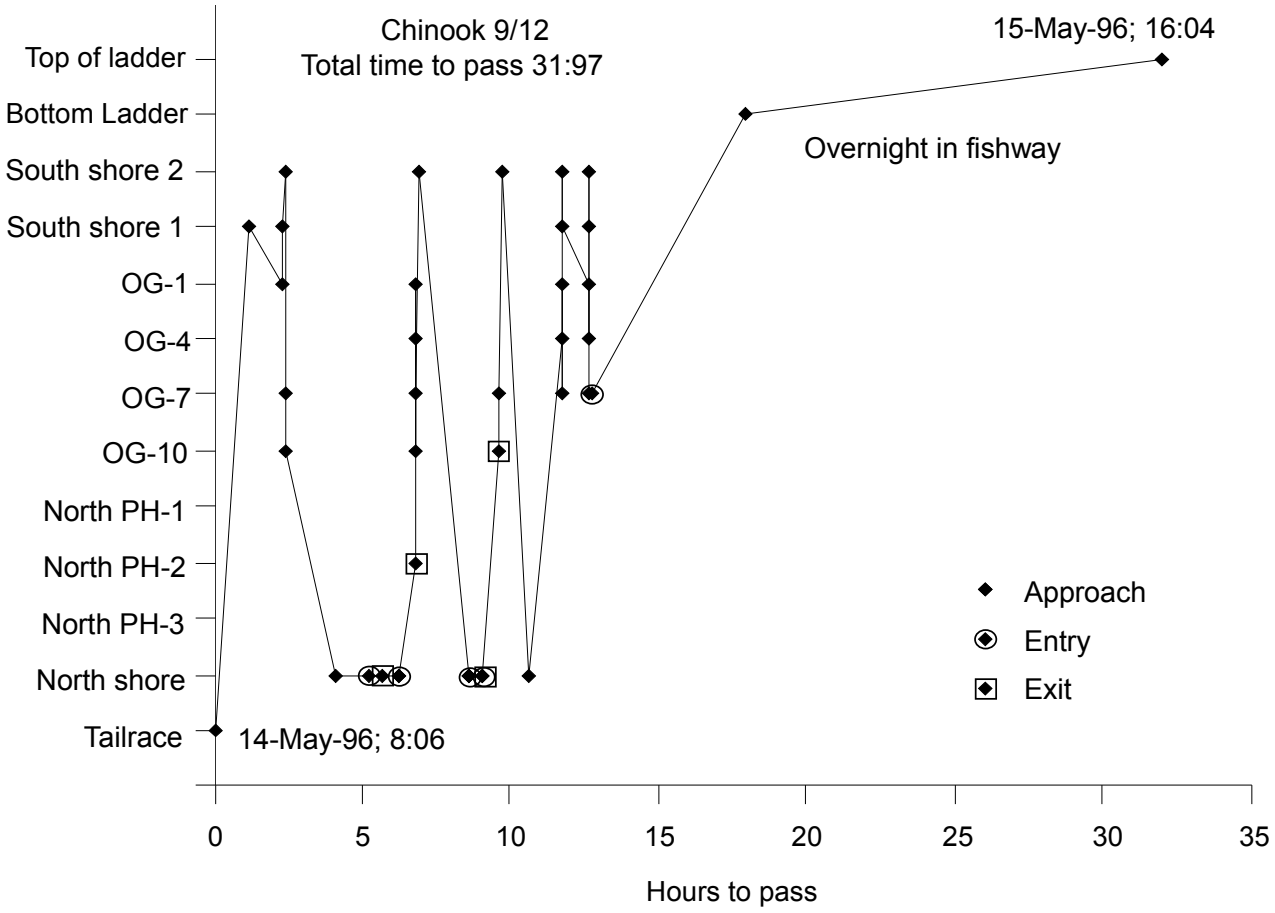


Figure 75. Illustration of the types of movements made by some chinook salmon in spring and summer 1996 when approaching Lower Granite Dam and entering, exiting, and passing through the fishway.

Of the 106 chinook salmon monitored at Lower Granite Dam, one did not enter the fishway. Of the chinook salmon that entered, 32 (30%) entered the fishway at Lower Granite Dam 1 time while the remainder exited and reentered 1 to 80 times (Figure 79). In 1996, chinook salmon entered the Lower Granite fishway 5.4 times on average (median of 3 entries).

Chinook salmon exited the fishway via all entrances, but the highest numbers did so at the north-powerhouse entrances and at north- and south-shore entrances. Few exited at orifice gates (Figure 80). Of the 105 chinook salmon that entered the fishway at Lower Granite Dam in 1996, 31 (30%) did not exit the fishway, 65 (62%) fish exited from 1 to 10 times, and 9 (9%) fish exited more than 10 times (Figure 79). Chinook salmon exited the fishway 4.6 times on average (median of 2 exits). Many fish moved up the collection channel to the transition pool located at the bottom of the ladder, returned down the channel,

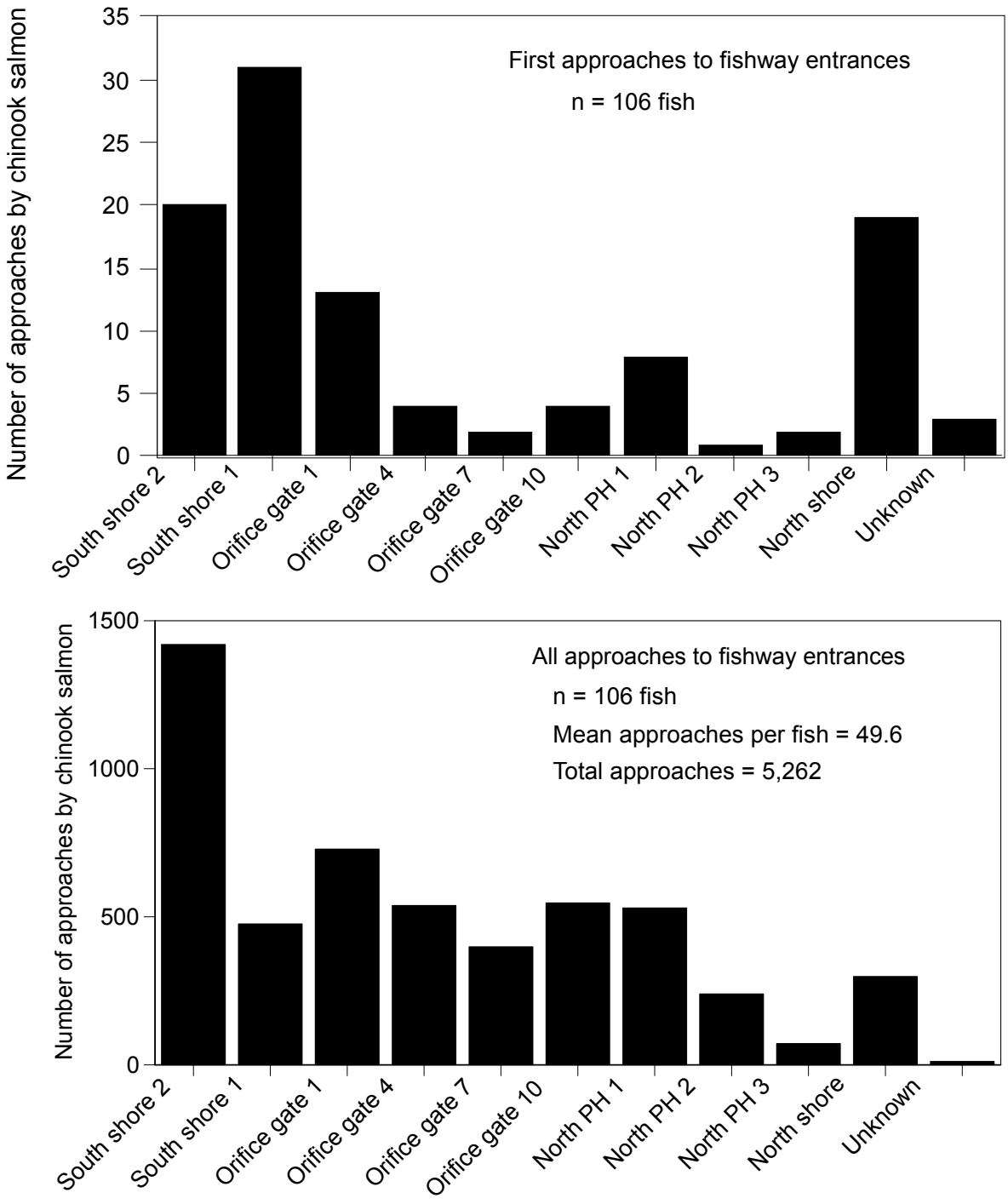


Figure 76. Number of first and total approaches at Lower Granite Dam fishway entrances by chinook salmon in 1996.

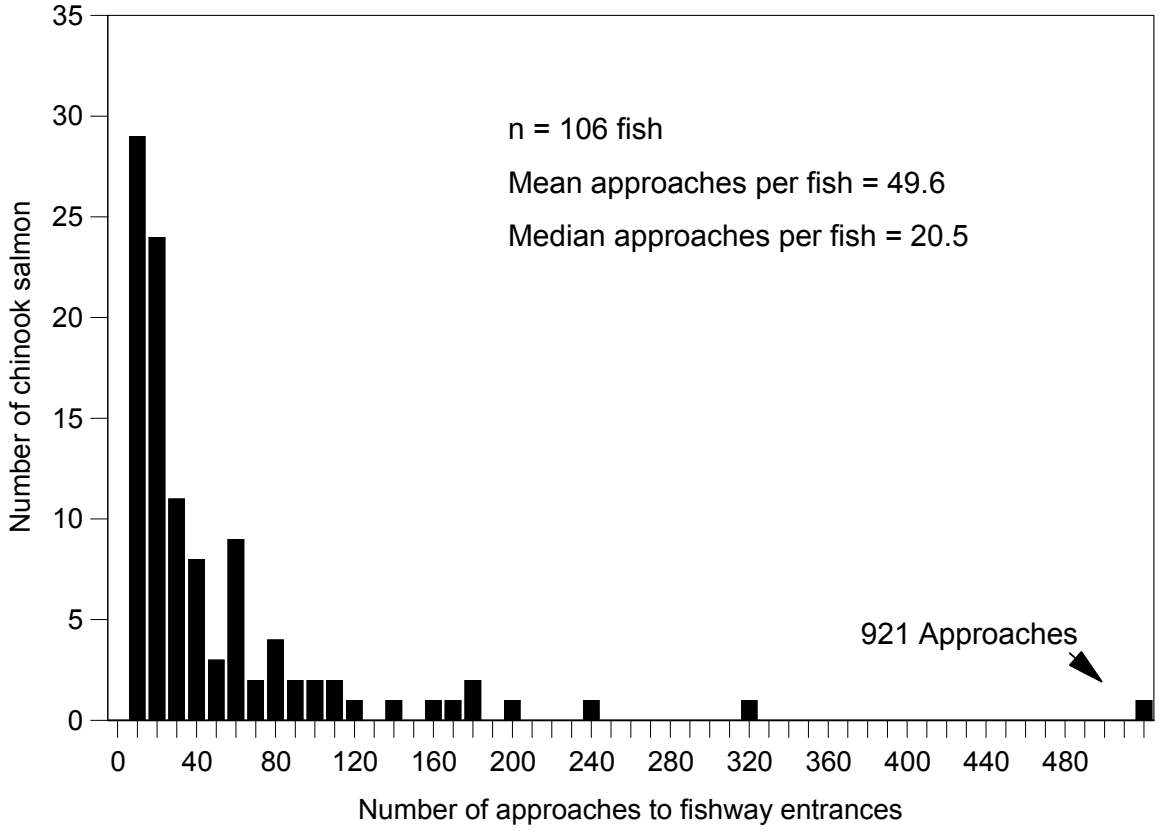


Figure 77. Number of chinook salmon that approached Lower Granite Dam fishway entrances one or more times in 1996.

and exited from the fishway one or more times. The median time from the first entry and first exit from fishways at Lower Granite Dam was 0.79 h.

Net entry rates (known entries minus exits) for fishway entrances ranged from -7 to 27 for first entries and exits, and -42 to 80 for all entries and exits (Figure 81). The north-shore entrance was the most effective, followed by orifice gate 1 and the south-shore entrance-2. There were more exits than entries by chinook salmon at the north-powerhouse entrance-1, south-shore entrance-1, and orifice gate 10.

Although some entrances had negative net entry rates, those sites were the last entrances used before passing the dam for 18 fish (17%) (12 at south-shore entrance-1, 5 at north-powerhouse entrance-1, and 1 at orifice gate 10) (Figure 82). The north-shore entrance was the most frequently used last entrance before passage of the dam.

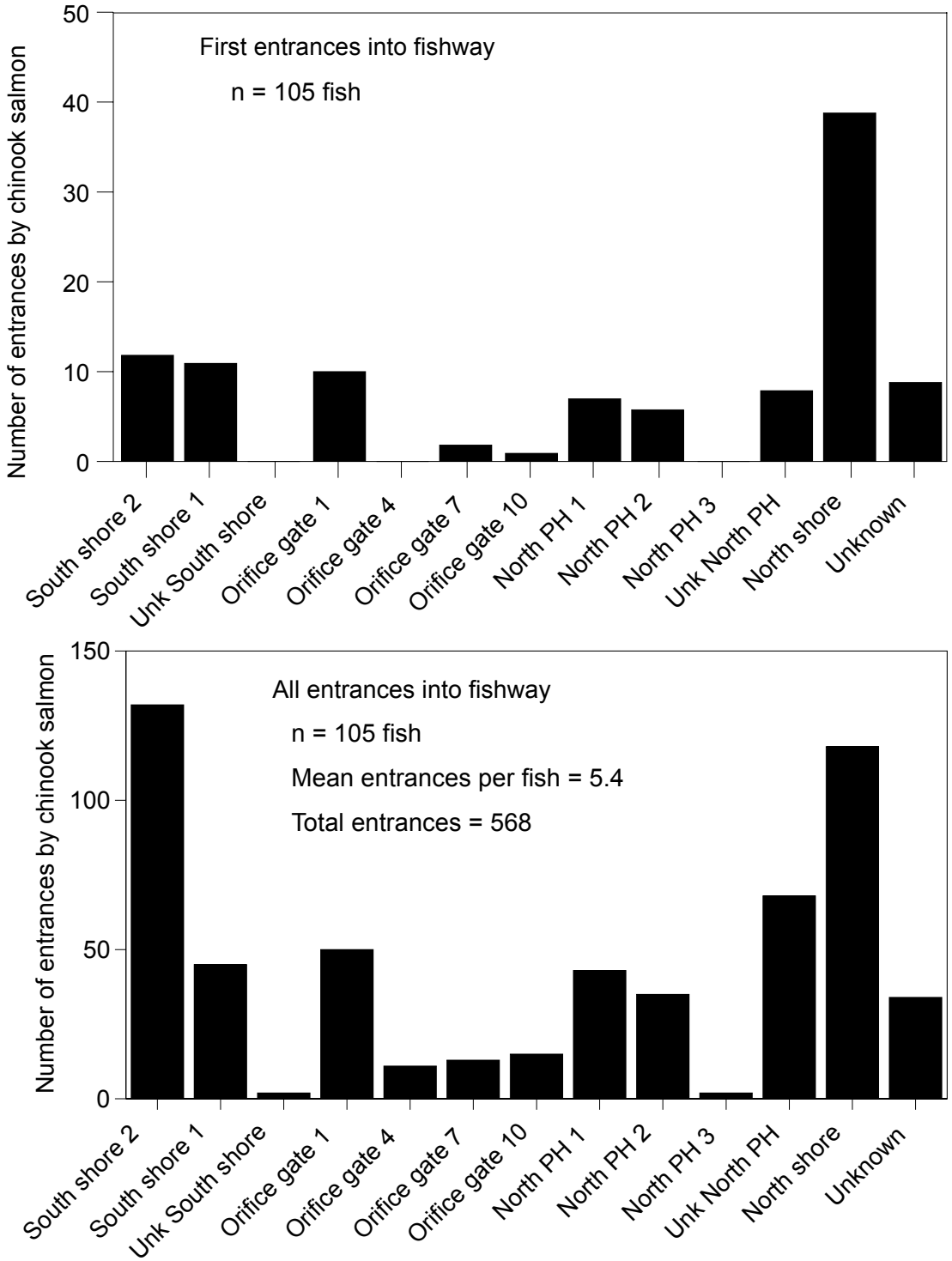


Figure 78. Number of first and total entries at Lower Granite fishway entrances by chinook salmon in spring and summer 1996.

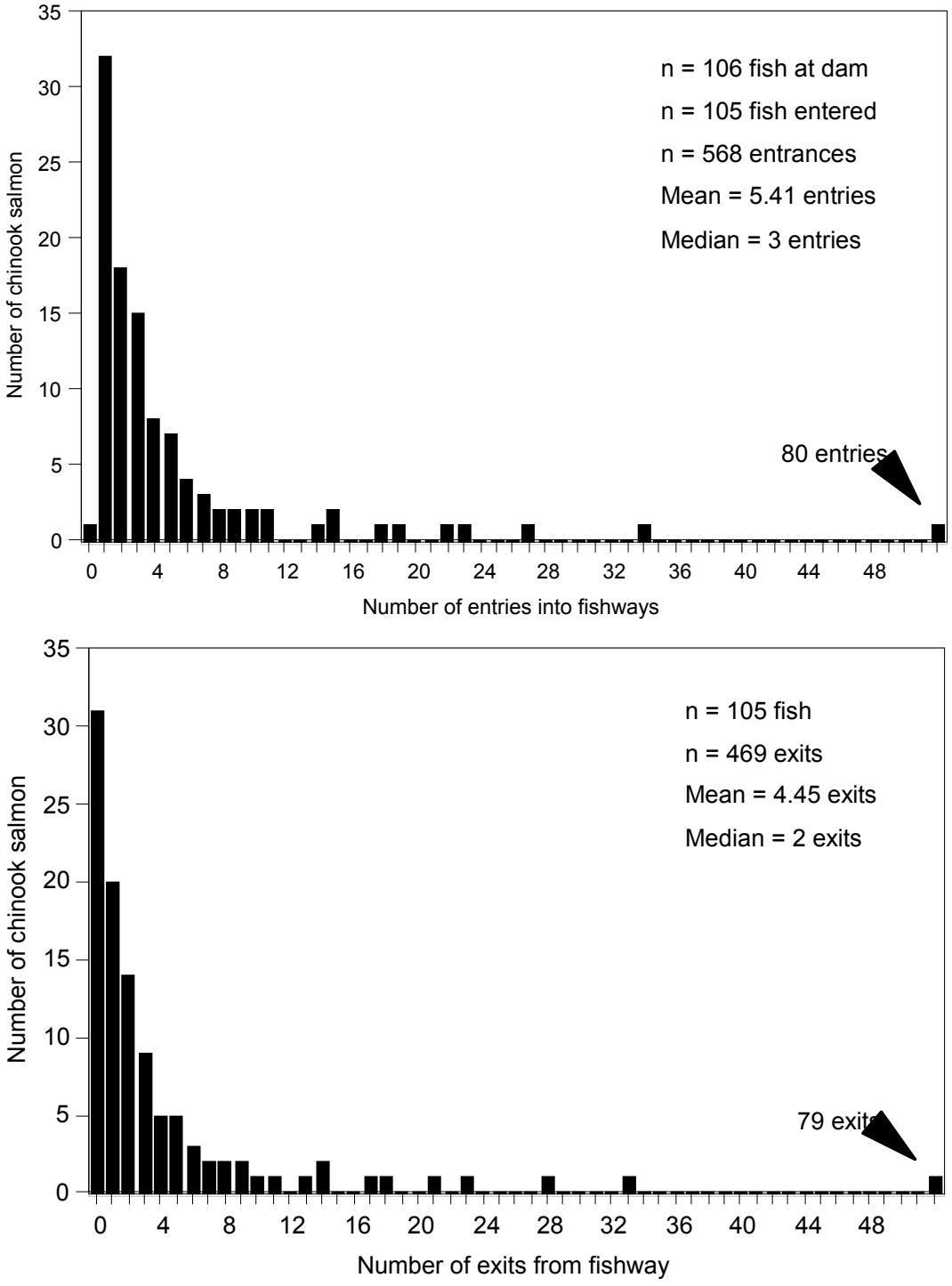


Figure 79. Number of chinook salmon that did not enter or exit, and those with multiple entries and exits into or from the fishway at Lower Granite Dam via the entrances in 1996.

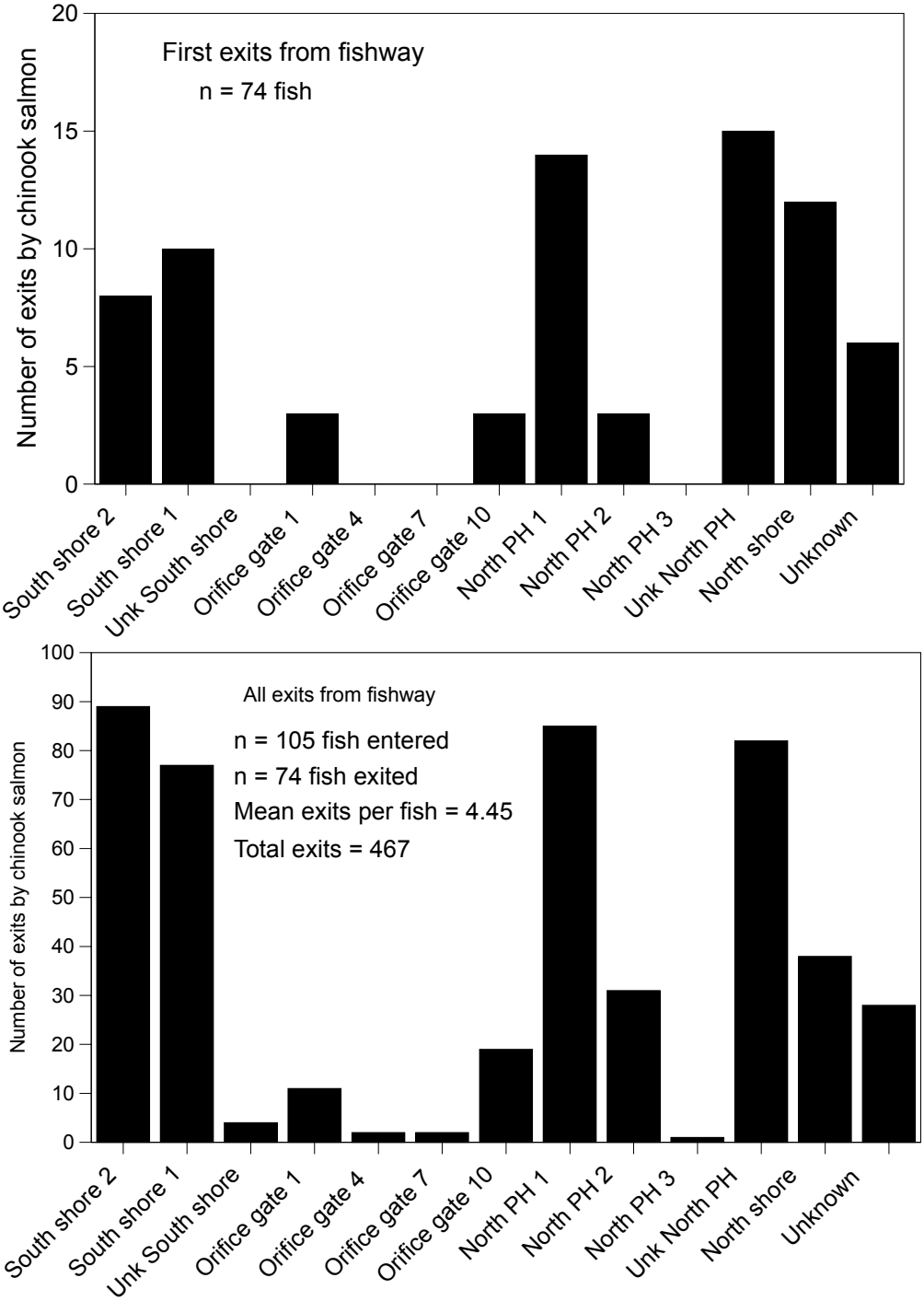


Figure 80. Number of first and total exits from the fishway for each entrance by chinook salmon at Lower Granite Dam in 1996.

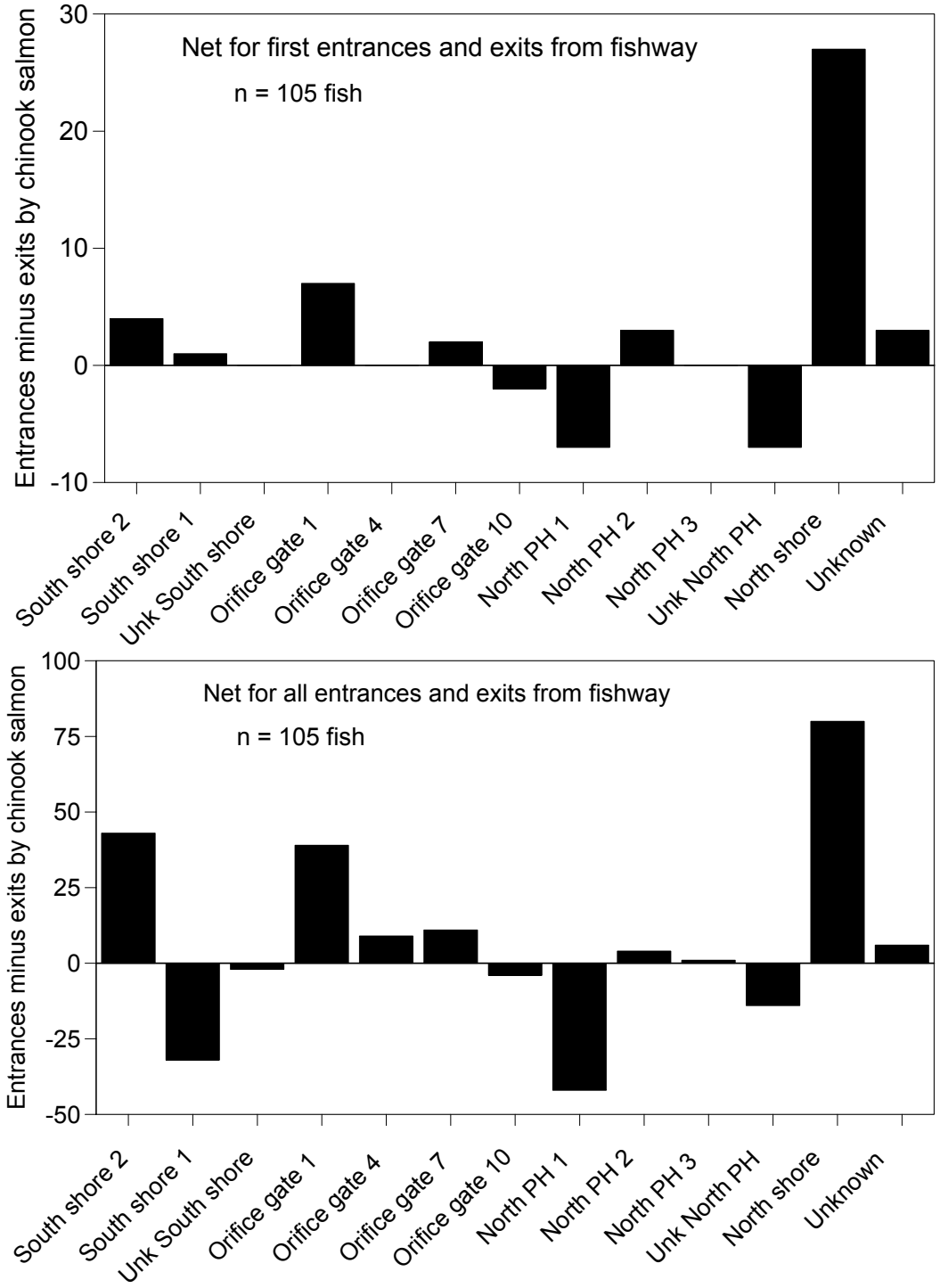


Figure 81. Net number of first and total entries and exits from fishway for each entrance by chinook salmon at Lower Granite Dam in 1996.

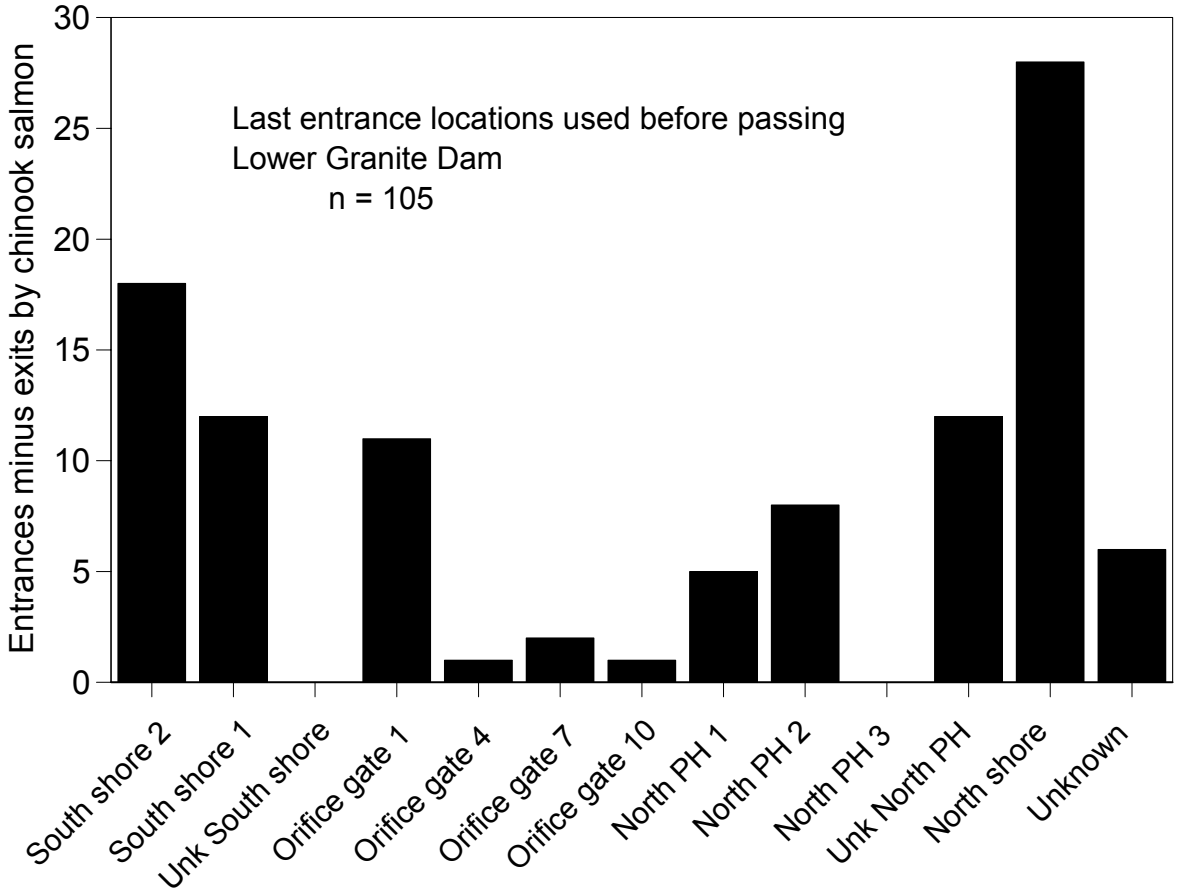


Figure 82. Last entrance locations for chinook salmon at Lower Granite Dam in 1996.

The furthest upstream fish reached before making their first exits at Lower Granite Dam were spread between the powerhouse collection channel (40.5% of 74 fish), south-shore entrance and transition pool (47.3%), and north-shore entrance and transition pool (12.2%). One salmon did not pass after reaching Lower Granite Dam. This fish only reached the tailrace receiver and then returned to a downstream tributary.

Movements Through Transition Pools

We analyzed behavior of 85 chinook salmon in transition pools at Lower Granite Dam in 1996. Five fish (6%) moved straight through the transition pool and entered the ladder, and 12 (14%) turned around in the transition pool, moved downstream and remained in the transition pool before entering the ladder. Eighty percent (68) turned around, moved downstream, and exited the transition pool before passing the dam, including 21 (25% of 85) that exited the transition pool into the collection channel but did not exit the fishway into the tailrace, and 47 (55% of 85) that exited the fishway into the tailrace.

Fishway entrances used by chinook salmon to exit the fishway after leaving the transition pool were similar to those used to subsequently reenter the fishway (Figure 83). About 41%

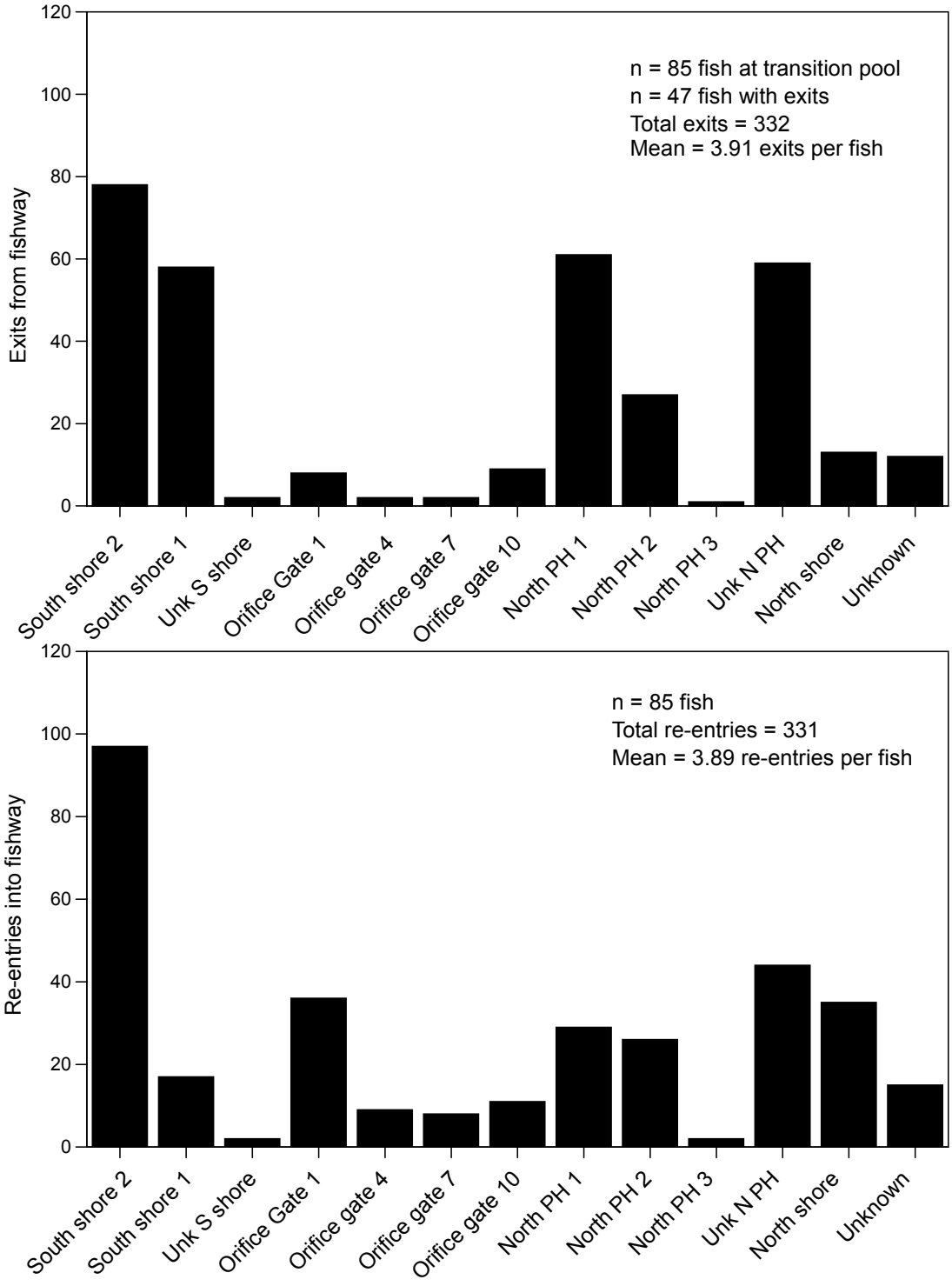


Figure 83. Entrances used to exit and reenter the fishway by chinook salmon that exited from the transition pool into the tailrace at Lower Granite Dam in 1996.

of the exits of chinook salmon were at south-shore entrances, 45% were at north-powerhouse entrances, and the remaining 14% were mainly at orifice-gate entrances. Reentries by chinook salmon were distributed among fishway entrances, with 34% at south-shore entrances (primarily entrance 1), 31% at north-powerhouse entrances, and 35% at north-shore and orifice-gate entrances.

Fish that passed straight through the transition pool (5) and those that hesitated before entering the ladder (12) were grouped together for the following analyses and were referred to as 'fish that passed through the pool into the ladder on the first attempt.' Passage times from first fishway entry to first transition pool entry, from first pool entry to exit into a ladder, to ascend the ladder, and from first fishway entry to exit the top of the ladder were skewed to the right; as a result, median values for passage time were more representative indicators of overall chinook salmon behavior than mean values.

For the 17 chinook salmon that moved through the Lower Granite transition pool and entered the ladder on the first attempt, median passage time from first fishway entry to first transition pool entry was 26 min (0.43 h); the 68 fish that made more than one attempt to pass the transition pool took a median of 56 min (0.93 h) to first enter the pool (Table 13). Median times from first transition pool entry to exit into the ladder were 13 min (0.22 h) for fish that moved through the pool on the first attempt and 9.02 h for fish that made more than one attempt to pass. Twelve chinook salmon were taken from the Lower Granite trap to hatcheries, and consequently did not have a record at the top of the ladder. Of fish that were recorded at the top of the ladder, median times to ascend a ladder were 19.84 h (mean 15.92 h) for 13 fish that passed through the transition pool on the first attempt, and 7.73 h (mean 12.74 h) for 60 chinook salmon that made more that one attempt to pass the pool. Median times from first fishway entry to exit from the top of the ladder were 20.83 h for fish that moved through the pool on their first attempt and 29.04 h for fish that made more than one attempt (Table 13).

Slightly more than 50% of the fish that made multiple attempts to pass through the transition pool entered the ladder in less than 8 h, and 13% took more than 24 h. Ten chinook salmon that made more than one attempt to pass the transition pool took more than 4 d to pass the dam after first entering the fishway, and another 11 fish took more than 2 d to pass the dam.

The 21 (25% of 85) fish that turned around in the transition pool and traveled downstream in the collection channel but did not exit the fishway before passing the pool and entering the ladder had median times of 43 min (0.71 h) from first fishway entry to first transition pool entry, 30 min (0.50 h) from first pool entry to entry into the ladder, 12.19 h to ascend the ladder, and 22.84 h from first fishway entry to exit the top of the ladder (Table 13).

Fish (68) that exited the fishway after leaving the transition pool had median times of 1.06 h to first enter the transition pool, 19.33 h from first pool entry to entry into the ladder; 60 of the 68 fish took 6.72 h to ascend the ladder, and 44.74 h from first fishway entry to exit the

Table 13. Median and mean passage times for chinook salmon that moved through transition pool at Lower Granite Dam by fish that passed through a transition pool on their first attempt or exited a transition pool into a collection channel or the tailrace. 12 fish were taken from the Lower Granite adult trap to hatcheries and were therefore not include in passage times summaries for ascending and exiting from the ladder. N in parenthesis was for passage times to ascend the ladder and from first entry to exit ladder; 12 fish did not exit from the top of a ladder because they were transported to a hatchery.

		Median passage time (h) from:			
Transition pool behavior	N	First entry to first pool	First pool to last pool	Ascend ladder	First entry to exit ladder
All behaviors	85 (73)	0.83	3.82	9.15	25.99
Passed through pool on first attempt	17 (13)	0.43	0.22	19.84	20.83
Exited pool to collection channel	21 (18)	0.71	0.50	12.19	22.84
Exited pool to tailrace	47 (42)	1.06	19.33	6.72	44.74
Exited pool one or more times	68 (60)	0.93	9.02	7.73	29.04
		Mean passage time (h):			
All behaviors	85 (73)	9.36	25.40	13.31	51.23
Passed through pool on first attempt	17 (13)	7.86	1.55	15.92	26.20
Exited pool to collection channel	21 (18)	8.18	0.68	13.68	22.13
Exited pool to tailrace	47 (42)	10.44	45.07	12.34	71.46
Exited pool one or more times	68 (60)	9.74	31.36	12.74	56.66

top of the ladder, and the other 8 fish were transported from the Lower Granite trap facility to hatcheries and did not have a record at the top of the Lower Granite ladder.

Discussion

This study of adult spring–summer chinook salmon behavior at Bonneville, McNary, Ice Harbor and Lower Granite dams successfully used radio telemetry to evaluate passage and delay concerns at mainstem Columbia and Snake River dams. We believe the sampled salmon were generally representative of the overall run from April through June, 1996, because fish taken from the Washington-shore ladder at Bonneville Dam and released downstream returned to the Washington-shore and Bradford Island fishways in similar proportions, passed successive upstream dams in proportion to the overall run and returned to major tributaries in patterns similar to the overall run (Bjornn et al. 2000). Because no summer chinook salmon were radio-tagged in July, the behaviors we observed by fish between April and June should not be inferred to apply to the later summer migrants.

Compared to means from 1986-1995, the 1996 spring–summer chinook salmon run included a relatively small Snake River component, and peak counts were two to three weeks later than average. Overall timing of the migration may have been later than average

because Columbia and Snake River discharge were nearly double the 1986-1995 average and were among the highest runoff years recorded since 1975, when Lower Granite Dam was completed. Cooler mainstem water temperatures in 1996 may also have contributed to the later timing of the run.

High flow, with associated high spill and turbidity likely affected salmon behaviors at the four study dams. We expect that searching behaviors in and around fishways and passage times at the dams may have been longer in this study than in years with low flow, spill or turbidity. Project operations in 1996 included nearly continuous spill at all dams, although levels were relatively low in parts or all of July at the four study dams. Powerhouse priority at Bonneville Dam included 15 to 20% of total flow through Powerhouse 1 and 28 to 34% through Powerhouse 2 in April, May and June; approximately 29% of total flow was routed through each powerhouse in July. Monthly proportions of river flow released as spill ranged from 41 to 52% at Bonneville, 40 to 65% at McNary, 35 to 51% at Ice Harbor and 34 to 40% at Lower Granite dams for all months (except spill averaged ~ 6% of total flow at Lower Granite Dam in July). Differences between day and night-time allocation of flow were limited at all dams, although there was a tendency for diminished turbine discharge at night at Ice Harbor and Lower Granite dams, with associated increases in spill during those times.

In 1996, median passage times from release downstream from Bonneville Dam to first records at a dam were 0.8 d to Bonneville Dam, 11.1 d to McNary Dam, 16.2 d to Ice Harbor Dam and 25.1 d to Lower Granite Dam. Most radio-tagged chinook salmon approached and entered fishways at the dams within hours after passing tailrace receivers. Passage time distributions were right-skewed, and mean times were higher than medians. It seems likely that the natural variation of salmon migration times under pre-dam conditions would also have been skewed; some fish would have migrated slower than the bulk of the run. What is unknown is if the portion of the radio-tagged salmon that took longer to pass dams or ascend segments of the river was higher than that during pre-dam conditions. Rand and Hinch (1998) reported migration swim speeds of adult sockeye salmon in the Fraser River were skewed to the left and swim speeds became slightly more skewed in constricted (narrower river widths, faster flow velocities) versus nonconstricted river reaches (Figure 1 in Rand and Hinch 1998). A similar effect may occur when adult salmon pass dams; dams may cause some fish to delay their migration analogous to natural constrictions in free-flowing rivers.

Chinook salmon made multiple approaches at fishway entrances in 1996. Median approaches were comparable at Bonneville Dam (13 per fish), McNary (14), and Ice Harbor (11) dams, but higher at Lower Granite Dam (20.5 approaches per fish) in 1996. At Bonneville Dam, most first approaches occurred at the Bradford Island fishway, primarily at the south-shore and sluice gates near the southern end of Powerhouse 1 the north-shore entrances at powerhouse 2. Fish tended to first approach at orifice gates at McNary and Ice Harbor dams, and at the south-shore entrance at Lower Granite Dam (Table 14). When all approaches by chinook salmon were considered, the highest number at all dams were at orifice or sluice gates, an indication that fish were attracted by the turbine outflow at dams (Table 14).

Table 14. Percentage of first and total approaches to fishways, entrances into fishways, and exits from fishways by chinook salmon at Bonneville, McNary, Ice Harbor and Lower Granite dams in 1996. (Entrances combined by location or type.)

Location	Percentage of:					
	First Approaches	Total Approaches	First Entries	Total Entries	First Exits	Total Exits
Bonneville, Bradford Is. fishway						
S Shore Powerhouse 1	22	6	24	21	**40**	**41**
Sluice Gates	**58**	**56**	23	23	11	12
N Shore Powerhouse 1	11	33	8	8	6	4
B Branch (S Spillway)	7	5	**34**	**38**	29	32
Unknown	2	< 1	11	10	15	12
Bonneville, WA-shore fishway						
Cascades Island (N Spillway)	5	4	17	19	10	12
S Shore Powerhouse 2	9	9	24	22	19	23
Orifice Gates	18	**54**	9	12	15	13
N Shore Powerhouse 2	**66**	32	**43**	**41**	**48**	**46**
Unknown	2	< 1	6	6	9	6
McNary Dam						
S Shore	2	2	38	31	36	25
Orifice Gates	**68**	**89**	10	16	7	6
N Powerhouse	4	3	4	7	14	28
N Shore	20	6	**42**	**40**	**40**	**38**
Unknown	5	< 1	5	6	3	4
Ice Harbor Dam						
S Shore	16	20	17	21	29	31
Orifice Gates	**61**	**71**	**30**	25	2	2
N Powerhouse	6	4	21	20	**34**	**35**
N Shore	16	5	27	**29**	29	30
Unknown	1	< 1	5	4	3	3
Lower Granite Dam						
S Shore	**48**	36	22	**32**	24	36
Orifice Gates	22	**42**	12	16	8	7
N Powerhouse	9	16	25	26	**43**	**42**
N Shore	18	6	**37**	21	16	8
Unknown	3	< 1	9	6	8	6

Although adult chinook salmon approached fishways at all entrances at each dam, they entered and exited mostly at the largest (in size and discharge) entrances in 1996. The larger fishway entrances were located at both ends of the powerhouse collection channels and adjacent to spillways. Relatively few fish used the smaller sluice and orifice gates to enter or exit fishways. The exception was at Ice Harbor Dam where good numbers of entries occurred at orifice gates near the south shore entrance, and where net entries were

comparable to that recorded at the south-shore entrance. A similar entry pattern was seen in an earlier study conducted in 1993 (Bjornn et al. 1998). Net entries at the sluice gates at Bonneville Dam powerhouse 1 were also relatively high. In general, however, fish more readily entered the largest openings with the greatest attractive flows. This may be an indication that adult salmon had difficulty sensing attractive flows from orifice gates amongst the turbine outflow, even though they approached these openings close enough to be detected on our antenna arrays. It is also possible that these adult fish are more hesitant to enter the smaller openings. At the large entrances, fish typically made greatest use of those along shorelines, probably because adult chinook salmon tend to orientate along shorelines when migrating upstream.

At Bonneville Dam, most entries were at the north- and south-shore entrances at powerhouse 2, the spillway entrances (likely in response to the higher than average spill that occurred in 1996), and the powerhouse 1 south-shore entrances. At McNary Dam, most chinook salmon first and subsequently entered shoreline entrances. Entries were more evenly distributed between sites at Ice Harbor Dam (Table 14). When all entrances were considered at Lower Granite Dam, the highest numbers of entries were at north-powerhouse and south-shore entrances (Table 14). Chinook salmon entered fishways a median of two times at Bonneville and McNary dams, once at Ice Harbor Dam, and three times at Lower Granite Dam (2.0 to 5.4 times, on average).

In 1996, more than half of the chinook salmon monitored at Bonneville, McNary and Lower Granite dams exited from fishways back into the tailrace one or more times, while about one third exited at least once from Ice Harbor Dam fishways. Most chinook salmon exited from collection channels from entrances closest to the bottom of the ladder, entrances at the end of the powerhouses, and entrances to ladders adjacent to spillways. Relatively few exited via orifice-gate or sluice-gate openings.

Most fishway entrances at all dams had more entries than exits throughout the study. The most ineffective entrances, determined by a negative net entry rate for the year, were the south-shore entrance (SSE) at powerhouse 1 and several of the orifice gates at powerhouse 2 at Bonneville Dam, the north-powerhouse entrance (NPE) at McNary Dam, the first (downstream) south-shore entrance (SSE-1) and NPE at Lower Granite Dam. In 1993, we also found a net exit rate at SSE-1 and NPE for chinook salmon we monitored at Lower Granite Dam (Bjornn et al. 1998). In previous years, a fishway fence was tested in the collection channel as a measure to reduce the number of fish exiting the NPE at Lower Granite Dam. The original fishway design was not effective, but a modified design tested in 1997 was effective at reducing the number of fish that exited at the north end of the powerhouse (Bjornn et al. 1999). No entrances had net negative entry rates for chinook salmon we monitored at Ice Harbor Dam in 1996. In 1993, Bjornn et al. (1998) reported a net exit rate at the north powerhouse entrance for spring and summer chinook salmon. No known structural changes were made to the NPE at Ice Harbor Dam that would explain this improvement between the two study periods. Although several entrances mentioned here had net exit rates, they were also the openings used by a large number of fish that ultimately

passed the projects. It is not suggested, therefore, that fishway entrances that have net entry rates be closed, but rather that methods to reduce fallout from fishways (i.e. fishway fences) be explored as the preferred strategy.

In 1996, about 14% of the chinook salmon outfitted with transmitters fell back over Bonneville Dam. Eighty-two percent of all fallback events at Bonneville occurred after fish passed the dam via the Bradford Island ladder, and this was reflected in the pattern of entrances and fishways used by these fish. Since fish that fell back were predominately from the Bradford Island ladder, their initial approaches, entries, and exits were more likely to occur at Powerhouse 1 and south-shore spillway entrance than during their second passage at the dam, when their behavior more resembled that for all tagged fish. The top of the Bradford ladder is located on Bradford Island and is the only ladder at a Columbia or Snake River dam located on an island. Mobile tracking in the Bonneville forebay by University of Idaho personnel has shown that many fish followed the Bradford Island shoreline into the boat-restricted zone above the Bonneville spillway and subsequently fell back over the dam (Bjornn et al. 1999). The routes of fallbacks were not known, but we presume many of the fish fell back through the spillway. In general, fish that fell back and reascended Bonneville Dam made fewer entries and exits from fishways on the second passage than on the first. Measures of passage time also indicated that chinook salmon moved through fishways and over the dam more quickly on their second passage of the dam.

After first passing tailrace receiver sites, chinook salmon approached (medians of 2 to 3 h) and entered (6 to 10 h) fishways relatively quickly, although some fish took more than 24 h to first enter fishways at each dam. Total median dam passage times were 23.1 h at Bonneville Dam, 25.4 h at McNary Dam, and 17.5 h (0.73 d) at Ice Harbor Dam. Median passage times at Ice Harbor Dam were slightly shorter than those we measured in 1993 (0.86 d, about 20 h), the only other time passage was determined for chinook salmon when trapping operations were not being conducted at the project (Bjornn et al. 1998). Because most fish with transmitters were diverted into the adult trap at Lower Granite Dam, median time to pass there was 38.1 h (1.59 d) in 1996. This is at the upper range of median passage times previously measured at Lower Granite Dam, 1.6 d in 1991, 1.4 d in 1992, and 1.2 d in 1993 (Bjornn et al. 1998b). Fish not diverted into the trap may have had passage times similar to those at Bonneville, McNary or Ice Harbor dams.

In an effort to quantify where chinook salmon passage delays occurred within fishways, we partitioned passage at Bonneville, McNary and Lower Granite dams into 3 passage segments: 1) first fishway entry to first entry into a transition pool, 2) first pool entry to exit from a pool into a ladder, and 3) ascend a ladder. A fourth measure, time from first fishway entry to exit from the top of a ladder, included all time fish spent in fishways as well as time chinook salmon spent exiting and reentering transition pools and fishways before passing a dam. Transition pools were located at the base of all ladders, either immediately upstream from fishway entrances (e.g. at the base of ladders adjacent to spillways) or at the end of collection channels, and mark the transition into overflow-weir portions of ladders. Most transition pools at Columbia and Snake River dams include either a turn in the fishway

and/or floor diffusers were water is added to the fishway, and the pools have been identified as a source of delay for some adult migrants (Bjornn et al. 1998c).

Due to configuration differences among fishways and transition pools, sites and passage times were not strictly comparable, but types of chinook salmon behavior in the pools were similar among all sites. Four transition pool behaviors were identified: 1) fish that moved through a transition pool with no downstream movement, 2) fish that moved downstream in a pool, but did not exit into the collection channel or tailrace, 3) fish that exited a pool into a collection channel but not into the tailrace, and 4) fish that exited a pool and fishway into the tailrace (Table 15). Between 6 and 26% of chinook salmon passed through transition pools with no downstream movement, and another 14 to 41% moved downstream in a pool but did not exit. Overall, 36% of the fish monitored at Bonneville, 60% at McNary, 56% at Ice Harbor, and 20% at Lower Granite dams passed through transition pools on their first attempt. Four to 25% of the monitored fish moved downstream into a collection channel, and from 27% to 55% exited into the tailrace after having been in a transition pool (Table 15).

Table 15. Number of chinook salmon sampled at the transition pools at Bonneville, McNary, Ice Harbor and Lower Granite Dams and the percent that fell into each of the four transition pool behavior groups.

	Bonneville (679)	McNary (294)	Ice Harbor (86)	Lower Granite (85)
No downstream movement in pool	23%	19%	26%	6%
Moved downstream but did not exit	13%	41%	29%	14%
Exited pool to collection channel	11%	4%	19%	25%
Exited pool to tailrace	53%	35%	27%	55%

Median passage times from first fishway entry to first transition pool entry and to ascend ladders were generally similar at Bonneville, McNary and Ice Harbor dams. Chinook salmon took longer to first enter the transition pool and to ascend the ladder at Lower Granite Dam but times did not appear to be related to transition pool behavior. Median times to pass through transition pools were less consistent among the different groups of fish. All chinook salmon that moved through individual transition pools on the first attempt had significantly faster passage times than chinook salmon that turned around in a transition pool and traveled downstream in a fishway but did not exit into the tailrace, and fish that exited a fishway into the tailrace after first entering a transition pool had the longest median times to pass through pools. At Bonneville Dam, chinook salmon that exited the fishway had median passage times from 1.27 to > 30 h to pass through transition pools, with the longest median times by fish that passed the dam via a different transition pool than the one they first entered. At McNary and Lower Granite dams, fish that exited the fishway had median times from 9.2 to 23.7 h to pass through transition pools; fish that exited an Ice Harbor pool into the tailrace had median pool passage times of < 5.1 h.

Migration delays associated with transition pool behavior were also evident in passage times from first fishway entry to exit from the top of a ladder. Fish that exited fishways generally had significantly longer times to pass dams than fish that did not exit fishways after reaching transition pool areas. The effect was less noticeable relative to total passage times for fish passing Lower Granite Dam, where operation of the adult trap delayed all monitored fish. Using medians, delays associated with exiting a transition pool into tailrace areas were mostly 7 to > 36 h at Bonneville Dam and were > 3 d in the extreme case. Delays were 7 to 24 h at McNary Dam, 5 to 20 h at Ice Harbor Dam, and 6 to 8 h at Lower Granite Dam. Passage delays for fish that moved back down the collection channels but did not exit the fishway into the tailrace were relatively minor, but in general median passage times for fish that exited to collection channels fell within the range of times for fish that passed through pools on their first attempt.

We also evaluated transition pool behavior for 89 chinook salmon that fell back over and then reascended Bonneville Dam. Of 81 fish that had complete transition pool records on both first and second passage of the dam, median times were shorter on the second passage than on the first. Fewer fish exited the fishway into the tailrace and more passed through transition pools into ladders on their first attempt during their second passage of the dam.

Once fish left the transition pools for the last time they generally ascended ladders and exited the fishways within a few hours. Some stopped moving if they were in ladders at nightfall, but then resumed their passage in the mornings. Two areas where delay occurred were in the Lower Granite Dam ladder, in response to trap operation. The other location of concern was for fish that traveled up the Cascades Island and through the UMT channel to reach the north-shore fishway exit at Bonneville Dam. Those fish had passage times 3 times longer than those for fish using the other three routes to pass the dam. This passage time may be related to the distance traveled and to the covered UMT channel.

In summary, overall passage conditions were best at Ice Harbor Dam, intermediate at Bonneville and McNary dams, and slowest at Lower Granite Dam. It is possible that the smaller size of the river and project at Ice Harbor Dam, relative to the Columbia River projects, makes it easier to negotiate for the adult migrants. Fish were delayed at Lower Granite Dam because of operation of the adult trap in the fishway. Fish not diverted into the trap at Lower Granite Dam would probably have passage times more comparable to those at the other dams. However, we also found that times prior to entry to the ladder were noticeably longer at Lower Granite Dam, as compared to the other dams. At all projects, behavior in transition pools was the best predictor of chinook salmon passage times past dams in 1996. We found that fish that exited fishways had significantly longer passage times, and the largest proportion of these fish exited after first reaching the transition pool or areas closely associated with the transition pool areas at dams. Non-uniform flows, lack of sufficient attractive flow, temperatures, or combination of these or other variables may contribute to the behavior we observed in the transition pools. Improving flows through the transition pools and/or closing or using fishway fences to reduce the number of fish that exit

fishways at specific entrances (e.g. NPE at Lower Granite Dam) may help reduce delay and improve overall passage times at dams.

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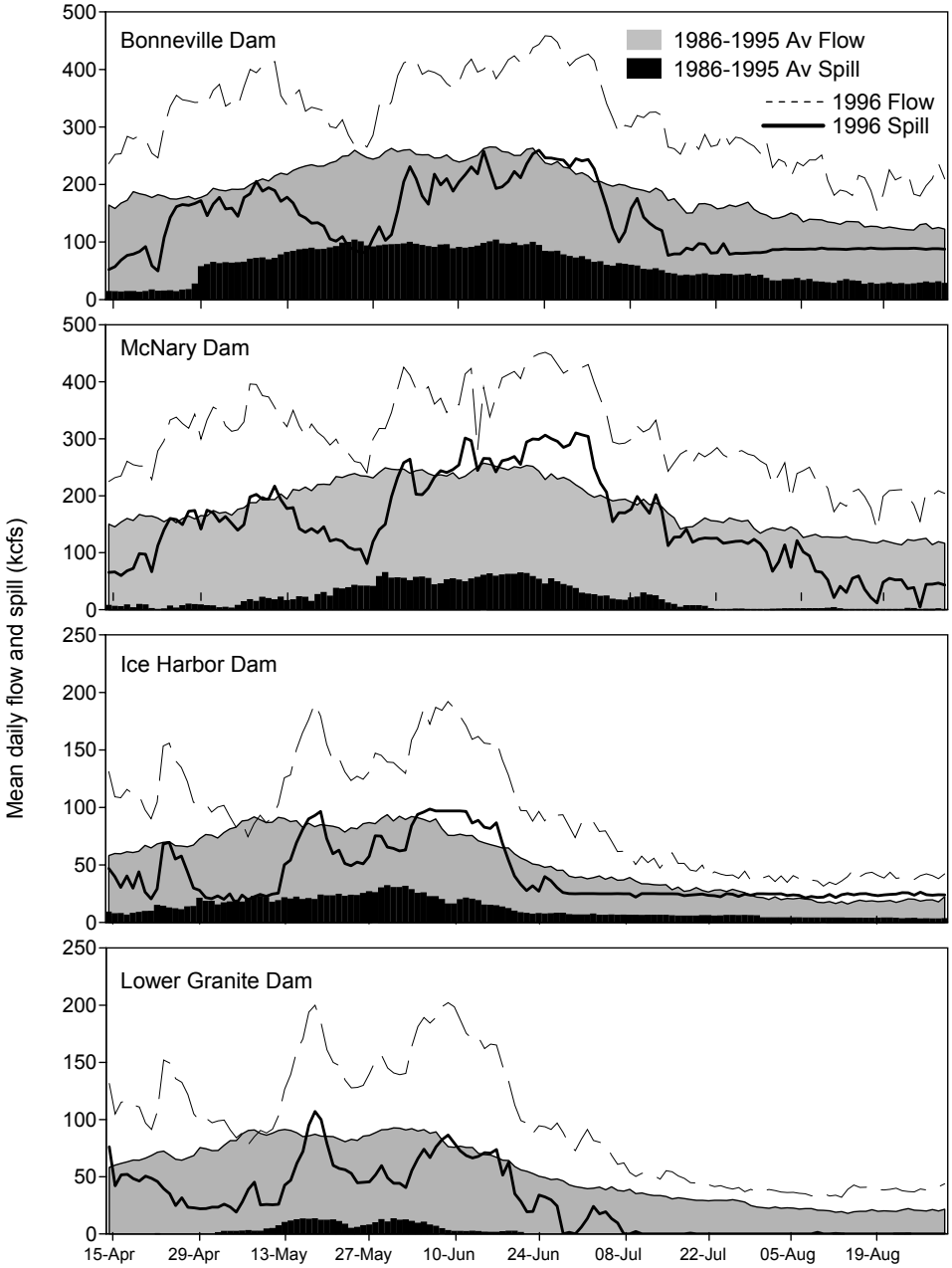
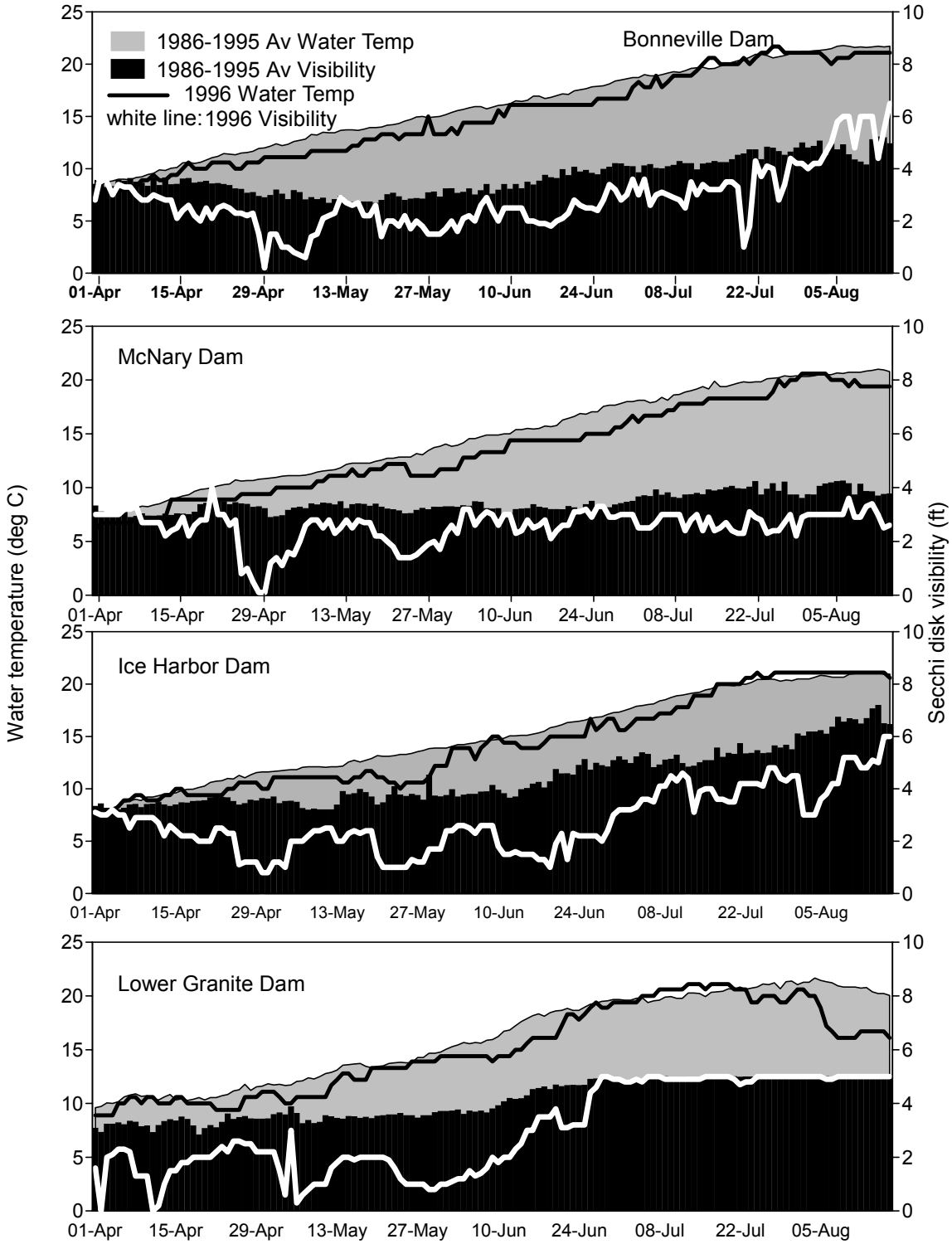
Appendix A

Figures of River flow, spill, temperature and visibility at dams in 1996



Mean daily flow and spill volumes at Bonneville, McNary, Ice Harbor, and Lower Granite dams in 1996 with 10-year averages (1986 to 1995).



Mean daily water temperatures and Secchi disk visibility readings at Bonneville, McNary, Ice Harbor, and Lower Granite dams in 1996 with 10-year averages (1986 to 1995).