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ADULT STEELHEAD PASSAGE THROUGH FISHWAYS AND TRANSITION POOLS AT BONNEVILLE, McNARY, AND LOWER GRANITE DAMS - 1996

A report for Project MPE-P-95-1

by

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Preface

Studies of adult salmon *Oncorhynchus* spp. and steelhead *O. mykiss* 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 steelhead 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, 2003). The focus of adult steelhead passage studies at the lower Columbia River dams began in 1995, when telemetry equipment was set up at the dams and tributaries, and the steelhead for this report were outfitted with transmitters at Bonneville Dam in 1996. In this report we present information on the use of fishway entrances and movements of steelhead through transition pools and past Bonneville, McNary, and Lower Granite dams, the three dams that had a full complement of receivers and antennas to monitor use of fishways and transition pools during the 1996 steelhead migration.

This and similar reports produced from this research project are available in .pdf format at http://www.cnr.uidaho.edu/uiferl/.

Acknowledgments

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Table of Contents

Abstract

Evaluation of fishway entrances used and passage through fishways by steelhead *Oncorhynchus mykiss* at dams in the lower Columbia and Snake rivers were objectives of the adult salmon and steelhead hydrosystem passage project. In 1996, we monitored passage through the fishways by outfitting steelhead with radio transmitters and installing full antenna/receiver coverage at Bonneville, McNary, and Lower Granite dams. Critical parameters studied were passage 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, 765 steelhead 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, 735 were subsequently recorded at Bonneville Dam tailrace monitors or in the Bonneville Dam fishways, 401 were recorded at McNary Dam, and 264 were at Lower Granite Dam. Median passage times from release after tagging to first tailrace record at the four dams were 0.3, 20.0, and 41.8 d.

After passing a tailrace receiver, median times for steelhead to first approach fishways in 1996 were 2.47 h at Bonneville Dam, 2.35 h at McNary Dam, and 2.04 h at Lower Granite Dam. Median times from tailrace receivers to first enter fishways were 3.62 h at Bonneville, 3.34 h at McNary, and 5.06 h at Lower Granite dams. Median times from tailrace receiver to exit from the top of a ladder were 17.02 h at Bonneville, 10.39 h at McNary, and 25.97 h at Lower Granite Dam. 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 steelhead occurred at all entrances, with a tendency toward shoreline entrances. The highest number of first approaches at Bonneville Dam were at shoreline entrances and entrances adjacent to the spillway. At McNary and Lower Granite Dams, the highest number of first approaches were at orifice-gate and shoreline entrances. Median numbers of pre-fallback approaches to fishway entrances by steelhead in 1996 were 9 at Bonneville and McNary dams and 10 at Lower Granite Dam.

Entrances used by steelhead in 1996 were more restricted than entrances approached. The highest number of first and subsequent entries at Bonneville Dam were at the powerhouse 2 north-shore entrance, the south-spillway, and the powerhouse 1 south-shore entrances. At McNary and Lower Granite dams, most first and subsequent entries were at south-shoreline entrances and the north end of the powerhouse. Median number of entries by steelhead in 1996 was two at Bonneville and one at McNary and Lower Granite dams. At most fishway entrances more fish entered than exited. Steelhead that exited the fishways from the collection channels did so mostly at the large entrances at the ends of the powerhouse collection channels, at shoreline entrances and at the entrances closest to the bottoms of ladders. Overall, the net number of entries were positive. Although many steelhead 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 steelhead that passed Bonneville Dam, fell back over the dam, and subsequently reascended. Overall, 37 fish fell back a total of 40 times, of which 84% initially passed the dam via the Bradford Island fishway. Of the 37 fish, 29 (78%)

ascended ladders and passed the dam a second time. Fish that fell back moved through fishways more slowly, but had 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 615 steelhead outfitted with transmitters at Bonneville Dam, 316 at McNary Dam, and 192 at Lower Granite Dam. The most efficient passage through a transition pool occurred at McNary Dam where about 51% of the steelhead passed through on the first attempt, without exiting to a collection channel or to the tailrace. At Bonneville Dam, 45% passed through on the first attempt, and at Lower Granite Dam 29% passed the transition pool on the first attempt. Of the steelhead that turned around in transition pools, 8 to 23% moved downstream into the collection channel but did not exit into the tailrace. Between 41 and 48% of the steelhead monitored at the dams turned around in transition pools, moved downstream, exited the fishway into the tailrace, and then reentered the fishway at least once before passing.

Median time for all steelhead with transmitters to first enter a transition pool after entering a fishway ranged from 4 to 7 min at all dams. Median times from the first entry into a transition pool until final entry into a ladder were 37 to 50 min for all fish. Median times for all steelhead to ascend ladders from a transition pool were 2.38 h at Bonneville, 2.23 h at McNary, and 7.32 h at Lower Granite dams. Median times from first fishway entry to exit from the top of a ladder were 4.26 h at McNary, 6.17 h at Bonneville, and 17.55 h at Lower Granite dams.

For steelhead that passed through transition pools on their first attempt, median times to pass through the pools ranged from 7 to 26 min (0.12 to 0.44 h) at each dam. Median times for steelhead that moved back into collection channels, but did not exit into the tailrace, were 0.34 to 1.09 h; for steelhead that exited to a tailrace median passage times through transition pools ranged from 3.98 h at McNary Dam to 10.40 h at Lower Granite 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 to pass from first fishway entry to exit from the ladders were 2.68 to 2.91 h for steelhead that moved straight through a transition pool at Bonneville and McNary dams. 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 were 3.31 to 3.49 h, and for fish that exited to a collection channel at Bonneville and McNary dams, median times to pass from first fishway entry to exit from the top of a ladder were 3.53 to 4.26 h. For fish that exited to a tailrace at these dams, median times to pass ranged from 7.36 to 13.94 h. At Lower Granite Dam, median times to pass from first fishway entry to exit from the ladder were approximately 11.46 h for fish that did not exit the fishway after exiting the transition pool, and 23.89 h for fish that exited to the tailrace at Lower Granite Dam.

Passage time comparisons based on behavior in transition pools showed that steelhead that exited into the tailrace from transition pools were delayed 3 to 23 h at Bonneville, 2 to 15 h at McNary, and 8 to 16 h at Lower Granite dams. Steelhead that moved through pools on their first attempt had the shortest passage times through fishways and past dams in 1996.

Introduction

An important aspect of the adult steelhead *O. mykiss* 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 fishway entrance use by steelhead at Lower Granite Dam in 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 steelhead 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.

Similar information and analyses presented here for adult steelhead were reported for radio-tagged adult chinook salmon passing Bonneville, McNary, and Lower Granite dams during 1996 (Keefer et al. 2003).

Methods

Steelhead 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). Detailed descriptions of sampling protocols, fish size and run-timing distributions, tagging methods, and monitoring sites used throughout the basin can be found in Bjornn et al. (2000a), Keefer et al. (2002), and Keefer et al. (2004). 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 aerial 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, McNary, and Lower Granite dams. The Dalles, John Day, Ice Harbor, Lower Monumental, and Little Goose dams had less than full coverage with SRX/DSP receivers during the steelhead migration in 1996 and were not included in these analyses. Tailrace SRX receivers were used to determine when fish first entered the tailrace area of a dam. SRX/DSP receivers were used to determine when a fish approached a dam at a fishway entrance, entered a fishway, moved within the fishway, and exited the fishway.

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 into a fishway, and the total time to pass over the dam. Start times were the time of release, 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 were included in analyses.

At the monitored dams in 1996, from 4% to 15% of steelhead with transmitters were recorded inside fishways before being recorded at an antenna outside the fishway. In these cases, the location and time of a fish's first approach at the dam was treated as unknown. Similarly, the time or exact location of the first entry into fishways was unknown for 12% of the steelhead at Bonneville, 27% at Lower Granite and 45% of steelhead at McNary 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 inclusion of these fish in passage time analyses had minimal impact on median passage times (first entrance time to ladder exit time) at Bonneville and McNary Dams (1 and 5 minutes); at Lower Granite Dam the difference was 1.71 h. Steelhead with unknown entrance dates were included in travel time analyses, 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 steelhead that fell back over Bonneville Dam, passage times were calculated from the first approach at a fishway 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 of the tendency for passage times to be skewed to the right.

Fishway Use

With the antenna/receiver setups at Bonneville, McNary, and Lower Granite dams we were able to determine the movements of adult steelhead with transmitters in the tailrace, approaches at entrances to the fishways, entrances used to enter and exit the fishway, and the fishway 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 and McNary dams have two fishways, while Lower Granite Dam has one fishway. Fishways at Bonneville Dam are the most complex. Some fish moved extensively in the tailrace and in the fishways of all dams. We believe the number of approaches fish made at the different entrances was evidence of the amount of searching conducted by fish to find a route past the dams; a high number of approaches per fish indicates more movement in the tailrace area.

The migration history of each fish at the dams was contained in the thousands of telemetry records collected as fish passed the various antennas at the entrances, in the fishways, and at the top of the ladders. A program, based on a decision tree, was used to aid in the manual coding of the records obtained at each dam. The program aided data processors code the movements of each fish at a dam by presenting codes that could be accepted or rejected. Passage at the dams was the most complex part of the migration history of most fish.

Movement Through Transition Pools

In 1996, we also collected data on steelhead outfitted with transmitters as they passed through transition pools during their passage at Bonneville, McNary, and Lower Granite dams. Transition pools are characterized as the portion of the fishway where water flowing down fish ladders meets tailwater elevation. This area of fishways usually contains one or more submerged ladder weirs and diffusers where auxiliary water is added. 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. In fishways with powerhouse collection channels, the transition pools extended from the upstream 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, whether or not fish passed directly into the ladder from the transition pools, how much time fish spent in 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. Steelhead 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

In 1996 we monitored time to pass, fishway entrance use, and movements within fishways at Bonneville Dam (Figure 1) for 765 steelhead outfitted with transmitters. Of the 765 fish released downstream from Bonneville Dam, 735 (96.1%) were subsequently recorded in the Bonneville tailrace or at the dam, 730 (95.4%) were recorded at the dam fishways or Navigation Lock channel, and 717 (93.7%) were recorded passing the dam one or more times. Thirty-one fish (4.3%) first passed the dam through the navigation lock at the south shore (13 of the 31 did not approach the fishways), 366 first passed through the Bradford Island fishway, and 320 first passed via the Washington-shore fishway and ladder. Two steelhead passed the dam without detection and were recorded in tributaries upstream. It is likely these two fish also passed the dam via the navigational lock. Four steelhead were recaptured at the Lower Granite Dam adult trap (identified by their VI tag) with no radio tag (regurgitations) for a total of 723 known passage at Bonneville Dam. Data on the remainder of the fish suggests that they stayed below Bonneville Dam. Three were last heard in downstream tributaries and sixteen were recaptured below Bonneville. Unreported harvest, fish that returned to downstream spawning areas undetected, or mortality are likely reasons for the failure of the remaining 23 fish (3.0%) to migrate above Bonneville Dam, although some fish may also have experienced tag failure or tag regurgitation.

In 1996, 37 steelhead with transmitters fell back over Bonneville Dam after passing the dam; records for these fish after falling back were analyzed separately.

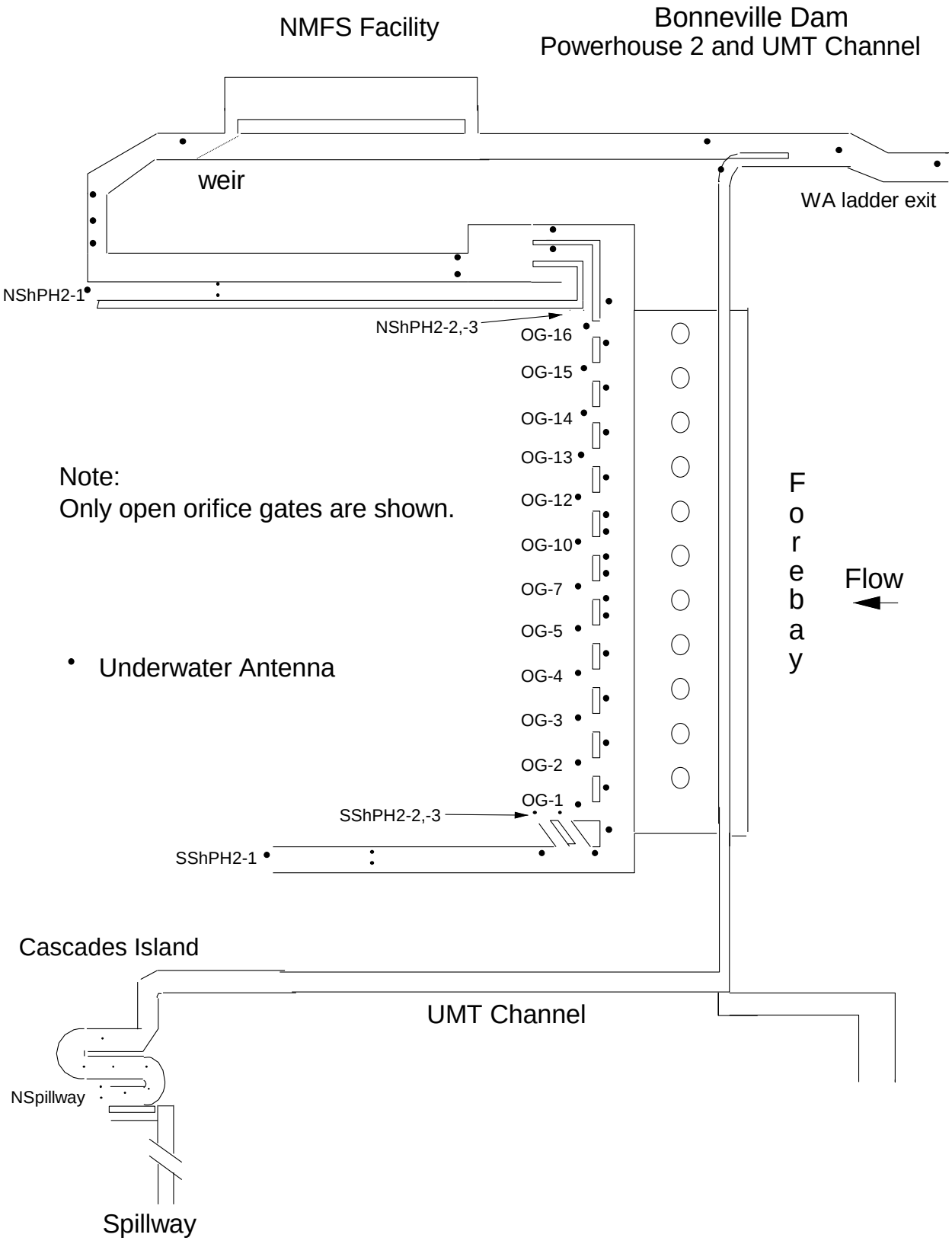

Figure 1. Location of antennas and fishway entrances for the Bradford Island and Washington-shore fishways at Bonneville Dam in 1996 while steelhead were passing the dam.

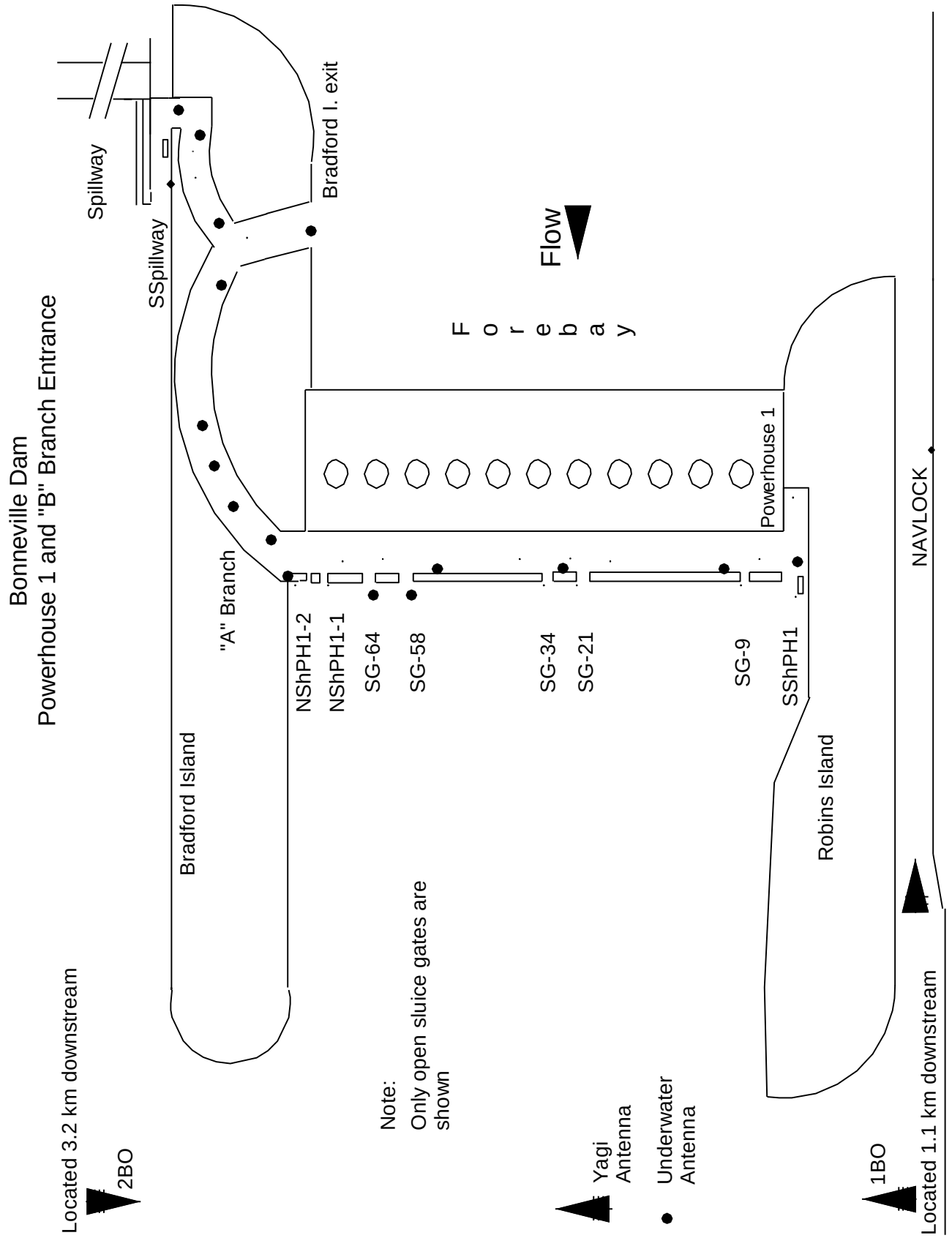

Figure 1. Continued.

Passage Times

Median passage time of steelhead from release downstream of Bonneville Dam to the tailrace receiver site was 0.31 d and was 1.14 d from release to passage over the dam (Figure 2). A few fish took several days to return to the tailrace, and six were first recorded at the tailrace antenna more than 25 d after their release downstream from Bonneville Dam.

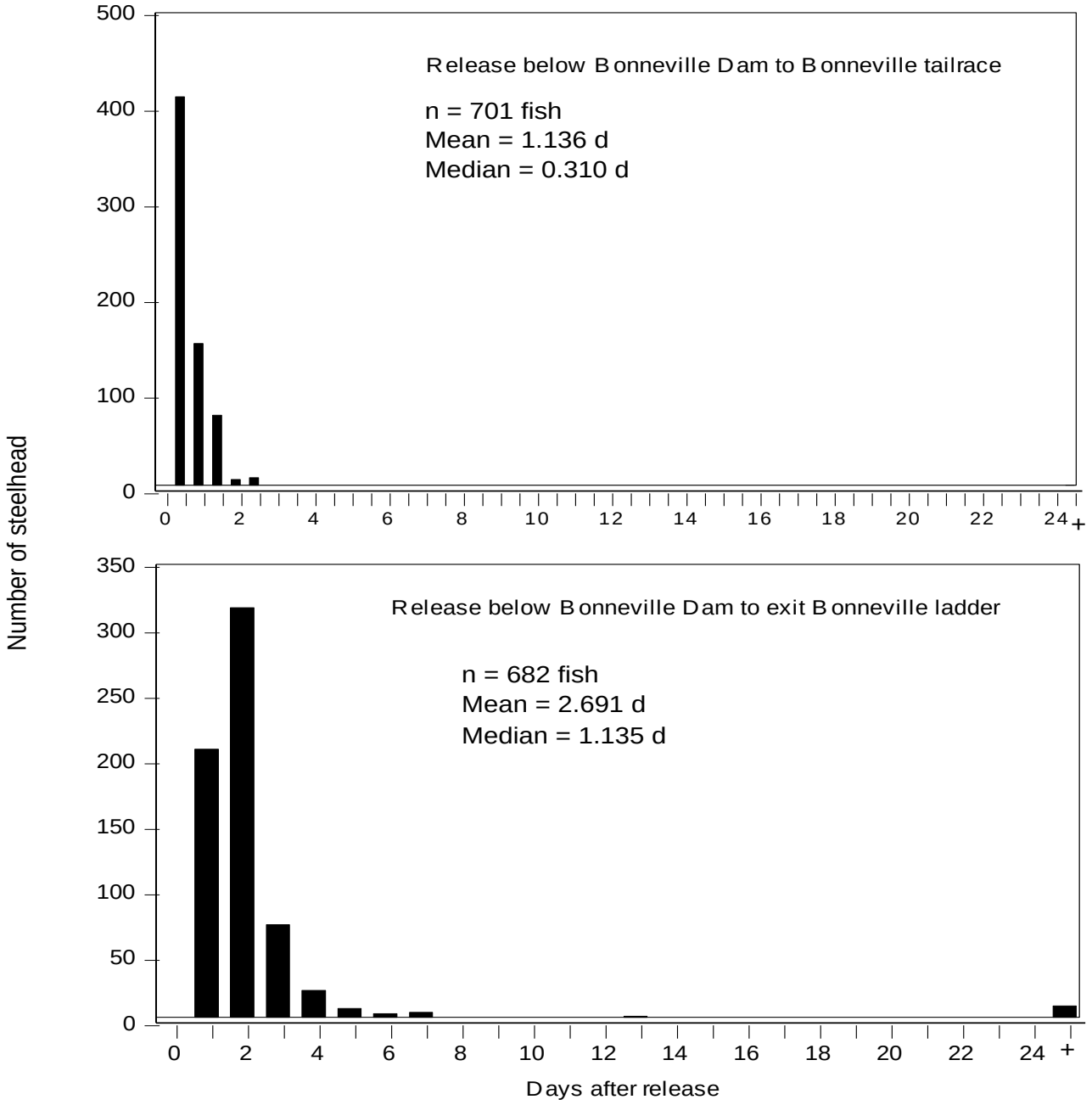

Figure 2. Frequency distribution of days to migrate from the release site downstream from Bonneville Dam to the tailrace and to exit from the top of the ladders at Bonneville Dam in 1996.

Median times from the first record on 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 2.47 h, 3.62 h, and 17.016 h (Figure 3). Median time from first approach at a fishway to first entry into the fishway at Bonneville Dam was 0.27 h, and median time from first entry into the fishway to exit from the top of the ladders was 6.24 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 steelhead (98% of 681 fish) entered fishways within 1 d after passing the tailrace receiver, but 9 (1%) took more than 2 d to enter fishways after passing the tailrace. About 78% percent (510) of the 652 fish that passed the dam via the fishways did so within 1 d after passing the tailrace receiver, though 8% (49 fish) took more than 2 d to pass the dam. Steelhead movement declined after sundown, and longer passage times occurred for fish that did not pass the dam on the same day, producing a bimodal pattern in passage times (Figure 3). Passage times were also longer for fish that spent time migrating up and down powerhouse collection channels, exiting and reentering fishways multiple times, or migrating between Bradford Island and Washington-shore fishways (see Figures 5-7 in Keefer et al. 2002 for comparable examples of individual fish movement patterns). Passage times between the tailrace and passage from the tops of the ladders included time used by fish that exited a fishway via one of the entrances into the tailrace and later reentered a fishway. Weekly average passage times (range 10.5 – 32.0 hours) did not change until water temperatures started declining (1 Sept.). When water temperature reached 21°C near the end of July, fish movement slowed for about a week. After this initial slowdown, steelhead began passing the dam again, though temperatures remained at 21 °C. Between 1 September and 31 December, seven (2%) of the 282 fish that passed had passage times greater than 500 hours (> 20 d). Without those seven fish, passage times were within the range of weekly-average passage times recorded earlier in the season.

Fishway Use

Approaches to fishways: Steelhead first approached Bonneville Dam at all of the Bradford Island fishway entrances and most of the Washington-shore entrances in 1996. Sixty-one percent (434) 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. The south-shore entrances had the most first approaches to the Bradford Island fishway (Figure 5). Thirty-nine percent (283) 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 (53%) at the entrance 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.

Total approaches made by steelhead in 1996 were distributed more evenly among entrances than first approaches. At the Bradford Island fishway, 551 fish made a total of 5,255 approaches for an average of 9.5 per fish. The highest number of approaches to the Bradford Island fishway occurred at the south shore entrances of Powerhouse 1, but many salmon also approached sluice-gate entrances (Figure 6). At the Washington-shore fishway, 441 fish made a total of 6,037 approaches for an average of 13.7 per fish. The highest number of approaches occurred at the north (27%) and south (20%) shore entrances of Powerhouse 2, but unlike first approaches, many fish also approached the orifice gates, particularly gates 5 and 12 (Figure 6).

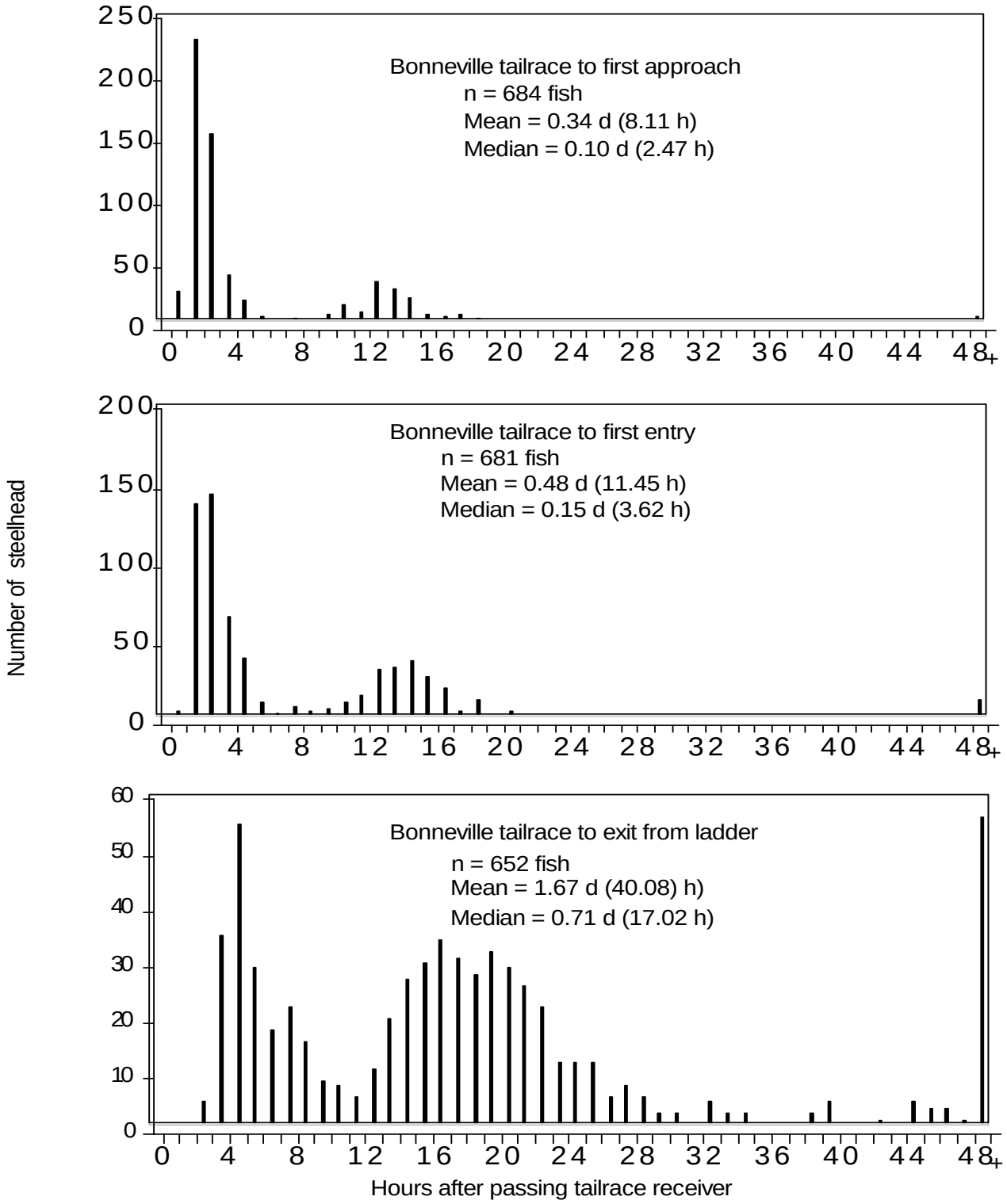

Figure 3. Number of steelhead and time to pass from the Bonneville Dam tailrace receivers to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladders in 1996.

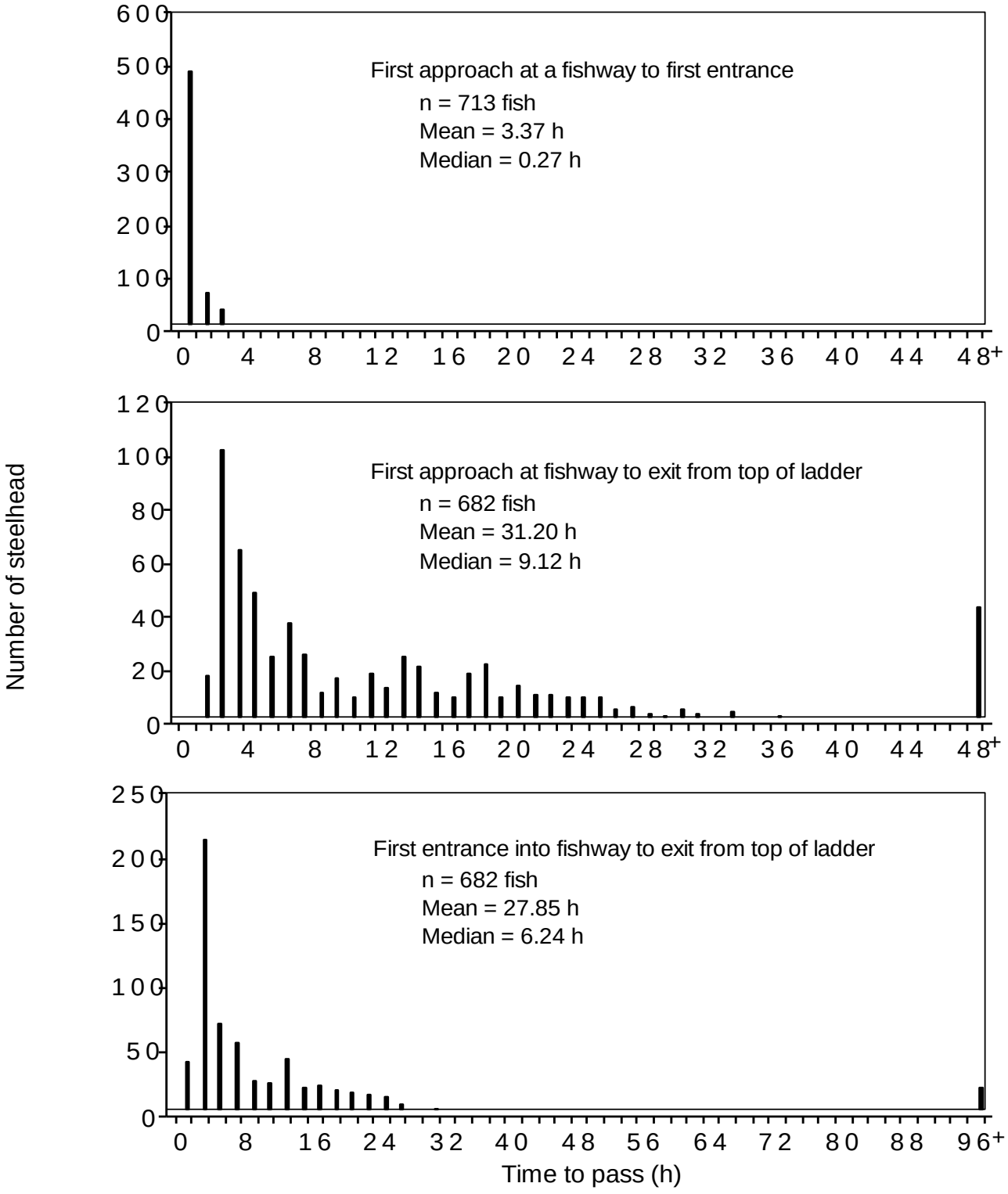

Figure 4. Number of steelhead and time from first approach at a fishway to first entry and time from first approach and first entry into a fishway to exit the top of the ladders in 1996. Note, scales are not uniform.

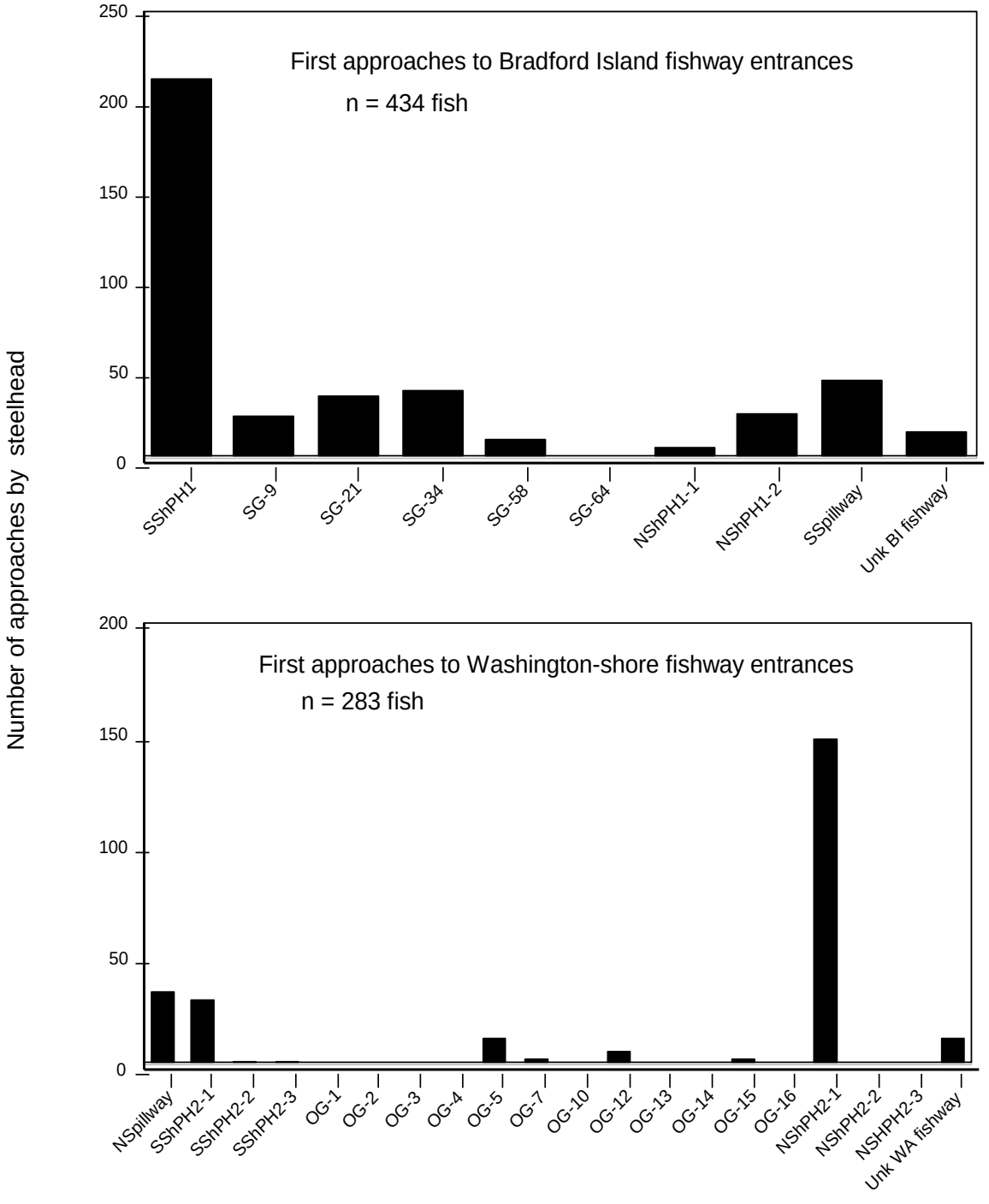

Figure 5. Number of first approaches by steelhead at Bonneville Dam fishway entrances in 1996. See Figure 1 for entrance locations.

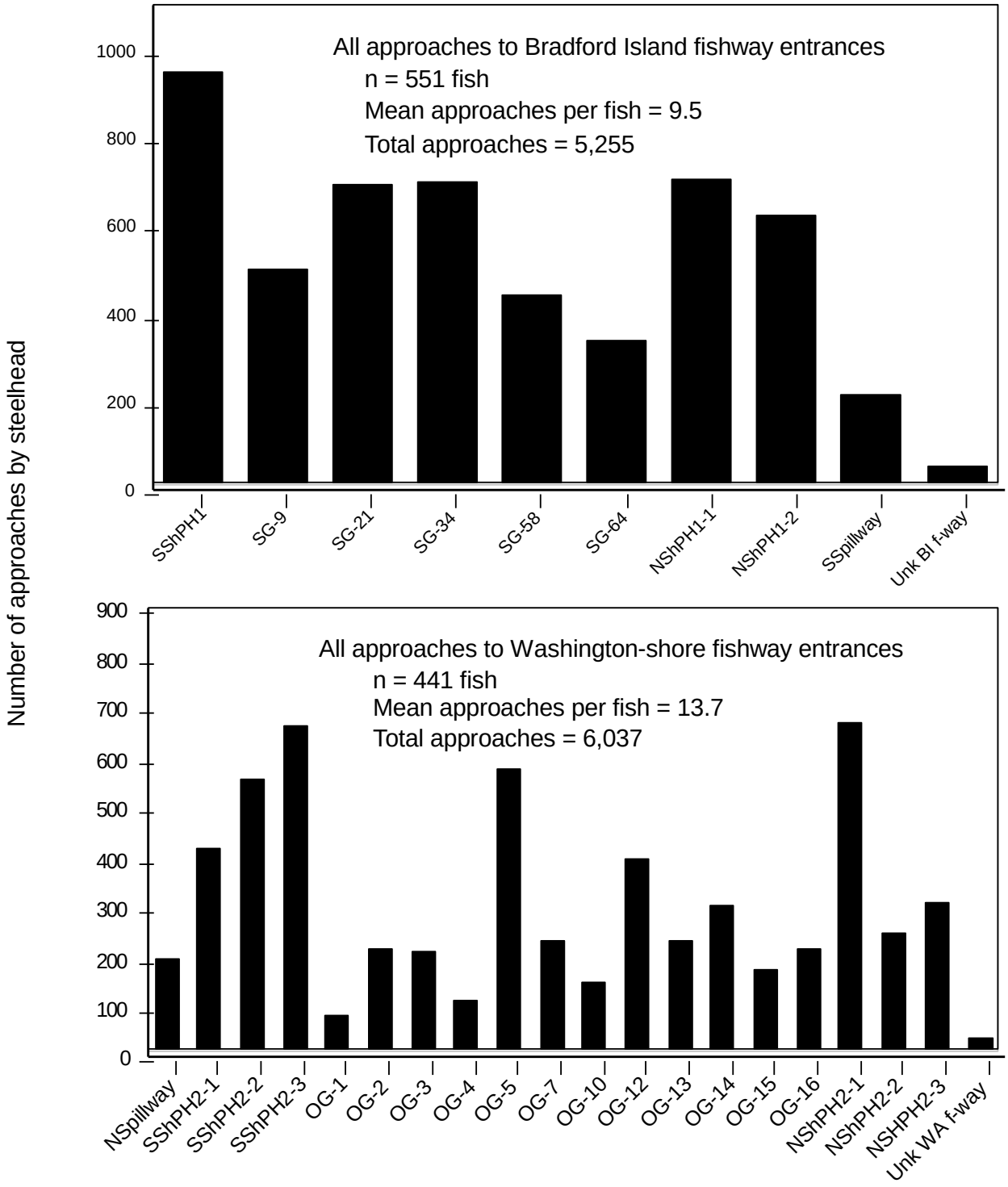

Figure 6. Total number of approaches by steelhead at entrances to both fishways at Bonneville Dam in 1996. See Figure 1 for fishway entrance locations.

Many fish moved between the spillway and both powerhouses and made approaches at entrances to both fishways. When all fishway approaches were considered together, 717 steelhead made 11,292 approaches at fishway entrances for an average of 15.8 (median = 9) per fish (Figure 7).

When comparing the location of first approaches versus all approaches, it was evident that fish move back and forth along the powerhouses and come within range of several of the antennas outside the entrances (Figure 8). 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 434 steelhead that first approached entrances to the Bradford Island fishway, 371 (85%) first entered there (though they may have made approaches to the Washington-shore fishway before their first entry), 59 (14%) first entered the Washington-shore fishway, 3 did not enter a fishway but passed via the Navigation Lock, and 1 did not enter a fishway and did not pass Bonneville Dam (Table 1). Of the 283 steelhead that first approached entrances to the Washington-shore fishway, 248 (88%) first entered there and 35 (12%) first entered at the Bradford Island fishway, and 4 did not pass the dam (Table 1).

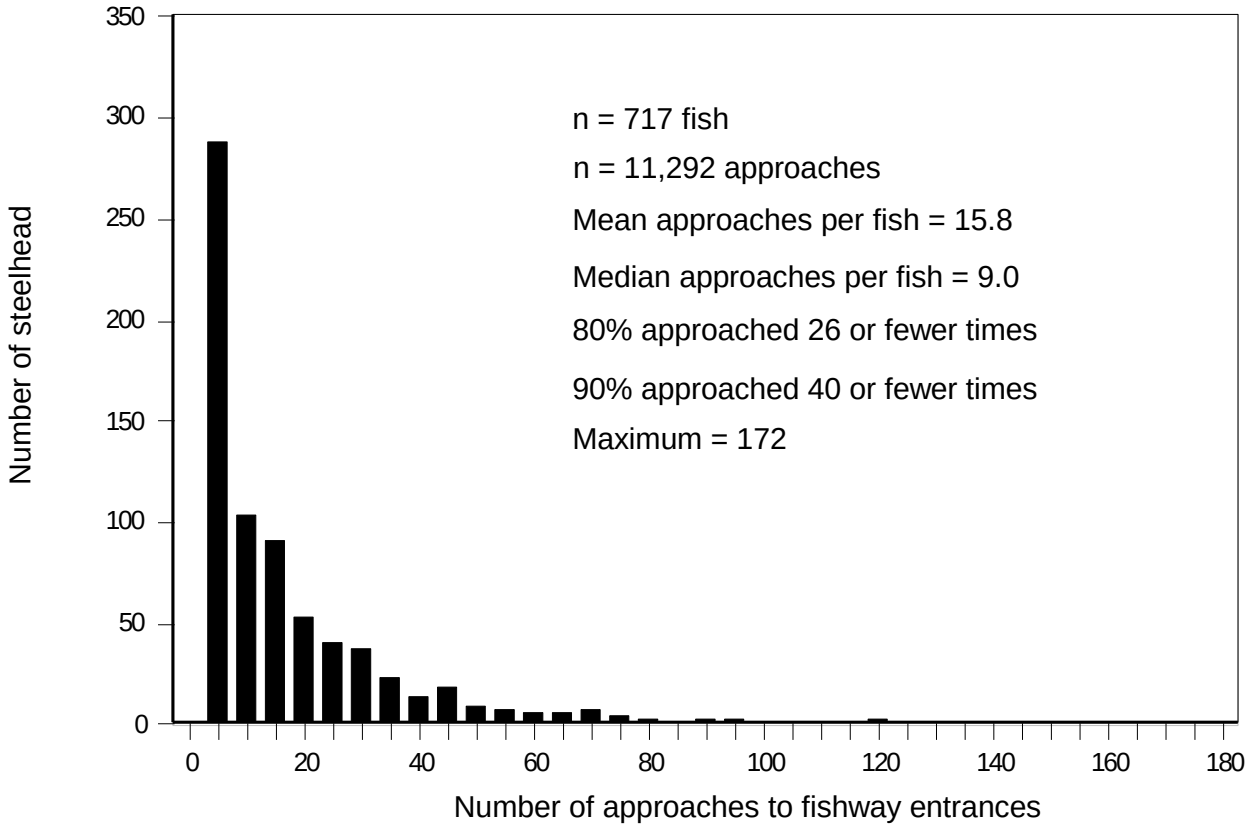

Figure 7. Number of steelhead with one or more approaches at fishway entrances at Bonneville Dam in 1996.

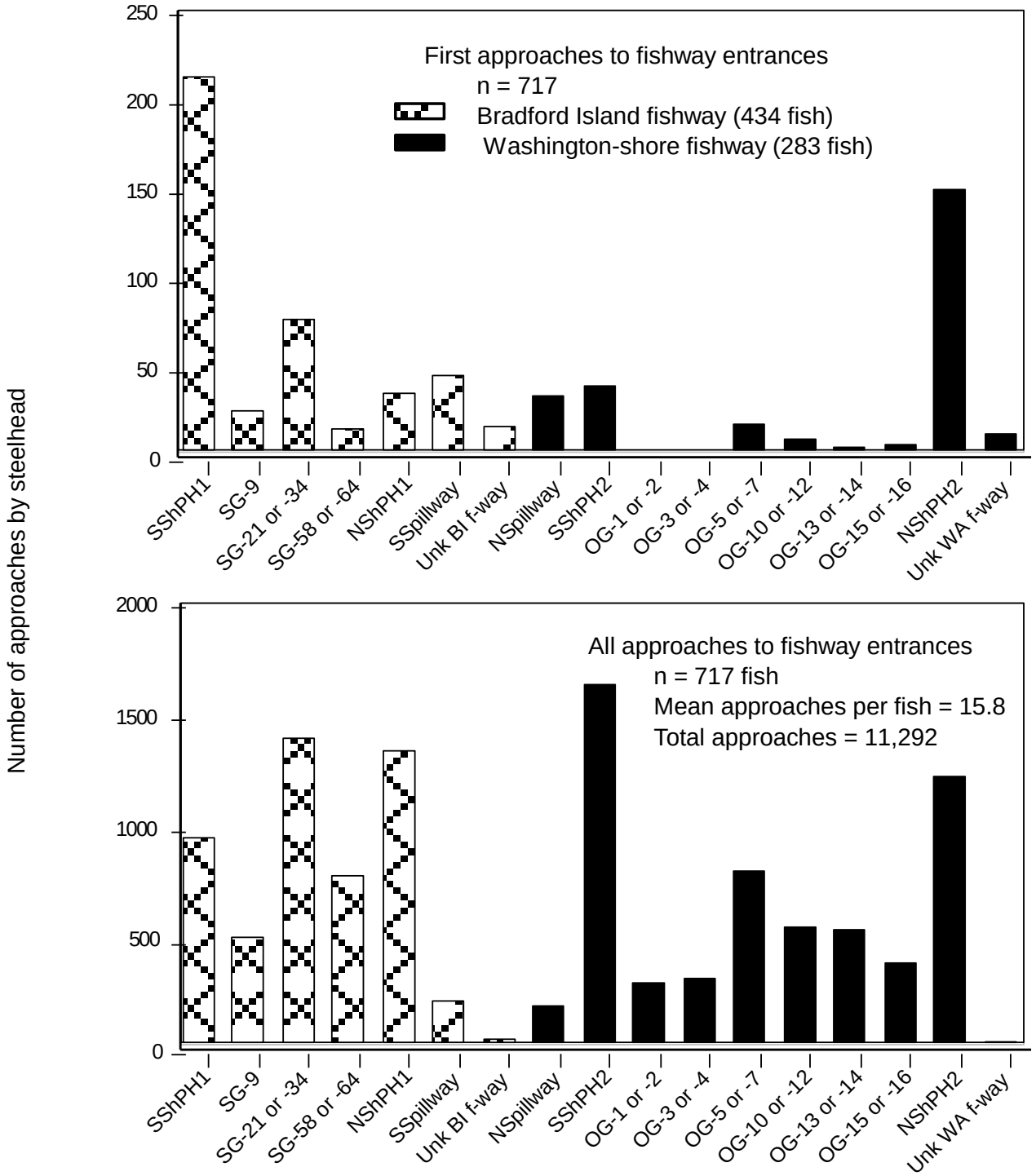

Figure 8. Comparison of location of first and all approaches by steelhead at Bonneville Dam fishway entrances in 1996. For ease of interpretation, approaches at some entrances grouped (see figures 5 and 6 for additional site summaries).

Table 1. Summary of movements by steelhead, 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 717
Steelhead that approached fishways in 1996	**717**	**100**	**100**
First approached Bradford Island fishway	**434**	**61**	**61**
First entered Bradford Island fishway	371	85	52
Passed via Bradford Island fishway	284	77	40
Passed via Washington-shore fishway	72	19	10
Passed via the Navigation Lock	9	2	1
Did not pass dam	6	2	1
First entered Washington-shore fishway	59	14	8
Passed via Bradford Island fishway	10	17	1
Passed via Washington-shore fishway	46	78	6
Passed via the Navigation Lock	1	2	< 1
Did not pass dam	2	3	< 1
Did not enter or pass	1	0	< 1
No fishway entry, Nav. Lock passage	3	1	< 1
First approached Washington-shore fishway	**283**	**39**	**39**
First entered Bradford Island fishway	35	12	5
Passed via Bradford Island fishway	26	74	4
Passed via Washington-shore fishway	8	23	1
Passed via the Navigation Lock	1	3	< 1
Did not pass	0	0	0
First entered Washington-shore fishway	248	88	35
Passed via Bradford Island fishway	46	18	6
Passed via Washington-shore fishway	190	76	26
Passed via the Navigation Lock	4	2	< 1
Passage via unknown location	4	2	< 1
Did not pass	4	2	< 1

Of the 371 steelhead with transmitters that first approached and first entered the Bradford Island fishway, 77% (284) eventually passed the dam via that fishway but some fish may have approached and/or entered the Washington-shore fishway at least once first. A similar proportion (76%; 190 fish) of the steelhead that first approached and entered the Washington-shore eventually passed there. About 19% (136) of the fish monitored exited the first fishway they entered, then entered and passed via the other fishway (Table 1).

We further analyzed how many steelhead approached and entered only one fishway before passing the dam and how many moved between fishways before passing. Of 717 fish that approached a fishway, 434 first approached entrances to the Bradford Island fishway, 334 fish first entered and 264 fish passed the dam using the Bradford fishway without fish approaching other passage routes, a 61% success rate. For the fish that did not initially pass via the Bradford Island fishway, 72 entered and exited the Bradford Island fishway and then passed the Washington-shore fishway, 46 fish did not enter the Bradford Island fishway before passing the dam via the Washington-shore fishway, and 52 fish approached and/or entered both fishways multiple times. Of the latter group, 30 fish eventually passed the dam using a fishway, 13 passed the dam using the navigational lock, and 9 did not pass the dam.

Of the 283 fish that first approached the Washington-shore fishway, 242 (86%) entered the fishway and 161 (67%) fish passed there without approaching entrances to the Bradford Island fishway. Of the remaining fish, 81 exited the fishway and passed the dam using the Bradford Island fishway, 4 used the navigational lock, 33 fish approached a Bradford Island fishway entrance before retuning and passing via the Washington-shore fishway, and 44 passed the dam using the Bradford Island fishway. Of the remaining fish, 27 that approached the Washington-shore fishway moved to and passed the dam via the Bradford fishway and 14 fish approached and/or entered both fishways multiple times before eventually passing the dam via a fishway.

Thirty-one steelhead 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 43% (310 of 717) of the steelhead 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 0.76 d for 262 steelhead that were recorded at both the downstream receiver and the navigation lock, compared to 0.48 d for 390 fish not recorded in the lock channel ($P < 0.001$, ranked median test). Median time from the last record on the tailrace receiver to first enter a fishway was 0.14 d for 262 fish that were recorded at the navigation lock, and 0.08 d for 390 fish not recorded there ($P = 0.03$). All steelhead recorded in the navigation lock channel passed that receiver before approaching a fishway entrance, entering a fishway, and/or passing the dam.

Entries to fishways: Entrances used by steelhead to enter fishways at Bonneville Dam differed from those they approached. First entries by 406 steelhead (57% of all first entries) were at the Bradford Island fishway, mostly at the south shore of Powerhouse 1 entrances and at the south end of the spillway (Figure 9). Relatively few first entries were at sluice gates. Of the 307 fish (43%) that first entered the Washington-shore fishway, the highest number entered at entrance 1 at the north shore of Powerhouse 2, with fewer entrances at the south end of the powerhouse and north end of the spillway entrance. For both fishways combined, steelhead first entered primarily at shoreline entrances of both powerhouses and the spillway. Few steelhead entered fishways for the first time via orifice gates or sluice-gate entrances.

For all (first and subsequent) entries combined, the entrances used were similar to those used for first entries (Figure 10). At the Bradford Island fishway, 503 steelhead made 1,217 entries (average = 2.42). The 409 steelhead that entered the Washington-shore fishway did so 1,016 times (average = 2.48). Many fish moved between fishways and entered at more than one location. When both fishways were considered together, 713 steelhead made 2,233 entries (average = 3.13, median = 2) entries per fish (Figure 11). However, 49% (295) of the steelhead made only one entry. Distributions of fish by entry location indicated that the main entrances were most heavily used and selected for both first and subsequent entries (Figure 12).

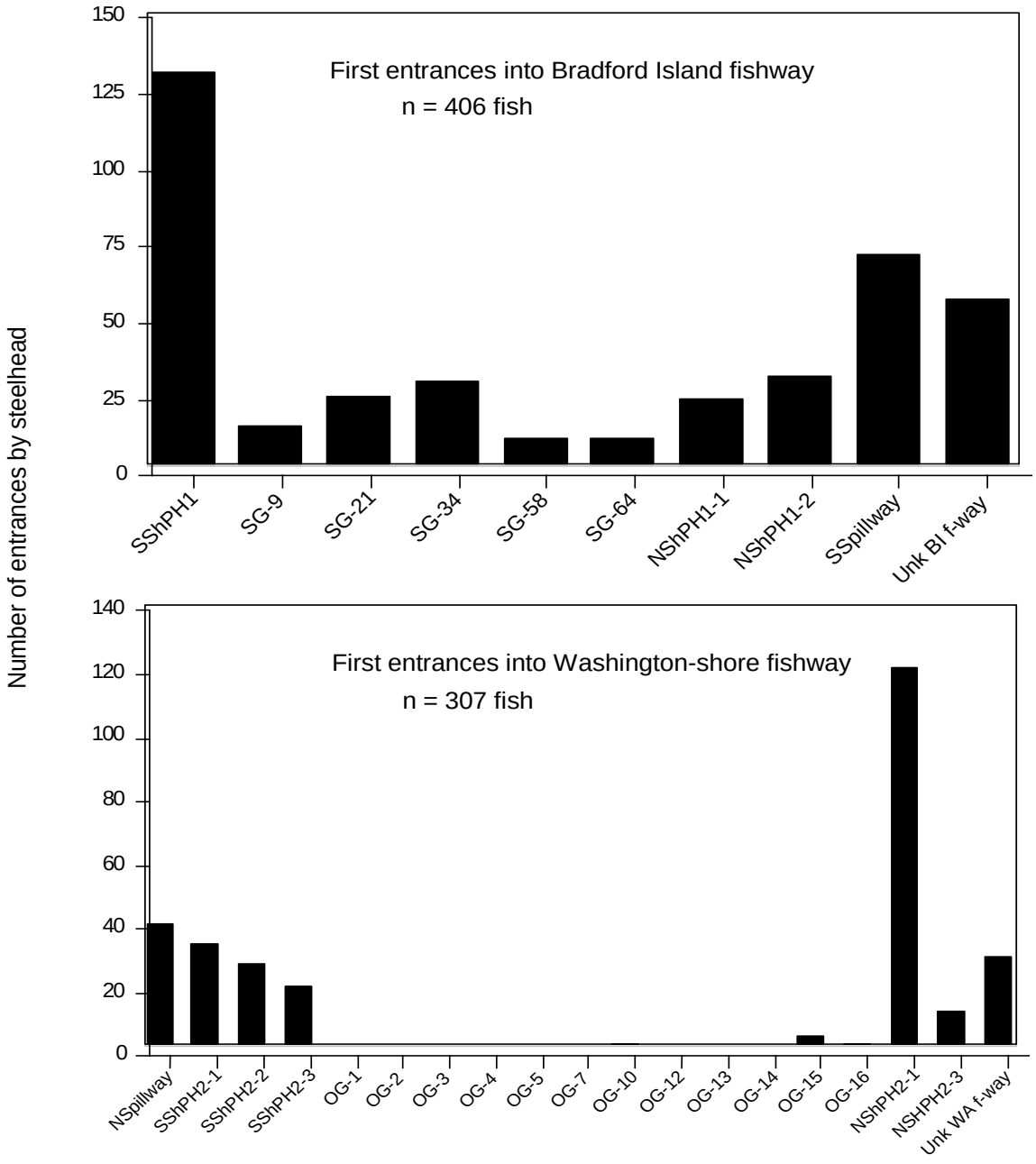

Figure 9. Number of first entries at Bonneville Dam fishway entrances by steelhead in 1996. See Figure 1 for fishway entrance locations.

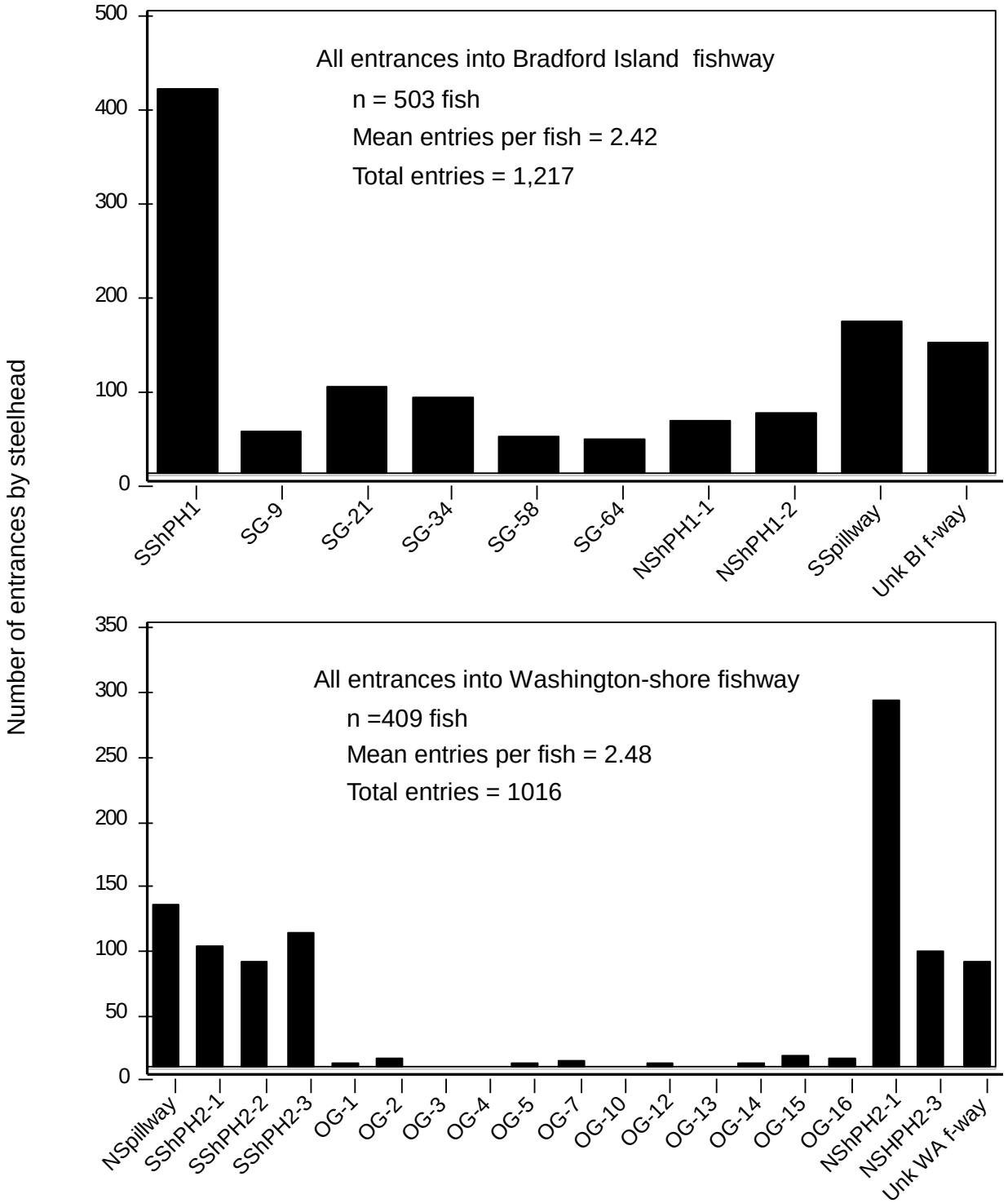

Figure 10. Number of total entries by steelhead at Bonneville Dam fishway entrances in 1996. See Figure 1 for fishway entrance locations.

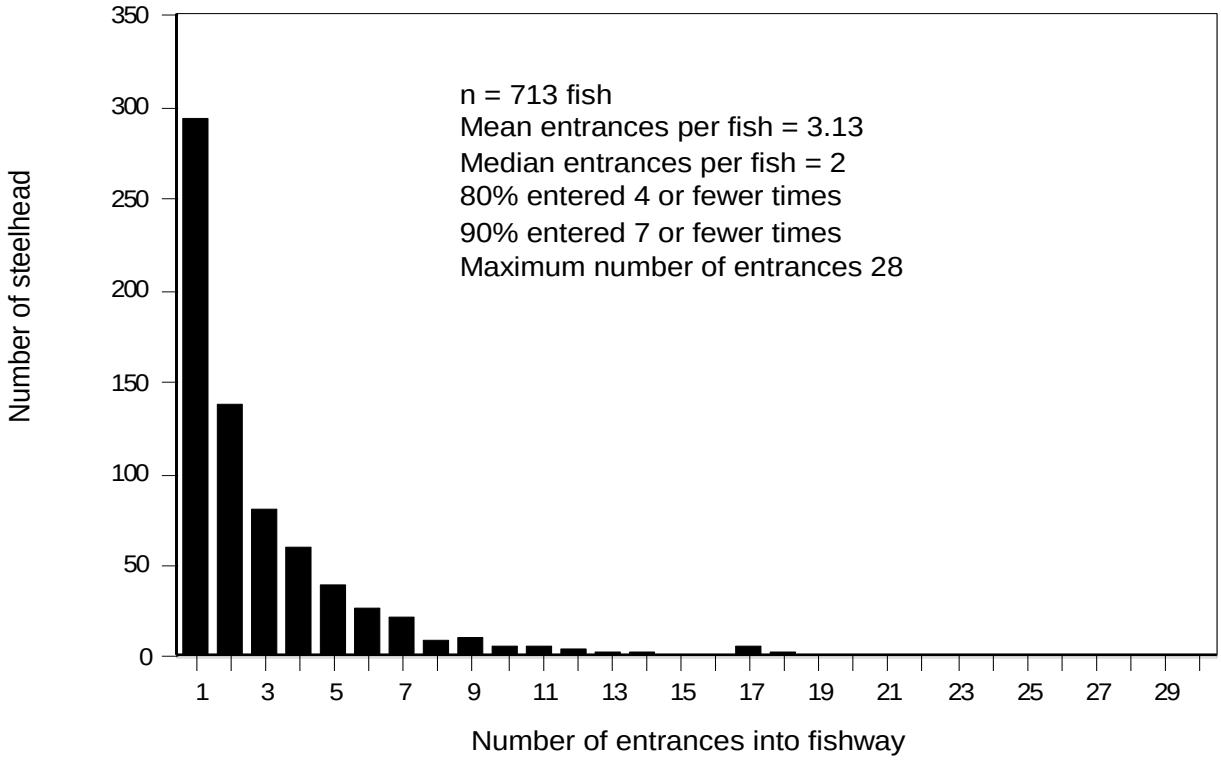

Figure 11. Number of steelhead that entered fishways one or more times at Bonneville Dam in 1996.

Amount of discharge, size of opening, and ease of following attraction flow to the opening were probably important factors for which entrances were used by steelhead. Orifice gates were 0.61 m wide and 1.83 m deep with discharges of 60 to 80 cfs; 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 to the north-shore of Powerhouse 2.

Exits from fishways: Of 713 steelhead that entered fishways, 424 (59%) exited to the tailrace an average of 2.17 times (median = 1) per fish (Figure 13). Of the 406 fish that first entered the Bradford Island fishway, 238 (59%) exited; most exits were at south-shore and south-spillway entrances (Figure 14). Sixty-one percent (186/307) that first entered the Washington-shore fishway exited; most exits were at the north- and south-shore entrances and the north-spillway entrance (Figure 14).

The distribution of total exits from fishways at Bonneville Dam was similar to that of first exits, with most occurring at entrances at the south and north shores of Powerhouse 1, the north and south ends of Powerhouse 2, and at both spillway entrances (Figure 15). There were 503 steelhead in the Bradford Island fishway and 306 of those made 856 exits from the fishway (average = 1.71). Of the 409 steelhead in the Washington-shore fishway, 248 made 694 exits (average = 1.70). When both fishways were considered, the 713 steelhead that entered in 1996 had 1,550 exits (average = 2.17 per fish); most exits occurred at shoreline and spillway entrances (Figure 16).

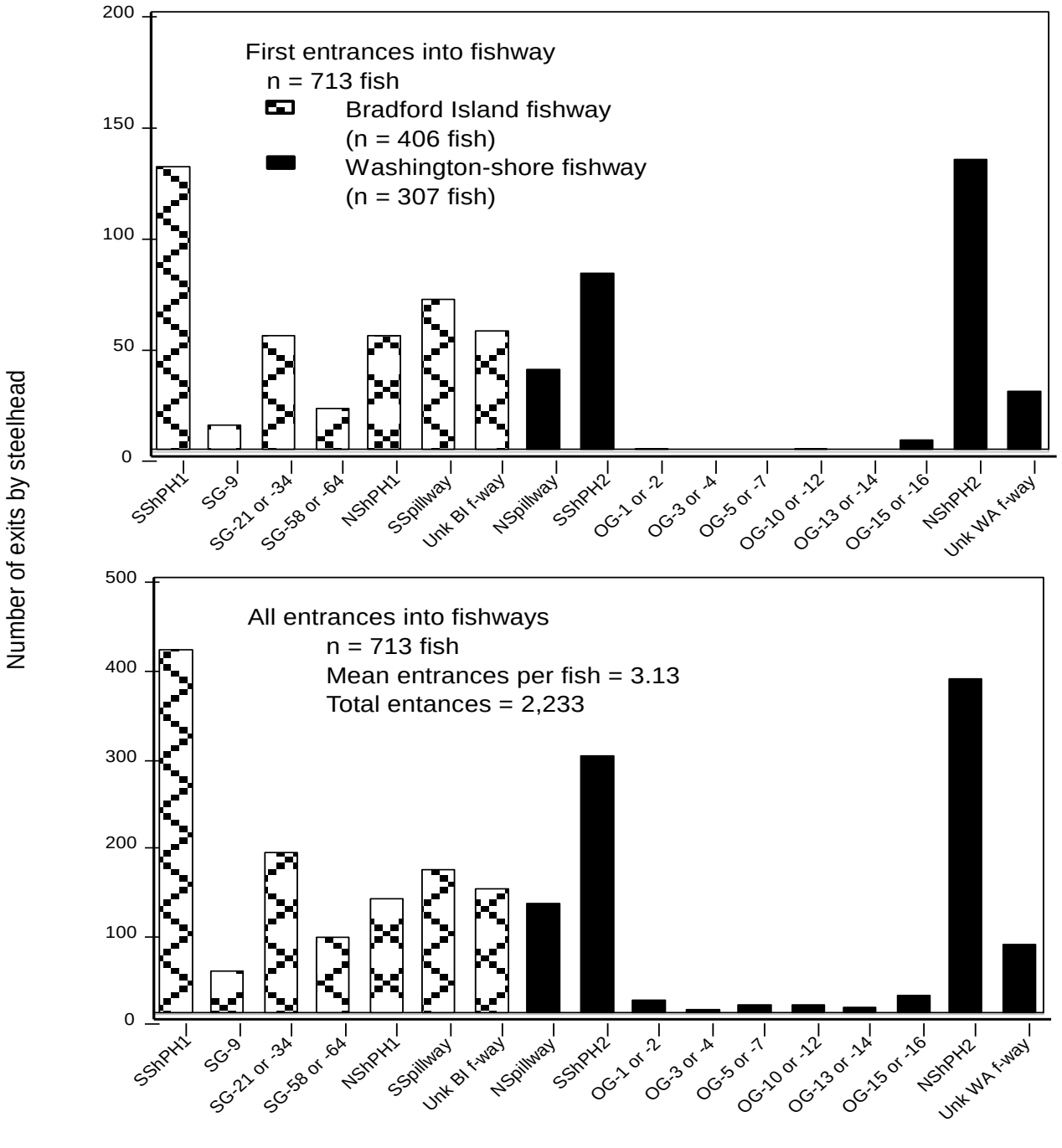

Figure 12. Number of first and total entries at Bonneville Dam fishway entrances in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped. See Figure 1 for fishway entrance locations.

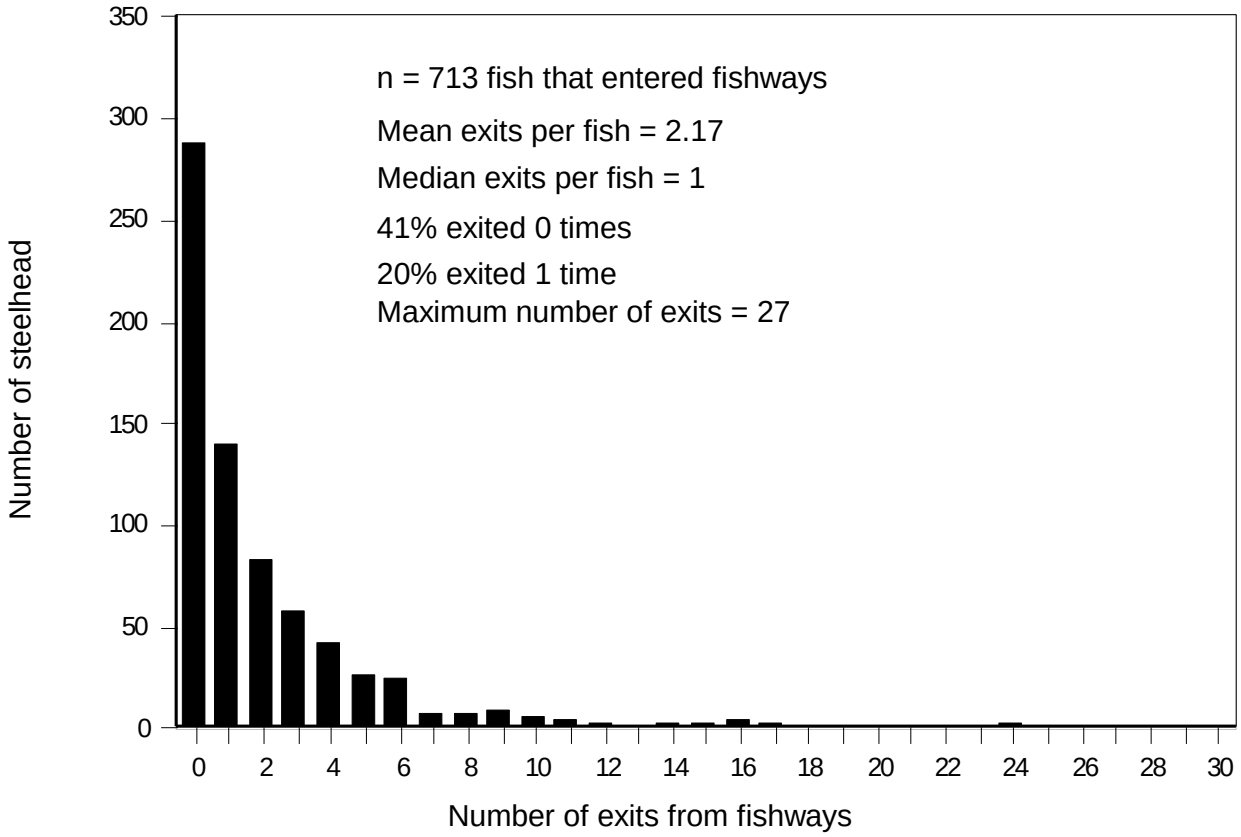

Figure 13. Number of steelhead that exited fishways at Bonneville Dam one or more times in 1996.

Net entry rates (entries minus exits) for steelhead that first entered the Bradford Island fishway ranged from -1 at the south shore of Powerhouse 1, to 38 at the south-spillway entrance (Figure 17). Net entry rates for all entrances and exits ranged from -85 at the south-shore entrance of Powerhouse 1, to 96 at the center of the powerhouse.

At the Washington-shore fishway, several orifice-gate entrances had more exits than entries for both first and total entries (Figure 18). The lowest net entrance rate was at the downstream entrance at the south-shore of Powerhouse 2. The entrances with the highest first and total net entries at the Washington-shore fishway were the north-shore, the upstream south-shore entrances of Powerhouse 2, and the north-spillway entrance. When both fishways were considered, the north-shore entrances of Powerhouse 2 had the highest net entry (Figure 19). The sluice-gate entrances at Powerhouse 1 had a slightly higher net entrance rate than the Powerhouse 1 north-shore and the spillway entrances, while orifice-gate entrances at Powerhouse 2 and the south-shore entrance to Powerhouse 1 had the lowest net entry rates.

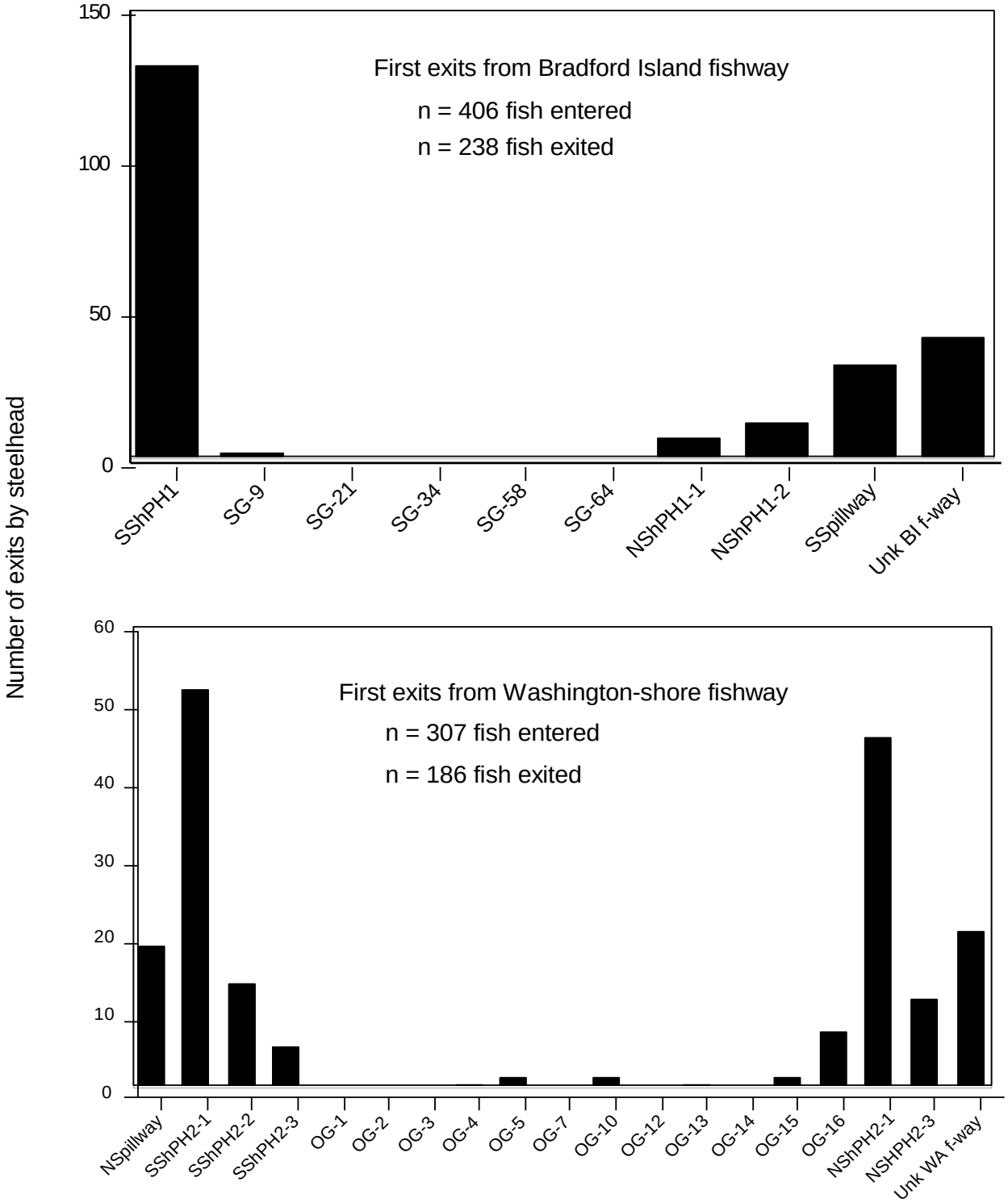

Figure 14. Number of first exits from Bonneville Dam fishway entrances by steelhead in 1996. See Figure 1 for fishway entrance locations.

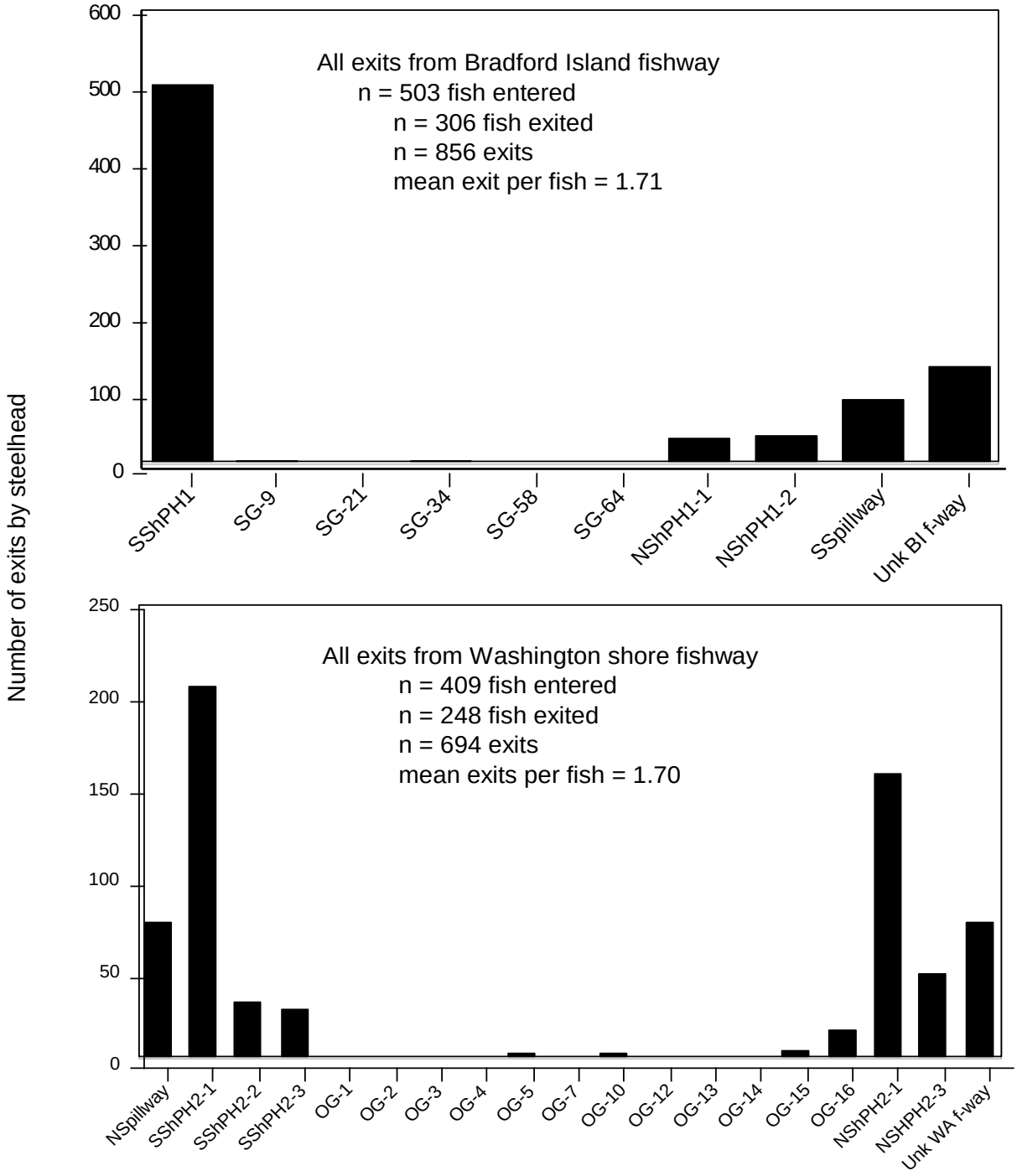

Figure 15. Number of total exits by steelhead from Bonneville Dam fishway entrances in 1996. See Figure 1for locations of entrances.

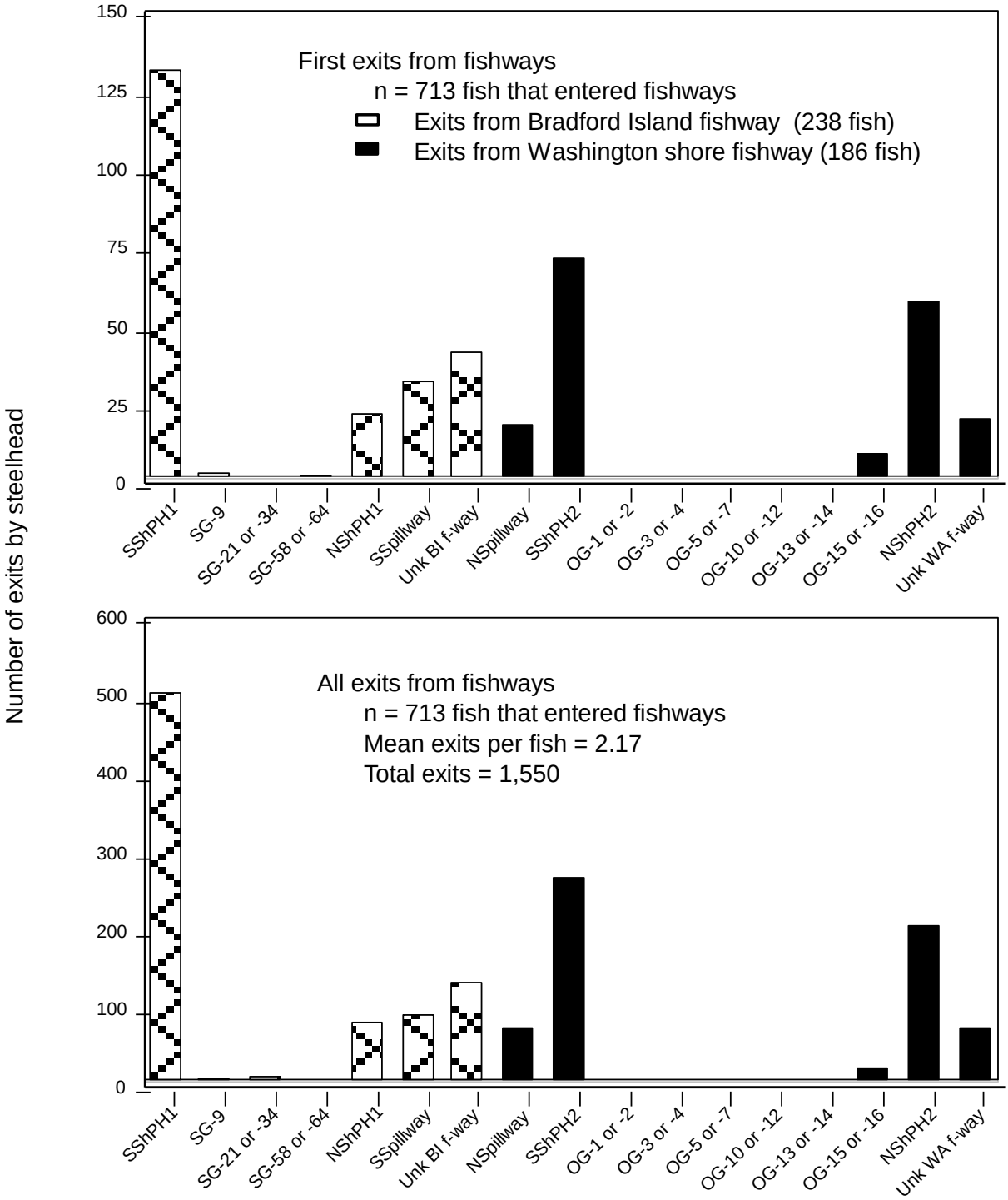

Figure 16. Number of first and total exits by steelhead from Bonneville Dam fishway entrances in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

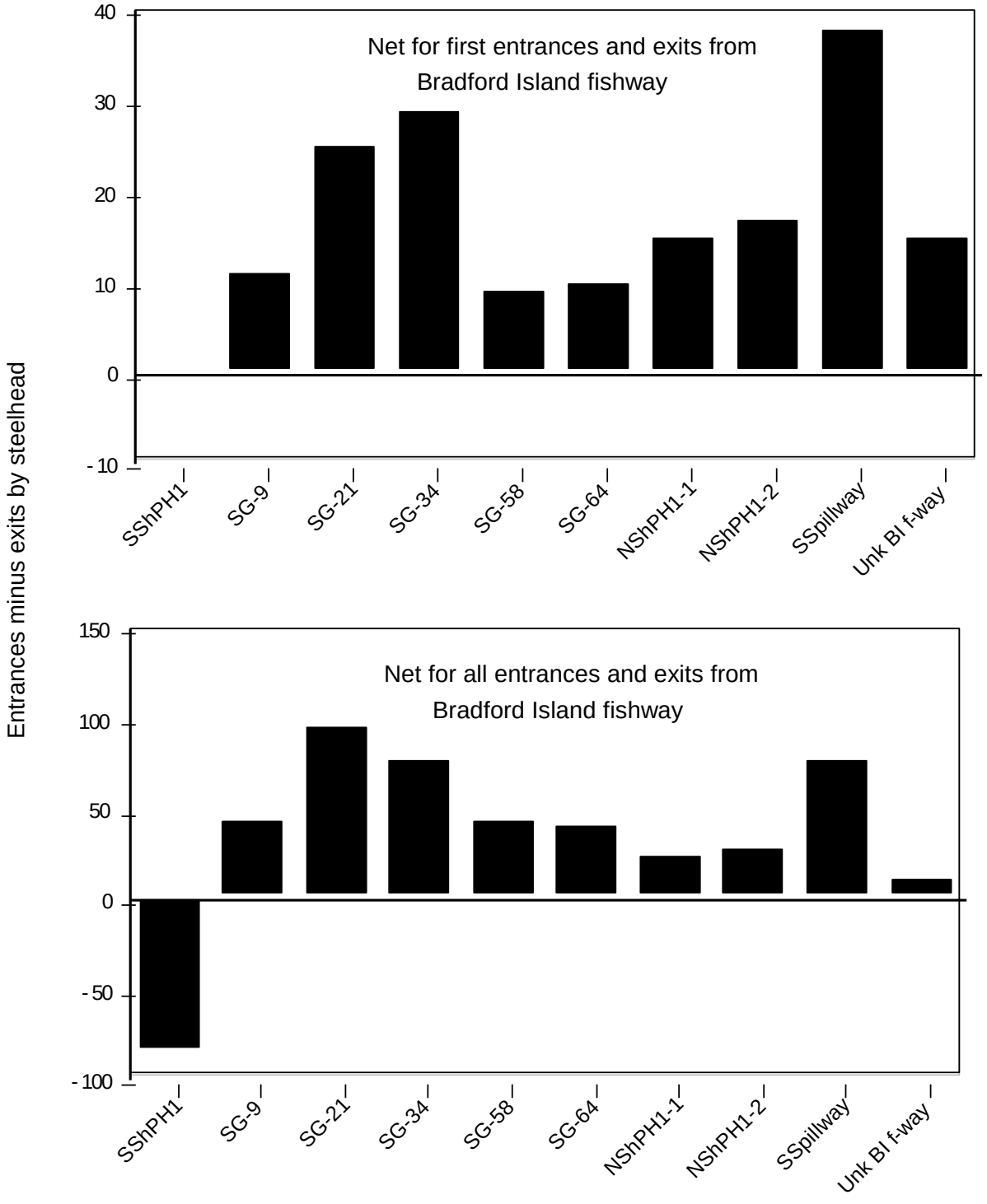

Figure 17. Net number of first and total entries and exits of steelhead from the Bradford Island fishway entrances at Bonneville Dam in 1996.

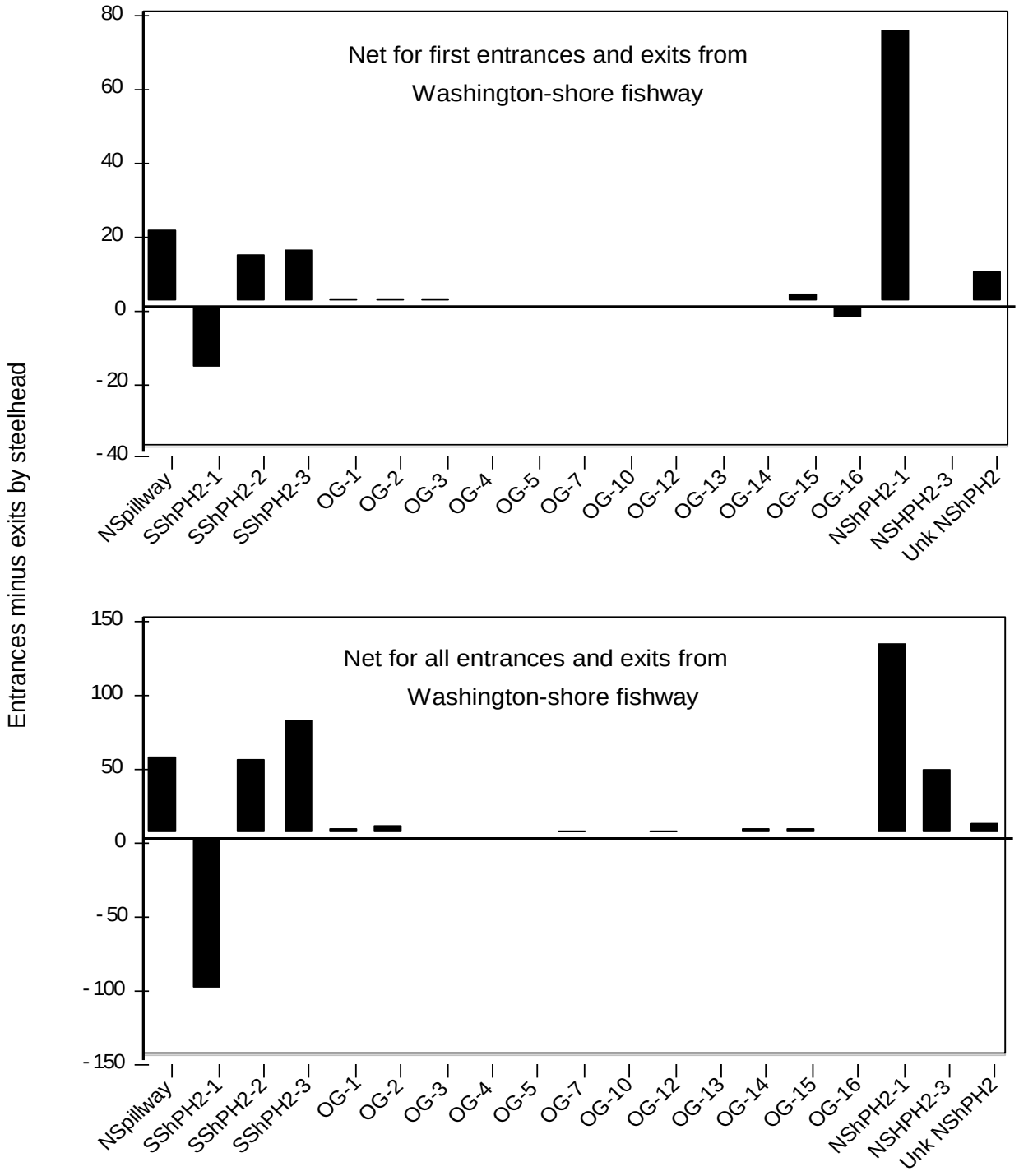

Figure 18. Net number of first and total entries and exits of steelhead from the Washington-shore-fishway entrances at Bonneville Dam in 1996. See Figure 1 for fishway locations.

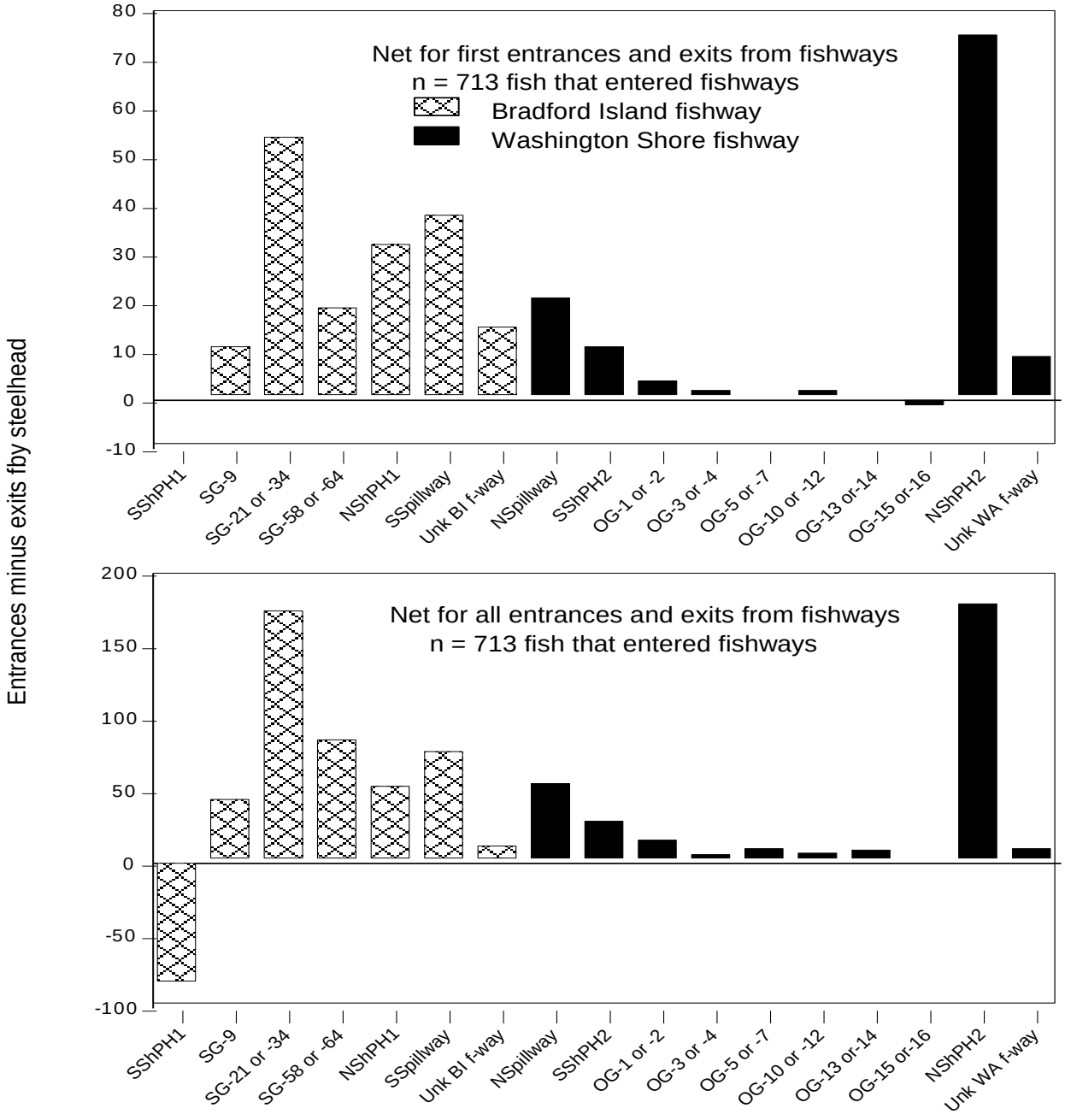

Figure 19. Net number of first and total entries and exits of steelhead from entrances to both fishways at Bonneville Dam in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

Negative net entrances at a fishway entrance did not necessarily mean that the entrance did not produce dam passages (Figure 20). The entries at the shoreline entrances produced the most steelhead passages at Bonneville Dam (SShPH1 and NShPH2), followed by the spillway entrances (SSpillway and NSpillway), and then the north-shore entrance to powerhouse 1, the center sluice-gates at powerhouse 1, and the powerhouse 2 south-shore gates. The high fishway exit rate from the powerhouse 1 south-shore gate suggests that fish that entered at other fishway entrance moved downstream and exited there.

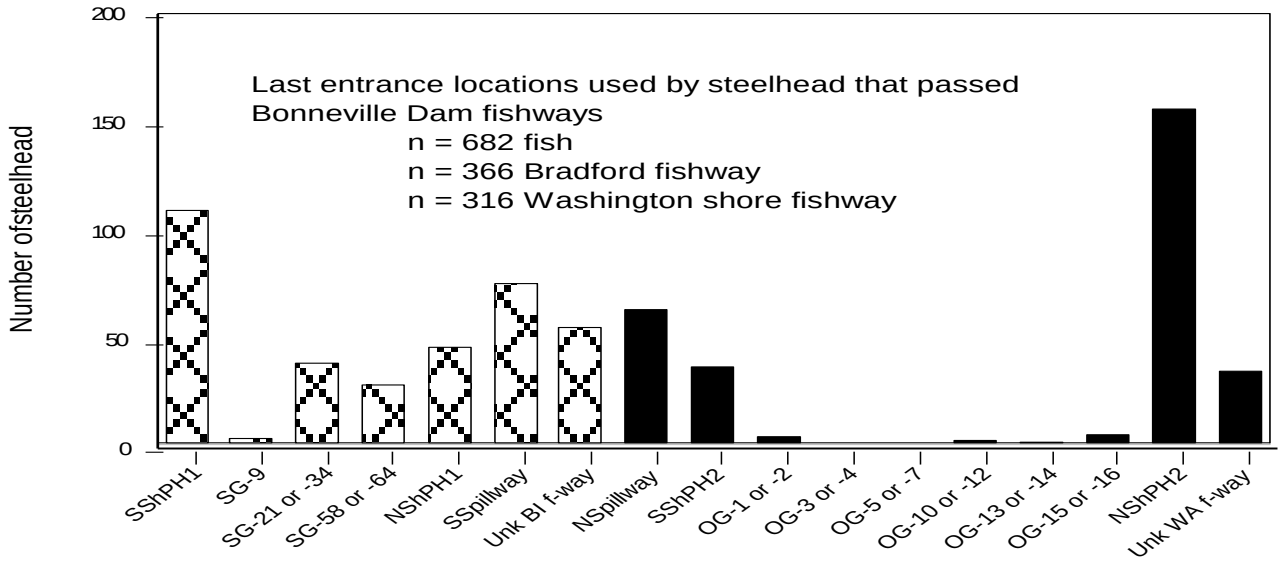

Figure 20. Last entrance locations used by steelhead that passed Bonneville Dam fishways in 1996.

Movements Through Transition Pools

We analyzed behavior of 615 steelhead that were recorded at all of the fishway transition points (fishway approach and entry, transition pool entry and last exit into the ladder, and ladder exit) as they moved within the four transition pools at Bonneville Dam in 1996. Forty-two percent (257) of the steelhead first entered the transition pool at the base of the A-Branch ladder of the Bradford Island fishway (A-Branch pool), 18% (110) first entered at the transition pool at the base of the B-Branch ladder at the south end of the spillway (B-Branch pool); 7% (44) first entered at the transition pool at the base of the Cascades Island ladder at the north end of the spillway (Cascades Island pool); and 33% (204) first entered at the Washington-shore transition pool (WA-shore pool) (Figure 21). Of the 615 fish, 84% (516) eventually passed the dam via the ladder associated with the pool they first entered, although not necessarily on the first attempt. The remaining 16% (99) entered one transition pool, turned around and exited the transition pool and fishway into the tailrace, then entered another fishway and transition pool before passing the dam.

Nearly half (46%, 284) of the steelhead monitored at Bonneville transition pools exited into the tailrace one or more times before they passed through a pool and over the dam (Figure 22). Thirty-five percent (217) moved straight through a transition pool and into a ladder with no downstream movement, and 10% (59) moved downstream in a transition pool but did not exit the pool before passing the dam. Hence, less than half the fish (45%) traversed transition pools on their first attempt. The remaining 9% (55) 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 615 steelhead from first fishway entry to first entry into a transition pool was 7 min (0.11 h); median time from first transition pool entry to exit a pool into a ladder was 0.62 h (Figure 23). Median time for all fish to ascend a ladder after exiting a transition pool into a ladder was 2.38 h, and median passage from first fishway entry to exit from the top of a ladder was 6.17 h (Figure 23, Table 2).

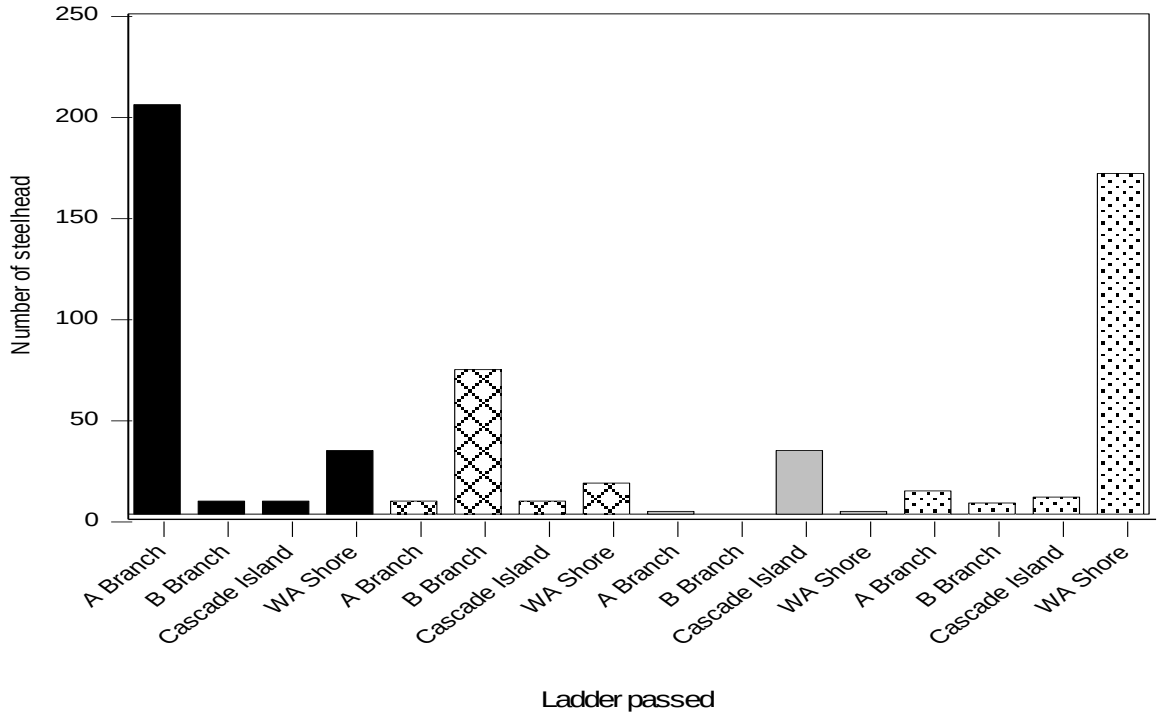

Figure 21. Number of steelhead that passed Bonneville Dam in 1996, the transition pool first entered, and the ladder used to pass the dam. First entered A-Branch pool: black bars; first entered B-Branch pool: checkered bars; first entered Cascade Island pool: gray bars; first entered Washington-shore pool: stipple bars.

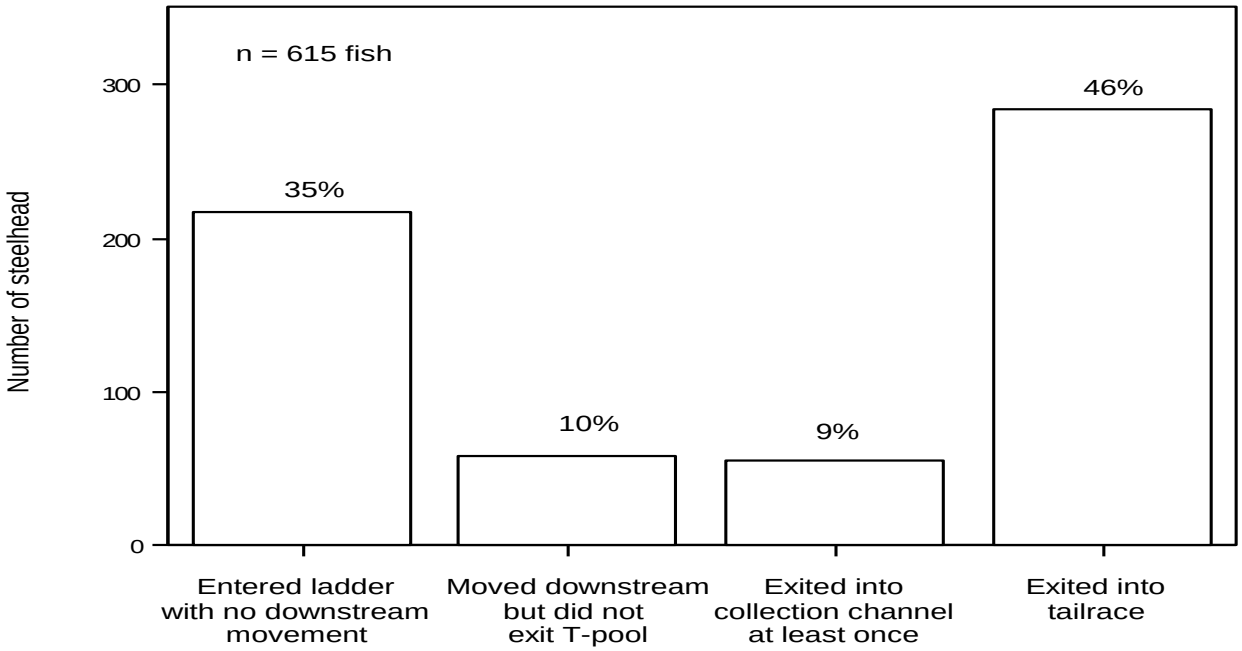

Figure 22. Number of steelhead that passed straight through a Bonneville transition pool into a ladder, moved downstream in a pool before entering the ladder, exited a pool into a collection channel, or exited a pool into the tailrace in 1996.

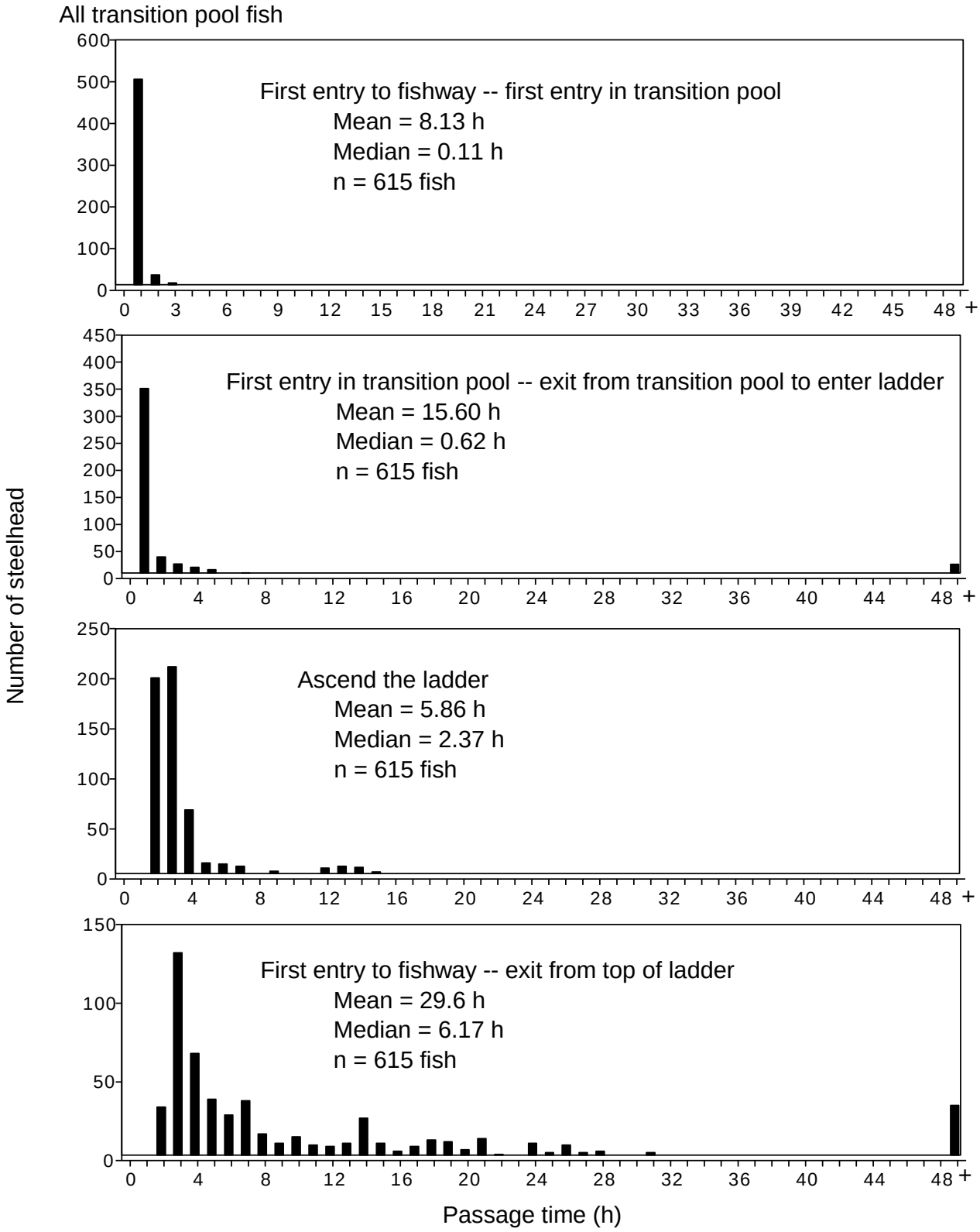

Figure 23. Time to first enter and to pass through a transition pool, to ascend a ladder, and to exit from the top of a ladder at Bonneville Dam by steelhead in 1996.

Table 2. Median and mean passage times for steelhead 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	615	0.11	0.62	2.38	6.17
Moved straight through	217	0.10	0.12	2.40	2.91
Moved downstream, but didn't exit	59	0.05	0.36	2.31	3.49
Exited pool to collection channel	55	0.24	0.34	2.45	3.53
Exited pool to tailrace	284	0.12	6.89	2.37	13.94

When all pools were considered together, median passage times from first fishway entry to first transition pool entry and to ascend a ladder appeared to be independent of steelhead behavior in the pools. Median times from first fishway entry to first transition pool entry ranged from 3 min (0.05 h) for fish that moved downstream in a pool but did not exit to 14 min (0.24 h) for fish that exited a transition pool into a collection channel (Table 2). Median times to ascend ladders ranged from 2.31 to 2.45 h (mean times 4.18 to 7.04 h) (Table 2).

Median passage times from first transition pool entry to last entry into a ladder and from first fishway entry to exit from the top of a ladder were significantly different with different steelhead behavior in the transition pools. For steelhead that moved straight through a transition pool, median time from first transition pool entry to enter a ladder was 7 min (0.12 h). Median pool passage times increased to 22 min (0.36) for fish that moved downstream in a transition pool but did not exit into a collection channel before entering a ladder, to 20 min (0.34 h) for fish that exited into a collection channel, and to 6.89 h for fish that exited into the tailrace before entering a ladder ($P < 0.0001$, median test) (Table 2). Using median values, steelhead that exited to the tailrace took 20 times longer to enter the ladder after first entering a transition pool than fish that exited to the collection channel only and 57 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 2.91 h for fish that moved straight through a pool on their first attempt, 3.49 h for fish that moved downstream in a transition pool but did not exit before entering a ladder, 3.53 h for fish that exited into a collection channel, and 13.94 h for fish that exited into the tailrace ($P < 0.0001$) (Table 2).

We also analyzed movements by steelhead 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, 257 (42%) of 615 steelhead first entered the A-Branch transition pool. Of these 257 fish, 50% exited to the tailrace, 18% exited to the collection channel, 28% moved straight through the pool into the ladder, and 4% entered the ladder after moving downstream in the pool but not exiting (Figure 24). Steelhead could enter the A-Branch transition pool only via the collection channel at Powerhouse 1 (Figure 25). The pool was relatively straight and short, with antennas separated by approximately 15.2 m. 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 most upstream antenna.

Of 204 steelhead that first entered the WA-shore transition pool, 46% exited to the tailrace, 47% moved straight through the pool into the ladder, 3% entered the ladder after moving downstream in the pool, and 4% moved downstream and exited to the collection channel but did not enter the tailrace (Figure 24). 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 25). 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 47 min) than fish that entered via the Powerhouse 2 collection channel or NSE2,3 (median of 22 min). Steelhead 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 channel upstream of the first inside 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 upstream end of the WA-shore pool and the location of the last transition pool record for steelhead in 1996 varied with tailwater elevation. A sequence of four paired antennas at different elevations in the ladder were used to mark a fish's exit from the transition pool into the ladder as tail-water elevations changed

The remaining 154 fish (25%) first entered transition pools at the base of the spillway ladders, 110 (18%) at the B-Branch pool at the south end of the spillway, and 44 (7%) at the Cascades Island pool at the north end of the spillway. These transition pools were nearly identical (Figure 26); 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 transition pool entry, and antennas that recorded the exits of fish from the transition pool into ladders were another 12.2 m upstream. There were no collection channels and, in 1996, no antennas to adjust for changes in tailwater elevation. More steelhead passed straight through the spillway pools, or passed through after some downstream movement, than at other Bonneville transition pools. Overall 58% (64) of the steelhead that first entered the B-Branch transition pool and 61% (27) that first entered the Cascades Island pool passed through on their first attempt (i.e., no exit to collection channel or tailrace) (Figure 24). Forty-two percent (n = 46) of fish exited from the B-Branch pool to the tailrace, and 39% (n = 17) exited to the tailrace from the Cascades Island pool.

Differences between individual transition pools and fishway configurations were reflected in steelhead passage times. Steelhead 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 3). By comparison, median times from first fishway entry to first transition pool entry were 5 min (0.09 h) for fish that passed straight through the WA-shore pool and 13 min (0.22 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 4 min (0.07 h) at Cascades Island and 8 min (0.14 h) at the B-Branch pools, and 12 min (0.19 h) at the WA-shore pool when all possible routes into the WA-shore pool were combined (Table 3). Fish that moved straight through the A-Branch transition pool did so in a median time of less than 1 min (0.02 h). Median times for steelhead to ascend ladders after passing transition pools were 2.10 h at the B-Branch ladder and 3.05 h at the Cascades Island ladder. Longer passage times up the Cascades Island ladder included time fish spent negotiating the

UMT channel and the junction pool at the top of the WA-shore ladder. Median times at the A-Branch and WA-shore pools were 2.21 and 2.46 h, respectively. Median time from first fishway entry to exit from a ladder was 2.61 h for steelhead that passed straight through the A-Branch, 2.70 h through the B-Branch, 3.34 h through the Cascade Island, and 3.59 h through the WA-shore transition pools (Table 3).

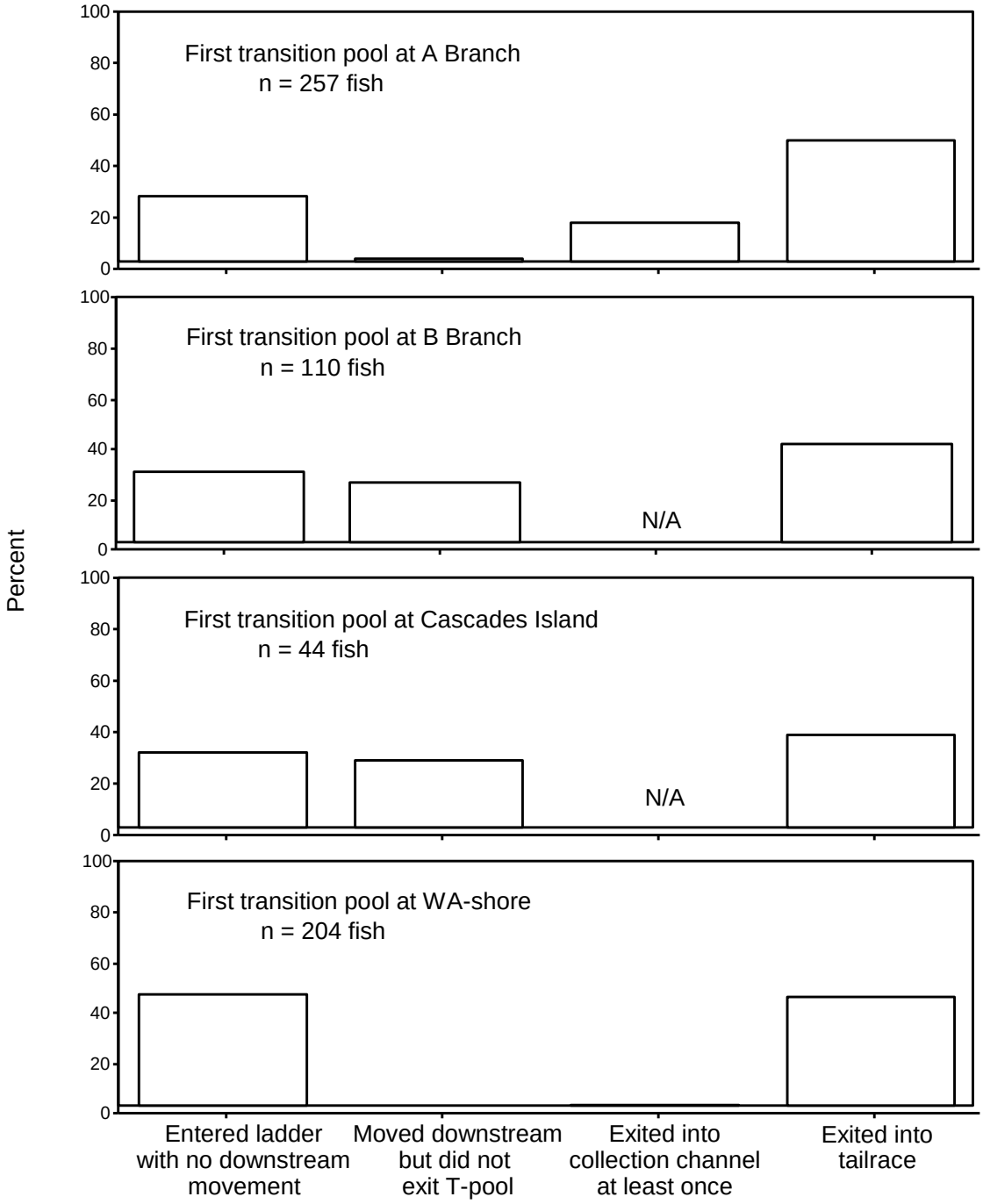

Figure 24. Percentage of steelhead in 1996 that passed straight through a Bonneville transition pool into a ladder, moved downstream in a pool before entering a ladder, exited a pool into a collection channel, or exited a pool into the tailrace based on which transition pool was first entered.

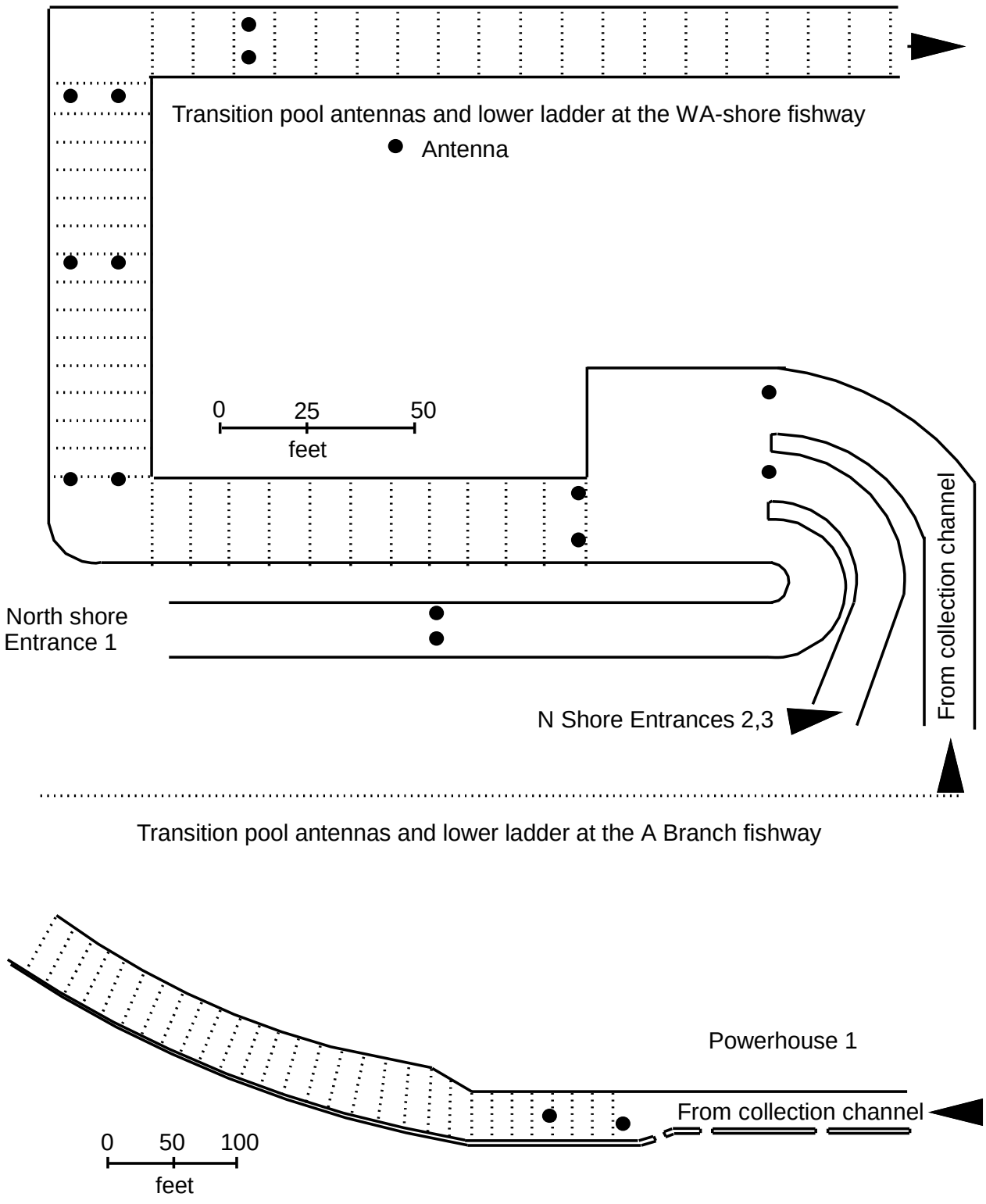

Figure 25. Location of antennas installed in the WA-shore transition pool of the Washington-shore fishway and the A-Branch transition pool at Bonneville Dam in 1996.

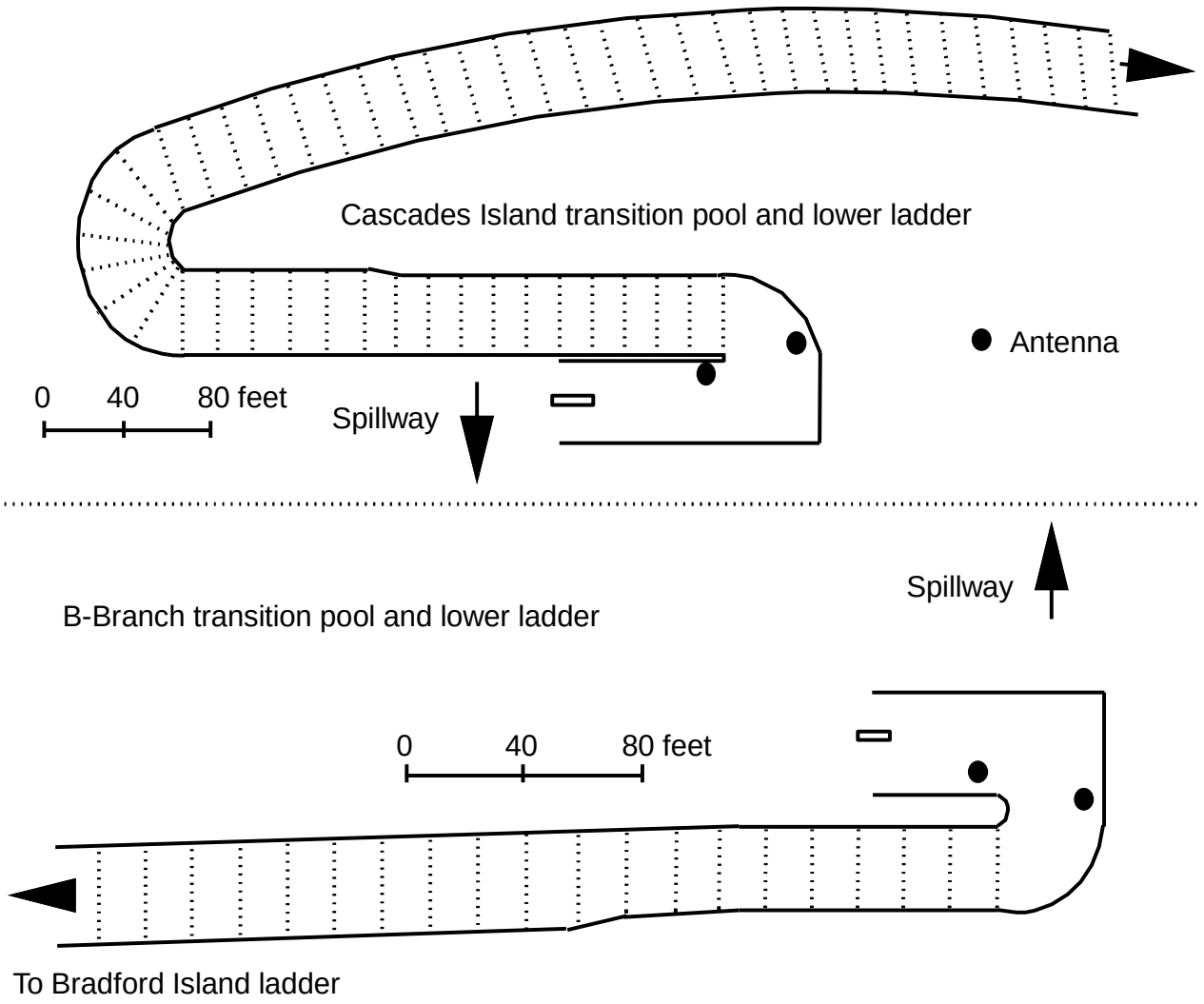

Figure 26. Location of antennas installed in the Cascades Island and B-Branch transition pools, in the ladders adjacent to the spillway at Bonneville Dam in 1996.

Steelhead 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 3 min (0.04 h) at B-Branch and Cascades Island transition pools, 4 min (0.06 h) at the WA-shore pool, and 24 min (0.41 h) at the A-Branch pool (Table 3). Median times from first transition pool entry to exit a pool into a ladder were 6 min (0.10 h) through the A-Branch pool, 49 min (0.82 h) through the WA-shore pool, 25 min (0.42 h) at the B-Branch pool, and 15 min (0.25 h) at the Cascades Island pool (Table 3). Median times for fish to ascend ladders after passing a transition pool were similar to those for fish that moved straight through pools (Table 3). Median times from first fishway entry to exit from the top of a ladder were 3.54 h through the B-Branch pool, 3.33 h through the WA-shore pool, 11.04 h through the Cascades Island pool, and 2.84 h through the A-Branch pool (Table 3).

Table 3. Median passage times at Bonneville Dam for steelhead 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	72	0.22	0.02	2.21	2.61
movement in pool	B-Branch	34	0.03	0.14	2.10	2.70
	Cascade Is.	14	0.03	0.07	3.05	3.34
	WA-shore	97	0.09	0.19	2.46	3.59
Moved downstream	A-Branch	10	0.41	0.10	2.07	2.84
but did not exit pool	B-Branch	30	0.04	0.42	2.10	3.54
	Cascade Is.	13	0.02	0.25	3.61	11.04
	WA-shore	6	0.06	0.82	2.30	3.33
Exited pool to	A-Branch	47	0.23	0.25	2.41	3.42
collection channel	B-Branch	n/a	--	--	--	--
	Cascade Is.	n/a	--	--	--	--
	WA-shore	8	0.64	0.74	2.79	4.09
Exited pool to	A-Branch	128	0.28	6.57	2.27	13.74
Tailrace[1]	B-Branch	46	0.02	6.50	2.39	13.58
	Cascade Is.	17	0.03	7.49	3.19	18.03
	WA-shore	93	0.04	7.55	2.46	14.14

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

In 1996, 47 steelhead 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, 15 min (0.25 h) from first transition pool entry to last exit the pool into the ladder, 2.41 h to ascend the ladder, and 3.42 h from first fishway entry to exit from the top of the ladder (Table 3). Eight fish exited the WA-shore pool into the powerhouse collection channel but did not exit into the tailrace. Median passage times for the 8 fish were 38 min (0.64 h) from first fishway entry to first transition pool entry, 0.74 h from first transition pool entry to exit the pool into the ladder, 2.79 h to ascend the ladder, and 4.09 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 6.50 to 7.55 h at the four transition pools; median times from first entry to

exit from the top of a ladder were 13.58 to 14.14 h at the A-Branch, B-Branch and WA-shore ladders and 18.03 h through the Cascade Island pool (Table 3).

Of the 284 steelhead that exited transition pools into the tailrace at Bonneville Dam, 153 (54%) reentered the same fishway and passed the dam via the transition pool they first entered, and 46% (131) exited a transition pool into the tailrace and 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 27). Steelhead that exited a transition pool into the tailrace and then passed the dam via a different pool took a median of 12.78 h to pass from first transition pool entry to last exit a pool into a ladder, nearly four times as long as fish that exited to the tailrace and then reentered and passed through the same transition pool (3.22 h). Fish that passed the dam via a different transition pool than they first entered took 18.04 h to pass from first fishway entry to exit from the top of a ladder, compared to 9.63 h for steelhead that passed via the same transition pool they first entered (Figure 27).

Of the 128 fish that exited the A-Branch transition pool into the tailrace, 59% reentered and passed there, 7% passed via the B-Branch pool, 7% passed via the Cascades Island pool, and 27% passed via the WA-shore pool (Table 4). Median passage times from first transition pool record at the A-Branch pool to the last exit of a pool into a ladder ranged from 2.78 h for fish that reentered and passed the A-Branch pool to 17.81 h for fish that passed via the WA-shore pool (Table 4).

Of the 46 steelhead that exited from the B-Branch transition pool, 22% reentered and passed there, 20% passed via the A-Branch pool, 20% passed via the Cascades Island pool, and 39% passed via the WA-shore pool (Table 2). Median passage times from first transition pool entry to the last exit of a pool into a ladder ranged from 4.03 h for fish that passed the Cascade Island pool to 17.33 h for those that passed the A-Branch pool.

Of fish that exited the B-Branch pool, median passage times from first fishway entry to exit from the top of a ladder were 19.88 h for fish that passed via the A-Branch pool, 9.91 h for fish that passed via the WA-shore pool, 17.44 h for fish that passed the dam via the Cascades Island pool and 15.24 h for fish that passed via the B-Branch pool (Table 4).

Of the 17 fish that exited the Cascades Island transition pool into the tailrace, 7 (41%) reentered and passed via the same pool, 4 (24%) passed via the A-Branch pool, 2 (11%) passed via the B-Branch pool, and 4 (24%) passed via the WA-shore pool (Table 4). Passage times for these fish were widely variable.

At the WA-shore transition pool, 59 steelhead were first recorded in the pool after entering NSE1, and 34 were first recorded in the pool after entering via NSE2,3 or the collection channel (Table 4). Combined, median transition pool passage times for these fish ranged from 3.24 h for those that passed the WA-shore pool to 20.23 h for those that passed the A-Branch pool; patterns were qualitatively similar when routes were analyzed separately (Table 4). In general, passage times of fish moving through transition pools increased as the distance between the location of first and last pool records increased.

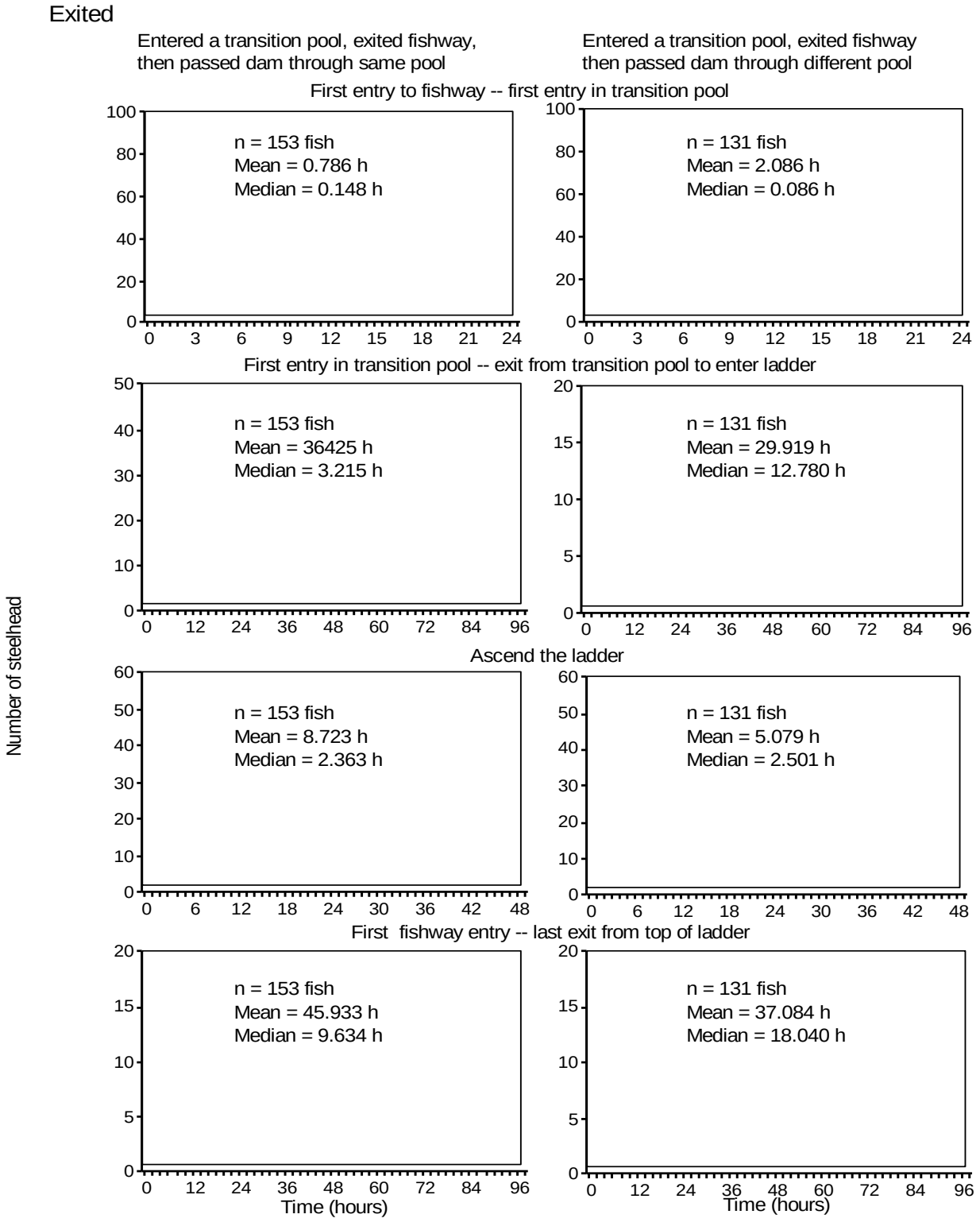

Figure 27. Median time to first enter and to pass through a transition pool, to ascend a ladder, and to exit from the top of a ladder at Bonneville Dam in 1996 by steelhead that exited a transition pool into the tailrace and either did or did not pass the dam via the same transition pool they first entered.

Table 4. 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 steelhead that exited a fishway between first and last records in a transition pool at Bonneville Dam.

			Median passage time (h) from:			
First pool	Last pool	N	First entry To first pool	First pool To last pool	Ascend Ladder	First entry To exit ladder
A-Branch	A-Branch	76	0.292	2.78	2.28	7.57
	B-Branch	9	0.204	12.22	1.84	17.02
	Cascade Is.	9	0.037	15.22	3.27	18.92
	WA-shore	34	0.297	17.81	2.15	22.20
B-Branch	A-Branch	9	0.018	17.33	2.54	19.88
	B-Branch	10	0.007	9.11	2.24	15.24
	Cascade Is.	9	0.029	4.03	11.76	17.44
	WA-shore	18	0.036	6.38	1.88	9.91
Cascade Is.	A-Branch	4	0.076	44.87	2.85	83.54
	B-Branch	2	0.303	6.45	3.57	10.31
	Cascade Is.	7	0.017	1.06	4.02	13.08
	WA-shore	4	4.140	15.67	2.29	36.52
WA-shore	A-Branch	14	0.044	20.23	2.08	24.22
	B-Branch	8	0.017	3.82	2.46	6.54
	Cascade Is.	11	0.172	13.23	3.25	16.27
	WA-shore	60	0.036	3.24	2.37	11.95
*WA-shore^{L}	A-Branch	8	0.015	15.83	2.29	24.22
	B-Branch	6	0.013	9.29	2.48	11.48
	Cascade Is.	6	0.029	12.18	3.01	15.21
	WA-shore	39	0.028	2.86	2.44	11.07
*WA-shore^{M}	A-Branch	6	0.309	21.58	1.98	23.41
	B-Branch	2	1.039	2.97	2.46	6.47
	Cascade Is.	5	0.195	13.54	3.31	17.05
	WA-shore	21	0.356	5.65	2.00	18.64

* 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.

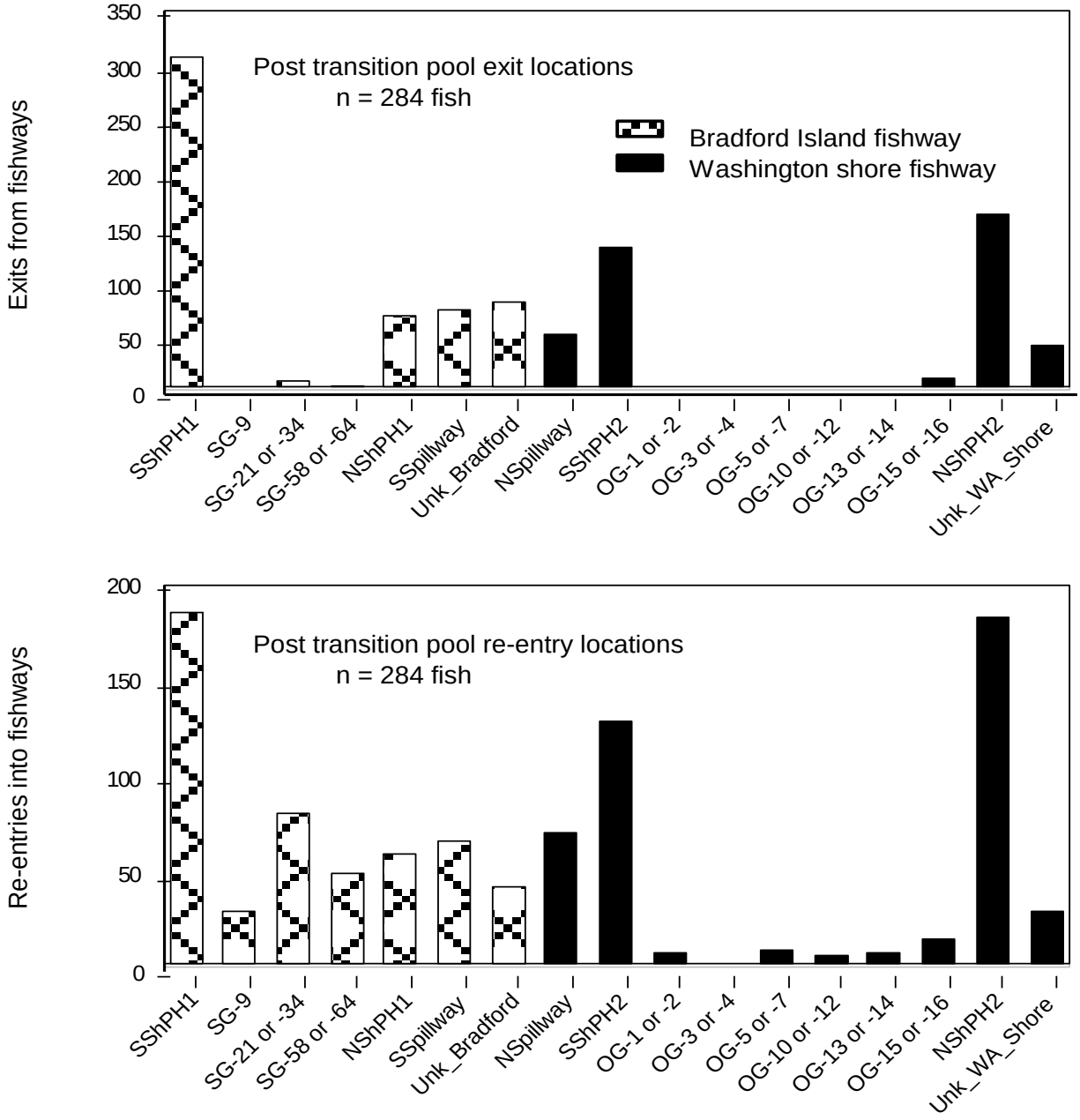

Figure 28. Entrances used to exit and reenter the fishways by steelhead that entered a transition pool, exited to the tailrace, and then reentered a pool and passed over Bonneville Dam in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

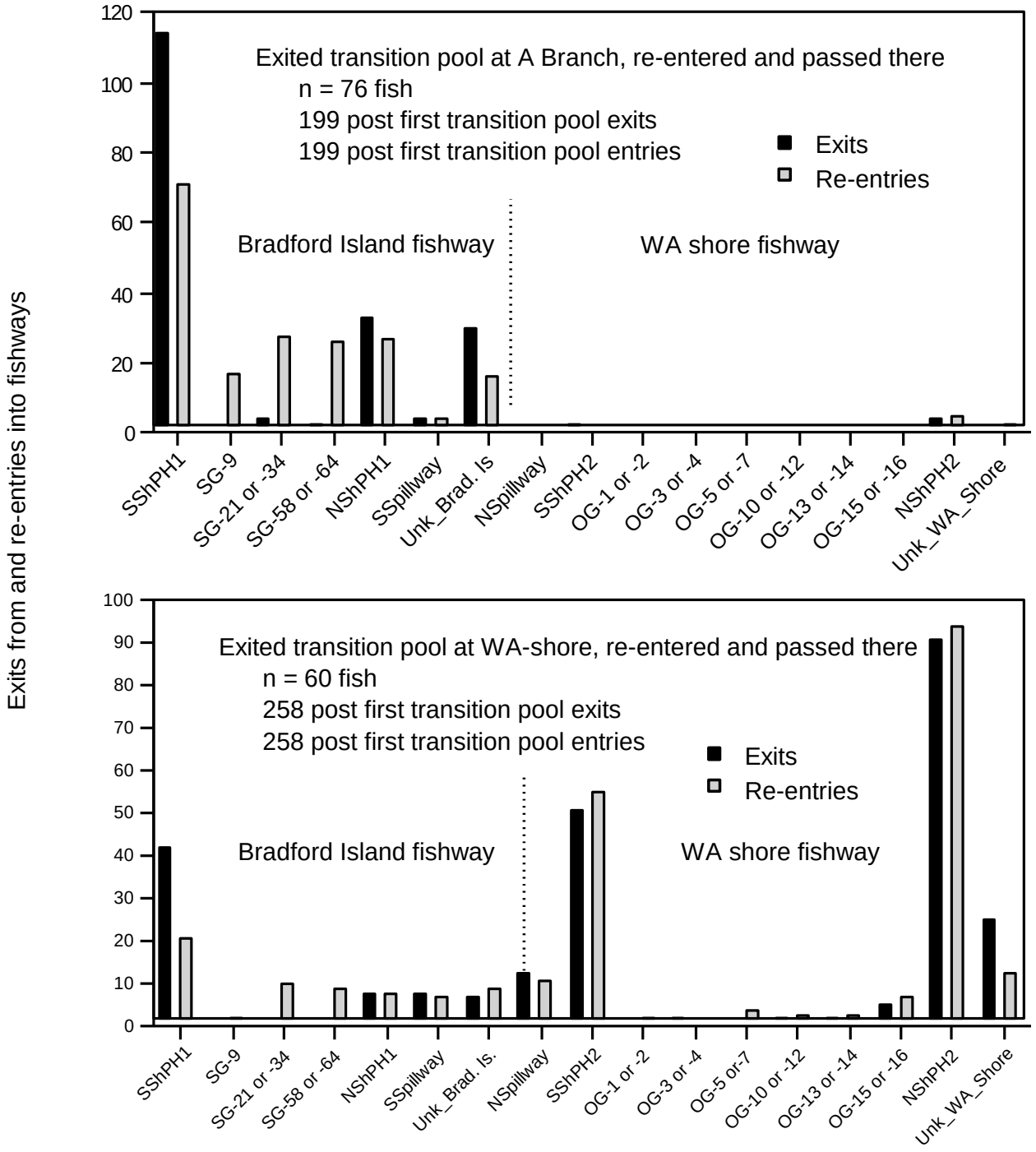

Figure 29. Entrances used to exit and reenter the fishways by steelhead that entered the A-Branch or WA-shore transition pool, exited to the tailrace, and then reentered the same pool and passed over Bonneville Dam in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

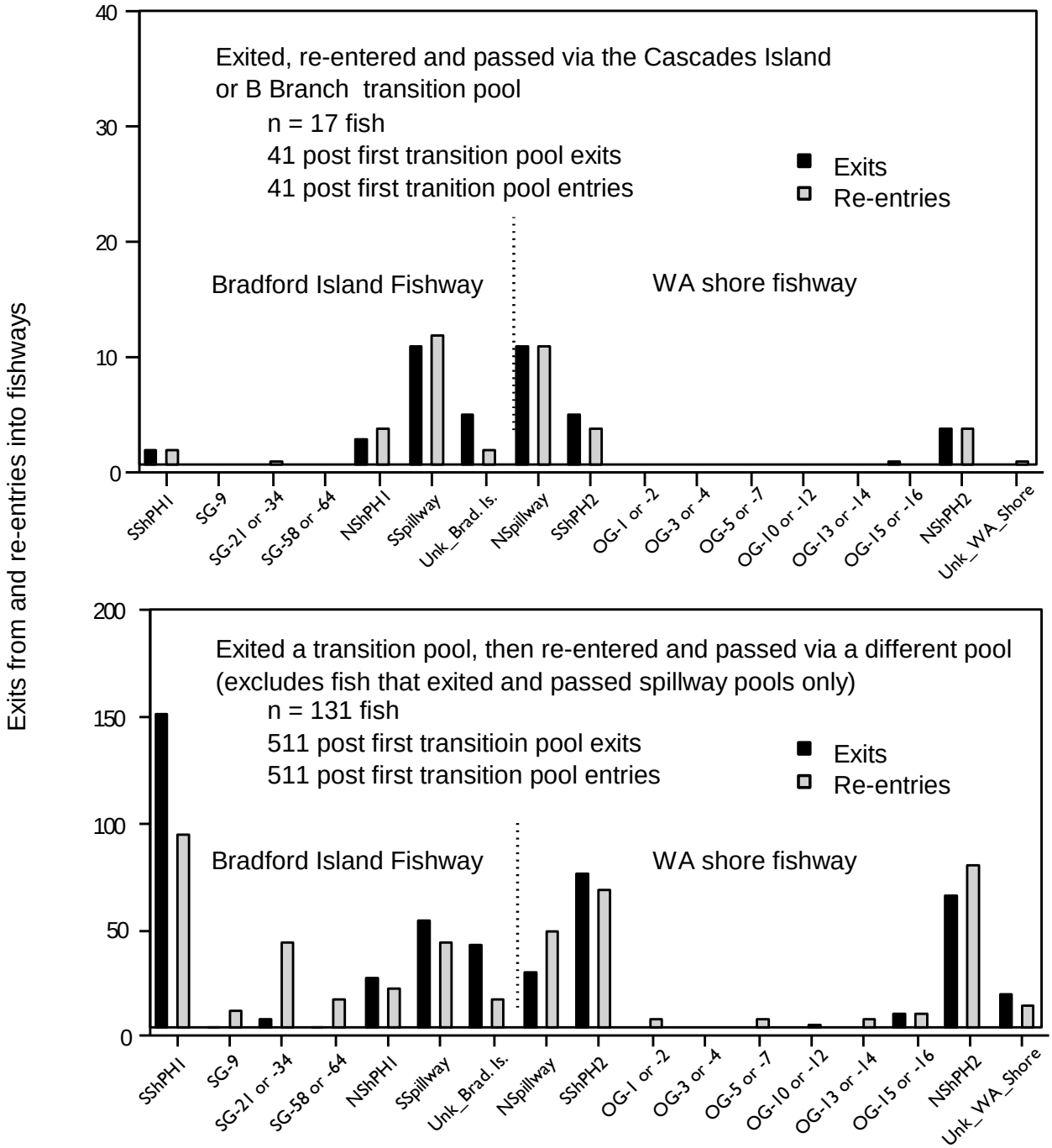

Figure 30. Entrances used to exit and reenter the fishways by steelhead that exited a spillway transition pool, exited to the tailrace, and then reentered a spillway pool and passed over Bonneville Dam and fish that exited a transition pool into the tailrace and passed the dam via a different pool in 1996. For ease of interpretation, adjacent entrances covered by the same receiver are grouped.

Fishway entrances used by steelhead to exit a fishway after leaving a transition pool were similar to those used to subsequently reenter the fishway (Figure 28). Most exits and reentries occurred at shoreline and spillway entrances and the highest number were from shoreline entrances.

The 60 steelhead that first exited the WA-shore transition pool, exited to the tailrace, and ultimately passed the dam via the WA-shore ladder, made 35% (91) of their 258 exits at the Washington-shore entrances and 20% (51) from the south-shore entrances at Powerhouse 2 (Figure 29). The remaining exits were from orifice-gate entrances, Powerhouse 1 entrances, or entrances adjacent to the spillway ladders. Fifty-eight percent (149) of the 258 reentries by the 60 fish were at north- or south-shore entrances at Powerhouse 2.

The 76 fish that first entered the A-Branch transition pool, exited to the tailrace and ultimately passed the dam via the A-Branch ladder, made 57% (114) of 199 exits at the south-shore entrance (Figure 29). Approximately 23% (45) of the exits were from other entrances to the Bradford Island fishway and 5% were distributed among entrances to the Washington-shore fishway. The remaining exits (15%) were from unknown locations. Reentries were distributed more evenly between fishway entrances, but approximately 87% (173) were at entrances to the Bradford Island fishway. The highest number of reentries was at the south-shore entrance to the Bradford Island fishway (Figure 29).

Seventeen steelhead 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 17 fish made 54% of 41 exits and 56% of 41 reentries at entrances to the ladders adjacent to the spillway (Figure 30).

The remaining 131 fish that exited transition pools into the tailrace eventually passed Bonneville Dam via a different transition pool than they first entered. These steelhead exited and reentered the fishways mostly at shoreline and spillway entrances (Figure 30).

Fallback Fish

Of 717 (4 with unknown passage dates) steelhead with transmitters that passed Bonneville Dam in 1996, 37 (5.2%) fell back over the dam a total of 40 times. Steelhead had passed the dam via the Bradford Island ladder prior to 85% (34) of all recorded fallbacks and 84% (31) of first recorded fallbacks. After their first fallback event, 78% (29/37) of the fish that fell back entered fishways, reascended the ladders, and passed the dam a second time. All three that fell back twice passed the dam a third time. Although the sample was small, we compared first and second passage behaviors and times for the 29 fish that reascended.

Median passage times from first approach at a fishway entrance to exit from the top of a ladder were 0.26 d on the first passage and 0.44 d on the second passage for the 29 steelhead that passed twice (Figure 31). By comparison, median first passage time from first approach to passage from a ladder for all 682 steelhead with known passage times at Bonneville Dam was 0.38 d. Two of the fish that fell back moved downstream after approaching a fishway entrance and took more than 5 d to eventually pass the dam.

After falling back, 17 fish (55%) first approached entrances to the Bradford Island fishway and 14 (45%) first approached entrances to the Washington-shore fishway (Figure 32), a distribution between fishways similar to first approaches by all 717 steelhead (Bradford 61% (434) and Washington 39% (283)) that approached Bonneville Dam in 1996 (Figure 8).

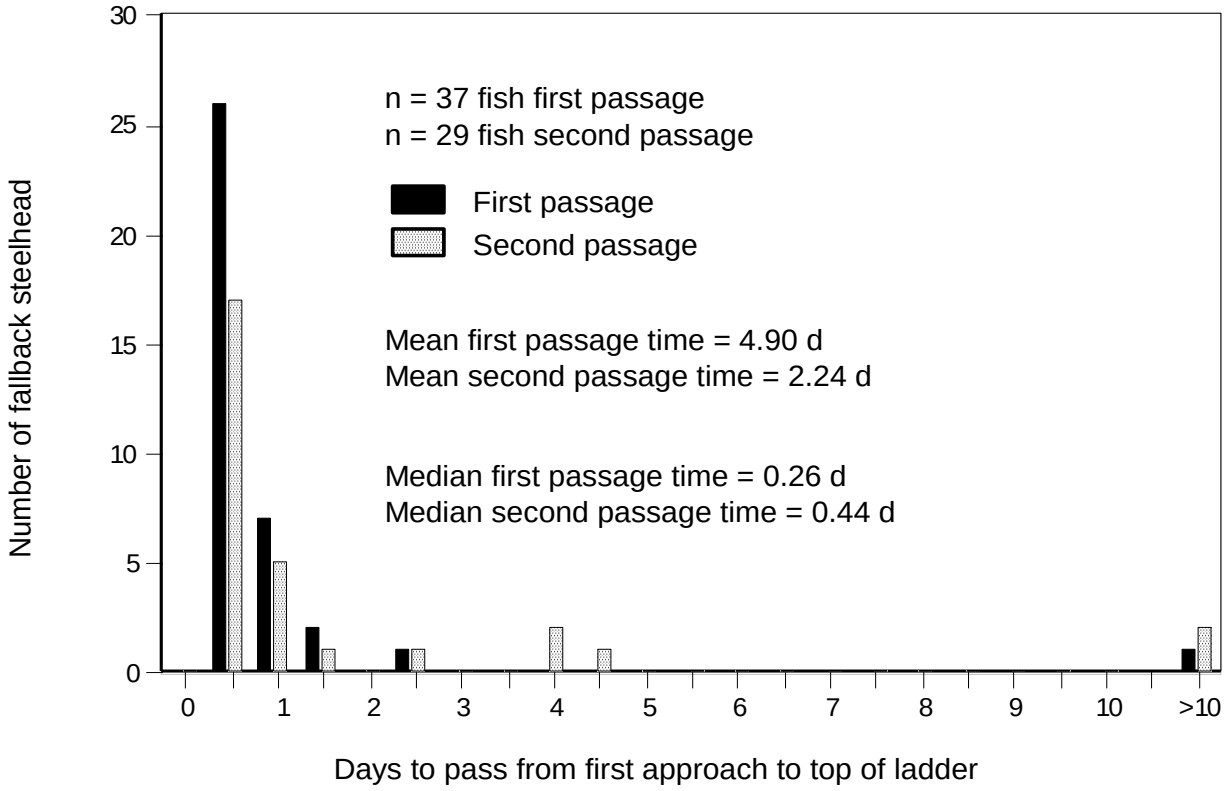

Figure 31. Mean and median passage times from the first approach at a fishway entrance to exit from a ladder for the first and second passages of steelhead that fell back at Bonneville Dam in 1996.

The entrances first approached after falling back differed somewhat from those first approached on the first passage by fallback fish. On the first passage, the largest numbers of fish first approached entrances at the south end of Powerhouse 1, and those at the north end of Powerhouse 2 (Figure 32). On the second passage, spillway entrances and shoreline entrances to the powerhouses were approached first by the largest number of fish. For comparison, only 6% (46/717) of all first approaches were at the south spillway, and 19% (6) of the fish that fell back first approached at the south spillway on their first passage (Figure 32).

The relative distribution of all approaches among entrances was similar for fish after they fell back (Figure 32) to that of all 717 steelhead with transmitters (Figure 8). On their second passage, however, fish that fell back made more approaches at the north-spillway entrance then on their first passage (Figure 32).

The 29 steelhead that reascended made a median of 6 approaches to fishway entrances on their first passage, and 2 approaches on their second passage (Figure 33). By comparison, the entire sample of 717 fish made a median of 9 approaches per fish (Figure 7).

Distributions of the number of fish with one or more fishway entries were not similar for steelhead that fell back and the larger sample of 713 steelhead that entered fishways in 1996 (Figures 33 and 11). Of 29 fish that fell back and reascended, 51% made one entry on their first passage, and 83% made one entry on their second passage (Figure 33). Fallback fish made a mean of 2.49 entries on the first

passage and 1.27 on the second, compared to 3.13 for all 713 steelhead (Figure 11) that entered Bonneville fishways in 1996.

Of fish that fell back, 2.1 times as many fish first entered the Bradford Island fishway on the first passage as first entered the Washington-shore fishway. On the second passage, the ratio was 1.2 (Figure 34), a distribution similar to that of the 713 fish that entered the fishways (1.32 to 1, Figure 9). First entries after a fallback for steelhead were concentrated at the shoreline entrances of both powerhouses and the spillway (Figure 34).

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 713 fish that entered fishways (Figures 35 and 15). Most fish exited via south-shore entrances at both powerhouses. Mean exits per fish were 2.17 for all first passage fish, 1.6 on the first passage of fish that fell back and reascended, and 1.5 on the second passage of fish that fell back. All three groups had a median of 1 exit per fish. On their first passage 49% (18) of the fallback steelhead did not exit the fishways; on the second passage 50% (15) did not exit. Forty-one percent (292/713) of all steelhead that entered did not exit.

On their first passage, 50% of first exits and 53% of total exits were from entrances to the Bradford Island fishway for fallback fish (Figure 35). On the second passage, 70% of first exits and 53% of total exits were from Bradford Island fishway entrances. By comparison, 56% of first exits and 55% of total exits were from entrances to the Bradford Island fishway for all 713 steelhead monitored in the fishways. Exit locations for steelhead that fell back were similar to where they entered fishways (Figure 35).

***Transition pool movements by fish that fell back*:** In 1996, 28 steelhead with transmitters passed Bonneville Dam, fell back over the dam, and were recorded in transition pools while passing the dam a second time. Due to the small sample size, we did not analyze transition pool behavior for these fish.

Effects of Spillway Discharge

Spill occurred 24 hours a day at Bonneville Dam until August 31, after which there was no spill. Before 1 July, spill was > 100 kcfs 24 hours a day. Between 1 July and 31 August night time spill was > 100 kcfs and daytime spill (passage hours) was between 70 and 90 kcfs. During spill, 41 percent of the steelhead passed Bonneville dam via the Bradford ladder (Table 5), 55 percent passed the Washington ladder, and 4 percent passed the navigation lock. During the no-spill period, the passage percentages were 65, 30 and 5 percent, respectively. This was a significant ($P < 0.005$, χ^2 test) shift to the Oregon fishway.

Distributions of all fishway approaches shifted slightly to Powerhouse 1 entrances during spill, but the difference was not significant ($P = 0.623$). First approaches to Bonneville Dam during spill may be affected by a combination of spill and second powerhouse flow near the Washington shore. First approaches at the first powerhouse increased from 49 percent during spill to 63% during no-spill ($P = 0.014$; Table 7), even though flow was nearly evenly split between the two powerhouses. More entrances also occurred at Powerhouse 1 during no-spill, though the difference in distributions was only marginally significant ($P = 0.077$; Table 8).

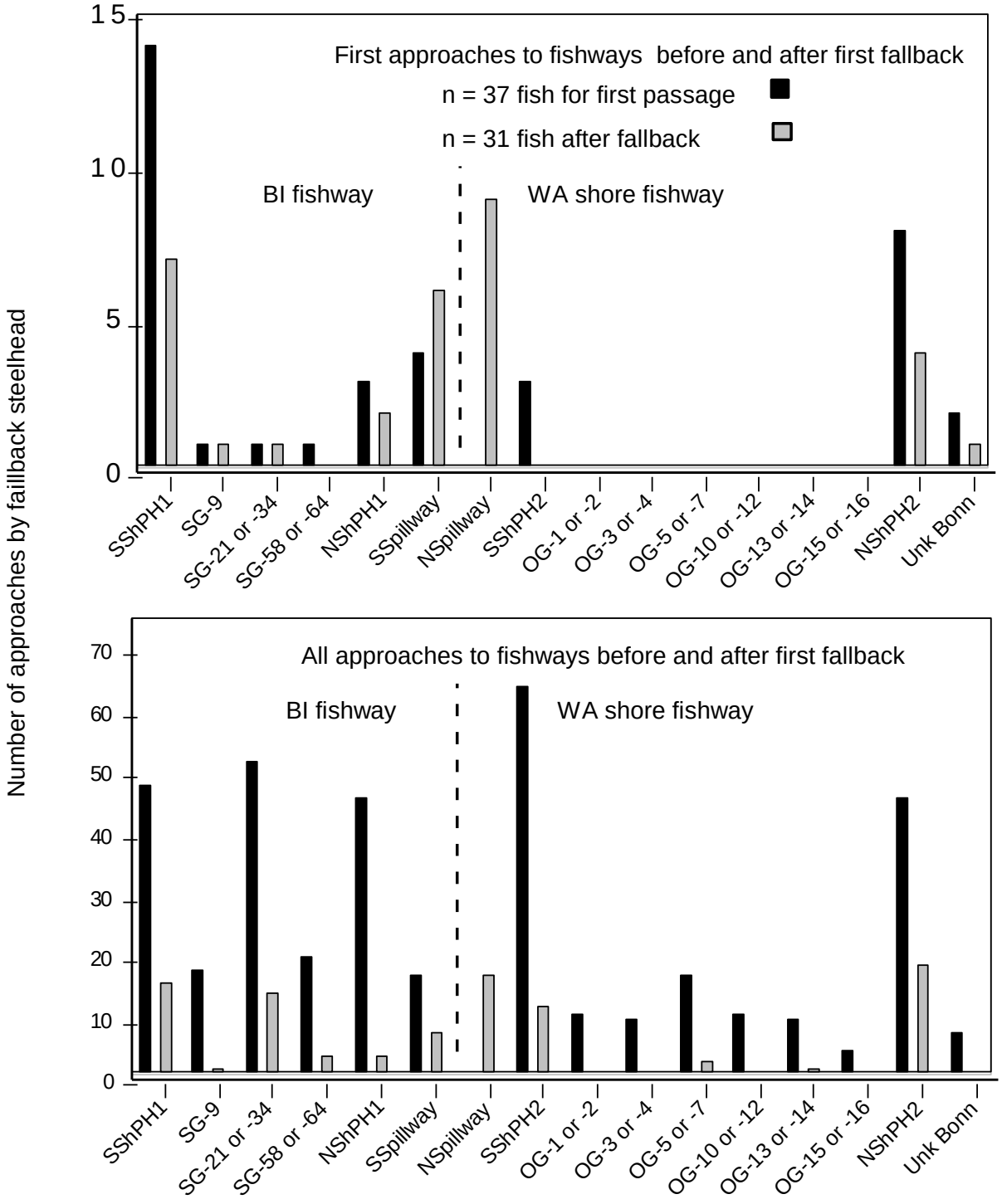

Figure 32. Distribution of first and total approaches to fishways before and after fallback for the 37 steelhead that fell back at Bonneville Dam in 1996.

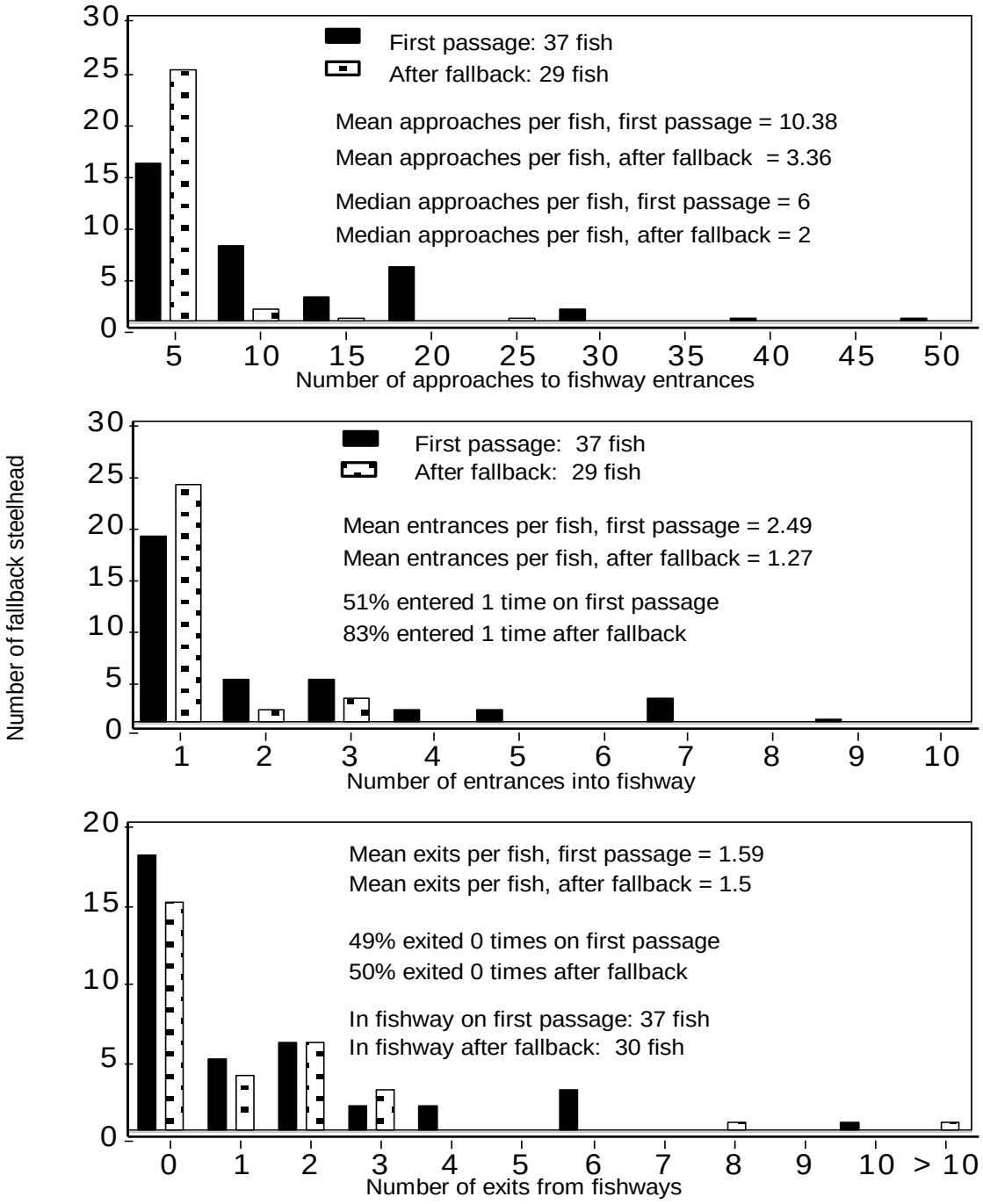

Figure 33. Number of approaches, entries, and exits by steelhead at Bonneville Dam fishway entrances on their first and second passages of the dam in 1996.

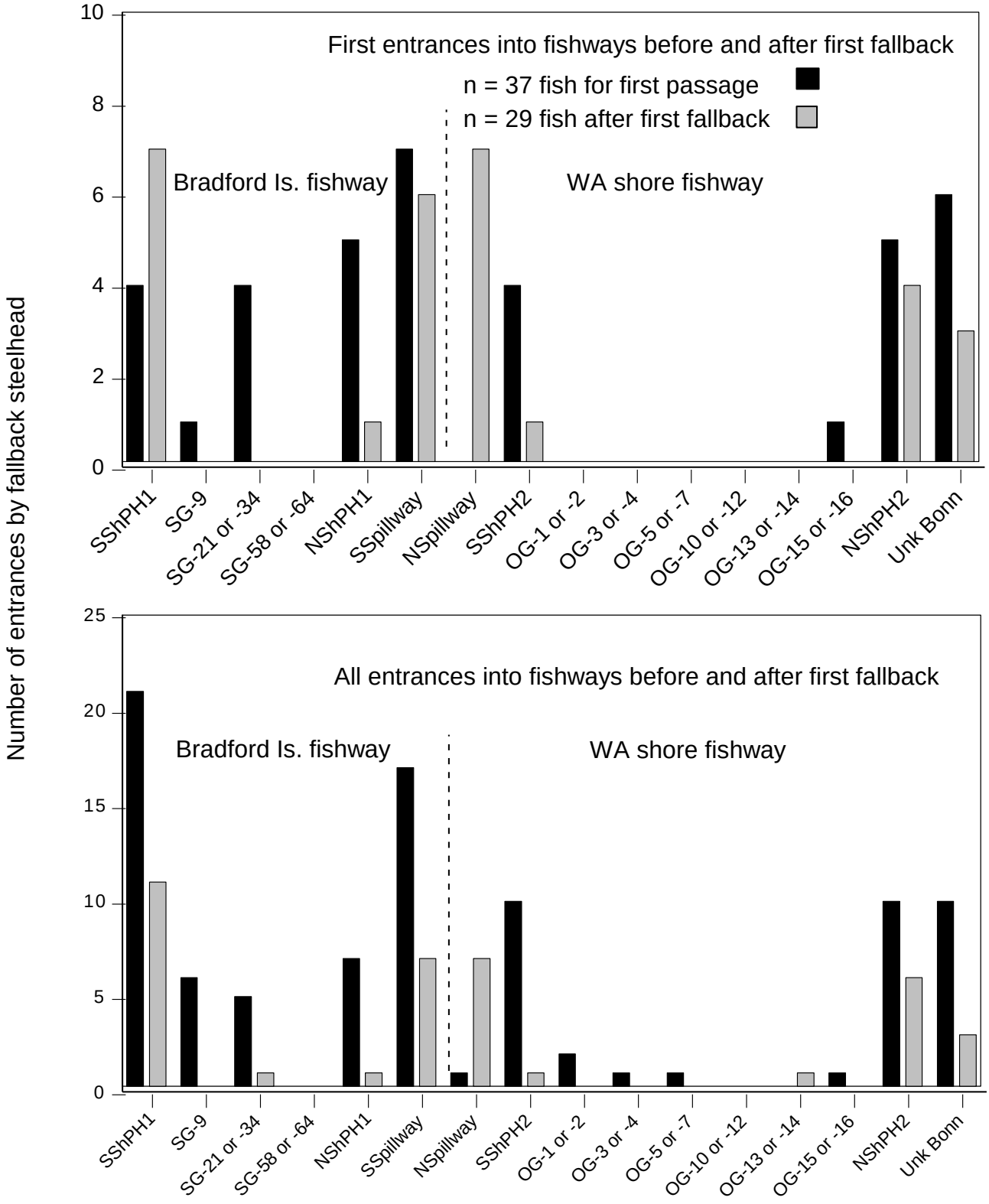

Figure 34. Distribution of first and total entrances to fishways before and after fallback for steelhead in 1996.

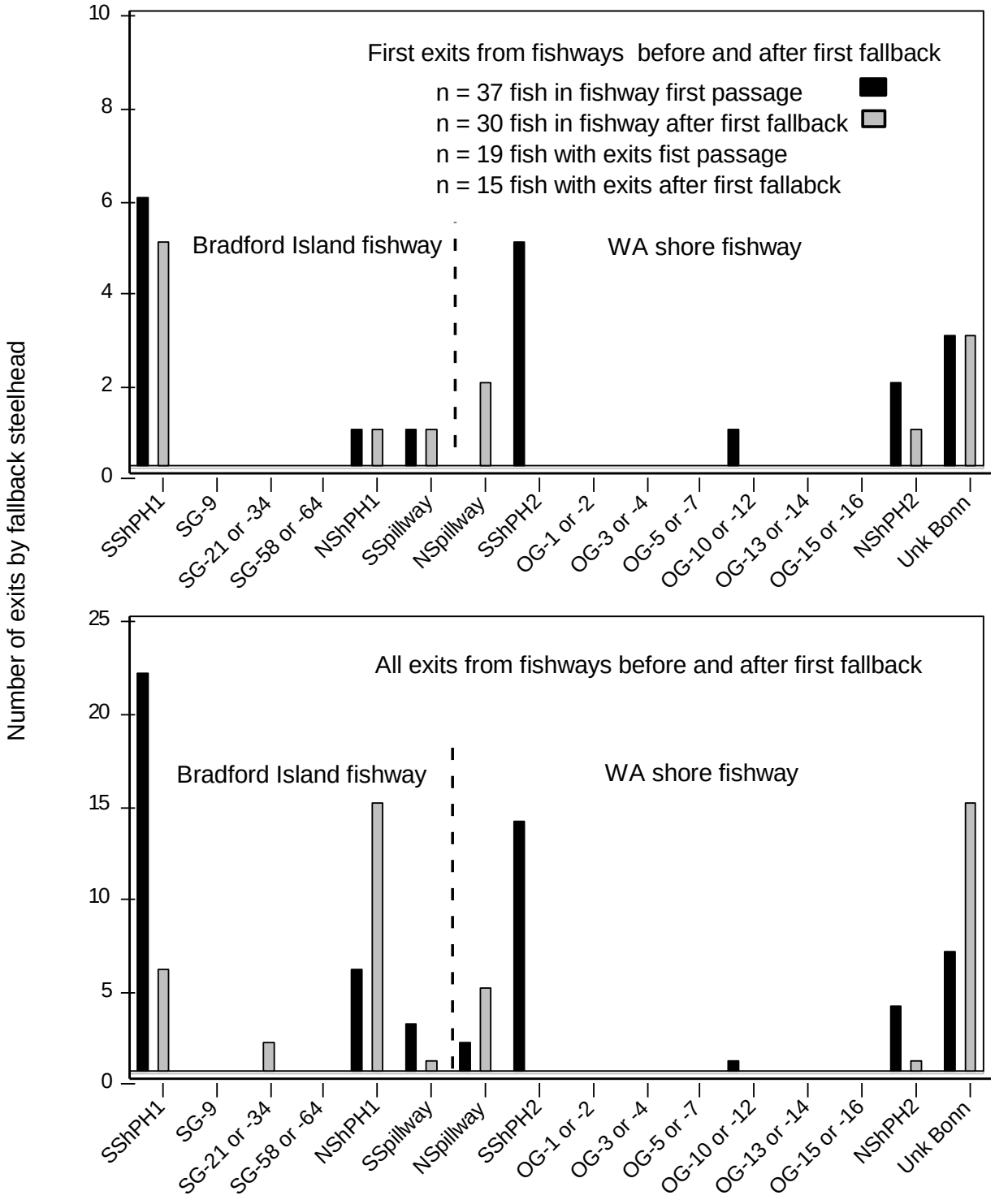

Figure 35. Number of first and total exits by steelhead from Bonneville Dam fishway entrances before and after their first fallback in 1996.

Table 5. Counts and percentages of steelhead passage by ladder at Bonneville Dam during spill and no-spill conditions.

	Spill		No Spill	
Passage Locations	**Total Count**	**%**	**Total Count**	**%**
Bradford Ladder	175	41	191	65
Washington Ladder	232	55	89	30
Navigation Lock	18	4	13	5
Total	425		292	

Table 6. Counts and percentages of all steelhead approaches at Bonneville Dam fishway entrances during spill and no-spill conditions.

	Spill		No Spill	
All Approach Locations	**Total Count**	**%**	**Total Count**	**%**
Powerhouse 1	2981	46	2031	41
Bradford Spill	168	3	91	2
Cascade Spill	123	2	86	2
Powerhouse 2	3167	49	2682	55
Total	6439		4890	

Table 7. Counts and percentages of first steelhead approaches at Bonneville Dam fishway entrances during spill and no-spill conditions.

	Spill		No Spill	
First Approach Locations	**Count**	**%**	**Count**	**%**
Powerhouse 1	212	49	158	63
Spill	55	13	26	10
Powerhouse 2	166	38	68	27
Total	433		252	

Table 8. Counts and percentages of all steelhead fishway entrances at Bonneville Dam during spill and no-spill conditions.

	Spill		No Spill	
Entrance Locations	**Count**	**%**	**Count**	**%**
Powerhouse 1	508	40	503	52
Bradford Spill	134	11	69	7
Cascade Spill	94	7	47	5
Powerhouse 2	528	42	351	36
Total	1,264		970	

Results – McNary Dam

Passage Times

Fishway entrance use and movements within the fishway at McNary Dam (Figure 36) in 1996 were monitored by recording movements of 401 radio-tagged steelhead. Median passage time of steelhead from release downstream from Bonneville Dam to the McNary tailrace was 19.99 d and was 21.17 d from release to passage over the dam (Figure 37). Median passage times of steelhead from the tailrace receiver (about 2.4 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 2.35 h, 3.34 h, and 10.39 h (Figure 38). Median time from first approach at a fishway to first entry into the fishway at McNary Dam was 0.36 h, and median time from first entry into a fishway to exit from the top of a ladder was 4.28 h (Figure 39).

Most fish entered the fishway within 24 h after passing the tailrace receiver, but 14 took more than 2 d to pass the dam because they overwintered at McNary Dam or moved downstream from the tailrace monitors before passing upstream. Seasonally, passage at McNary Dam nearly stopped when water temperatures reached 21º C. However, weekly-average passage times did not increase much because the few fish that were at the dam passed within normal passage times. In November, when water temperatures dropped to ~10º C., fish passage again slowed and passage times were longer. Nine steelhead passed McNary Dam in early 1997; mean times were 40 d for three fish that passed in February and 12 h for six that passed in March.

Fishway Use

Approaches to fishways: Steelhead tended to first approach McNary Dam at the south-shore entrance, at orifice gates 1, 3, and 14, and at the north-shore entrance. However, many first approached at orifice gates 3 and 26, and at least one fish first approached at every entrance (Figure 40). When all approaches at fishway entrances were considered, approaches were most frequent at orifice gates 26, 14, 3, and 21. Shoreline entrances were approached less frequently than many of the orifice gates (Figure 40). The large number of approaches (averaged 15.7 per fish; 6,244 total) is an indication that steelhead moved back and forth along the dam before entering the fishway. Of 401 steelhead monitored at McNary Dam, 2 (0.5%) did not have a recorded approach at the dam, 60 (15%) approached the dam only once, 220 (55%) approached the dam 1 to 10 times, 172 (43%) approached the dam 11 to 100 times, and 7 (2%) approached various entrances from 101 to 174 times (Figure 41). The time between first approach and first entry into the fishway was about 0.36 h (Figure 39).

Entries to and exits from fishways: As at Bonneville Dam, more adult steelhead entered larger entrances and those near shorelines. The majority of first and subsequent entries into the fishway occurred at the north-powerhouse, south-shore, and north-shore entrances (Figure 42). Orifice-gate entrances were used less frequently. Of the 401 steelhead monitored at McNary Dam, 4 did not enter the fishway. Of those that entered, 199 (50%) entered only once and the rest exited and reentered 1 to 12 times (Figure 43). Steelhead entered McNary fishways 2.2 times on average (median = 1).

Steelhead exited the fishway via many entrances, but most did so at the north powerhouse and the south- and north-shore entrances (Figure 44). Few fish exited at orifice gates. Of the 397 steelhead that entered a McNary fishway in 1996, 191 (48%) did not exit the fishway, over half (206, 52%) exited from 1 to 10 times, and 2 (< 1%) exited more than 10 times (Figure 44). Steelhead exited the McNary

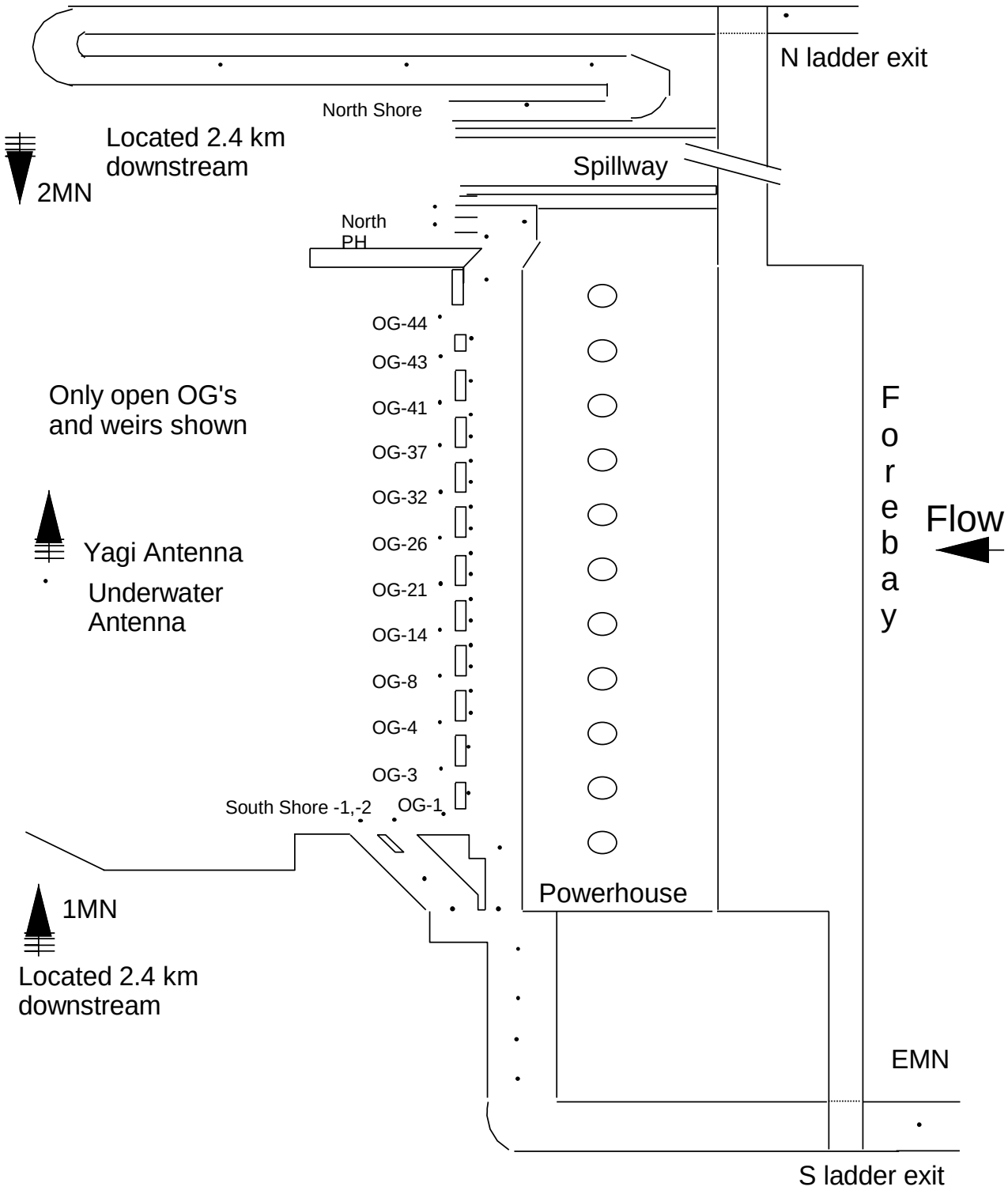

Figure 36. Location of antennas and fishway entrances at McNary Dam in 1996 while steelhead were passing the dam.

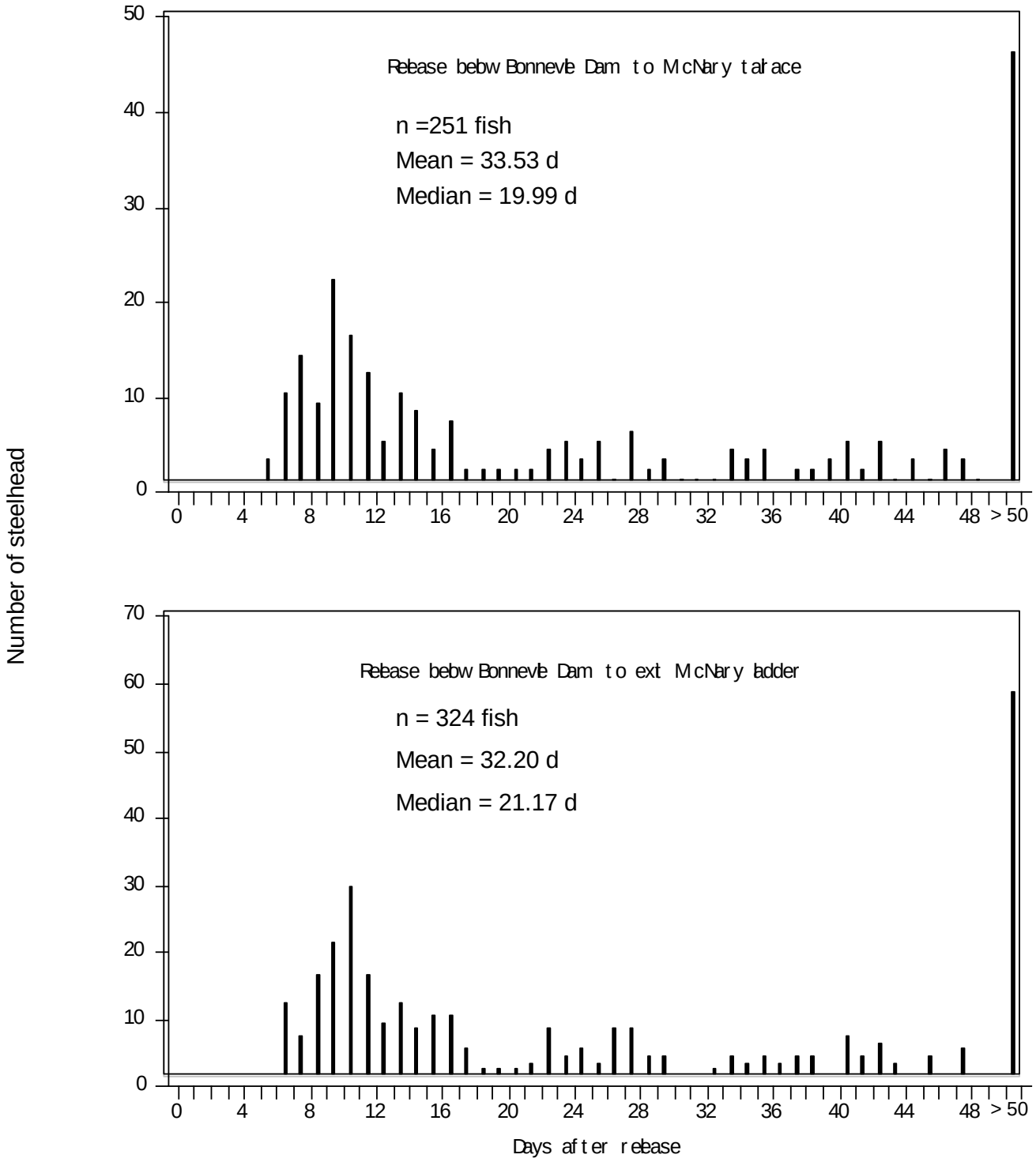

Figure 37. Number of steelhead and days to migrate from the release site below Bonneville Dam to the tailrace and to exit from the top of the ladder at McNary Dam in 1996.

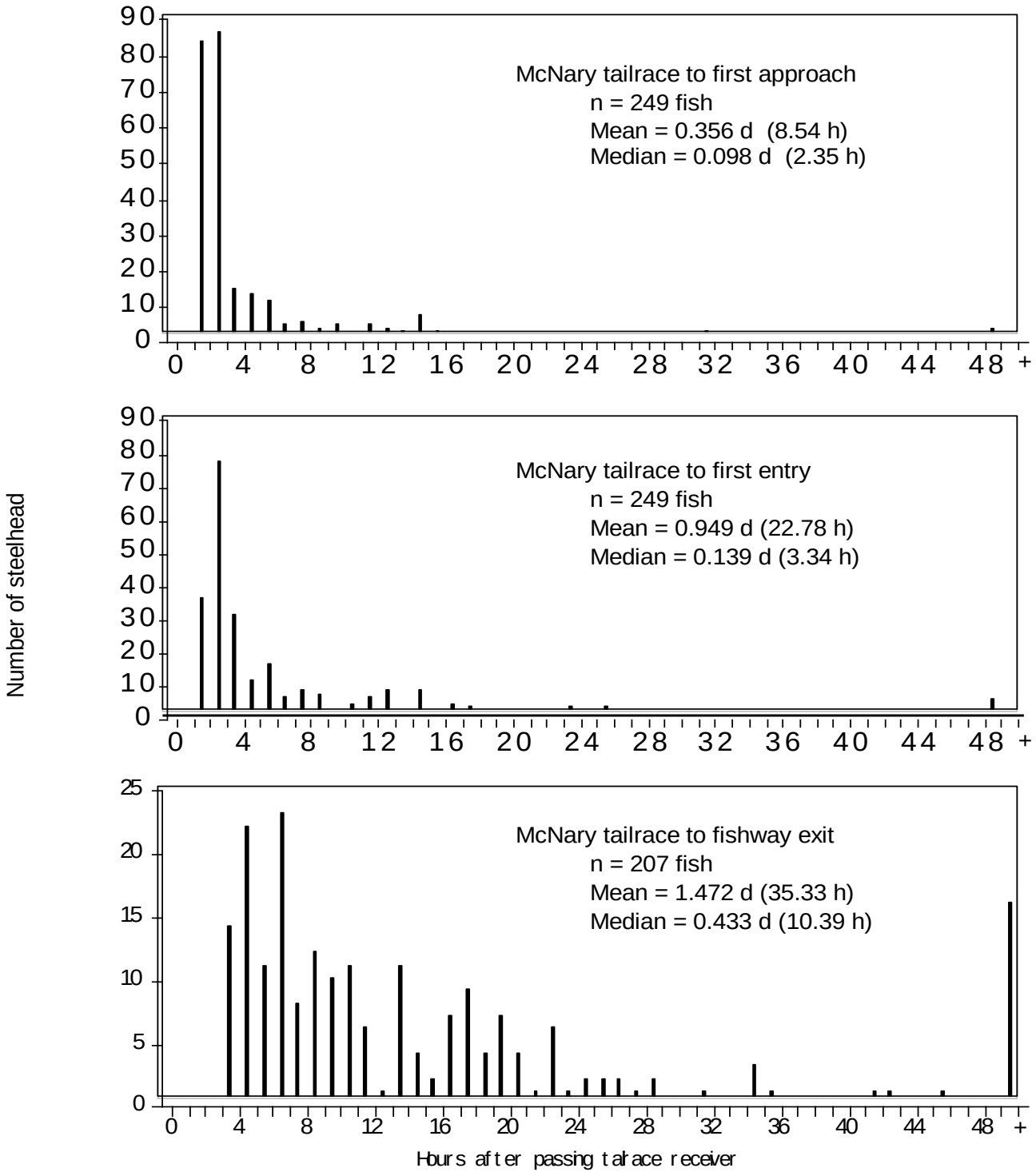

Figure 38. Number of steelhead and time to pass from the McNary tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladders in 1996.

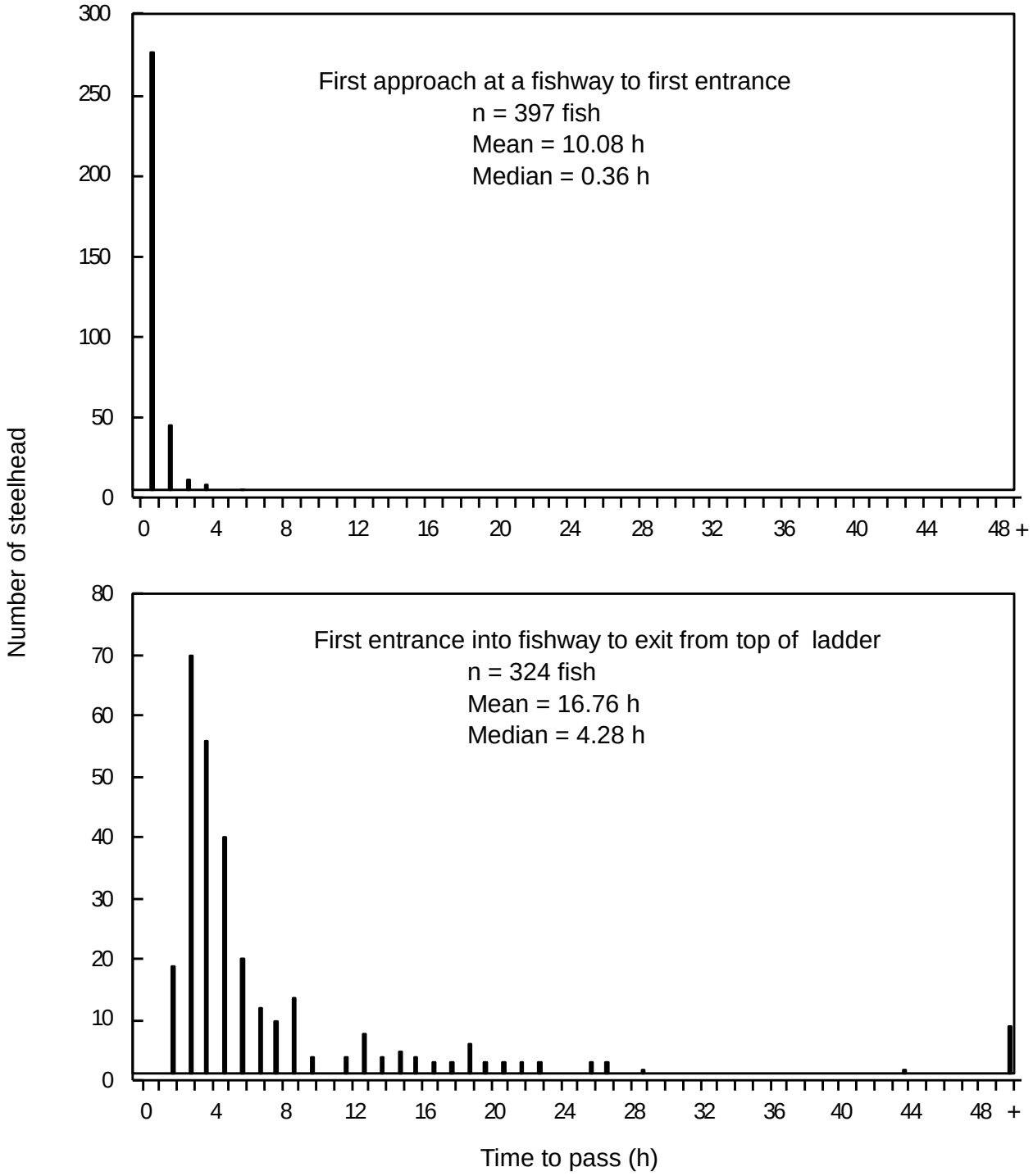

Figure 39. Number of steelhead and time to pass from first approach at a fishway entrance to first entry into a fishway to exit from the top of the ladder at McNary Dam in 1996.

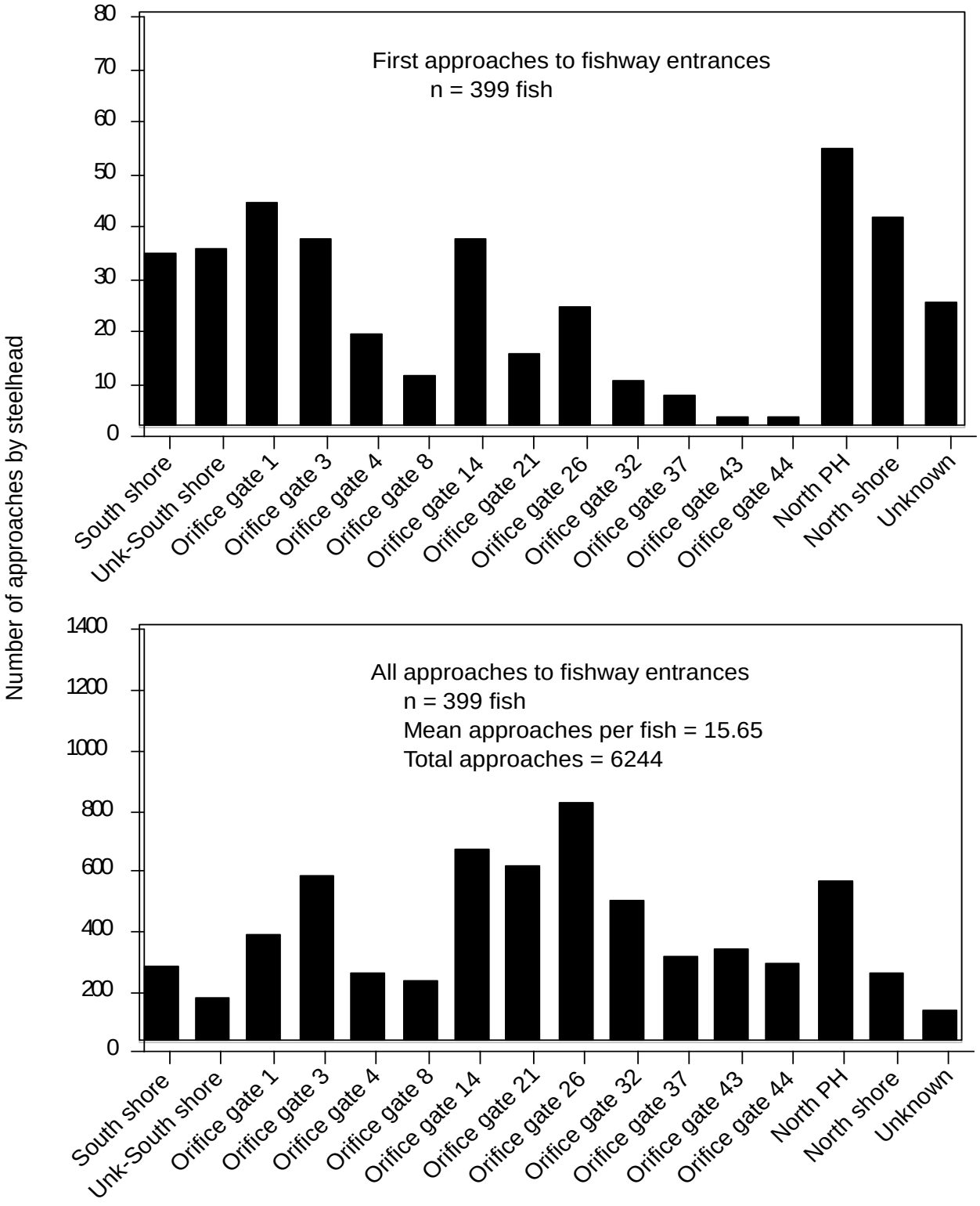

Figure 40. Number of first and total approaches at McNary Dam fishway entrances by steelhead in 1996.

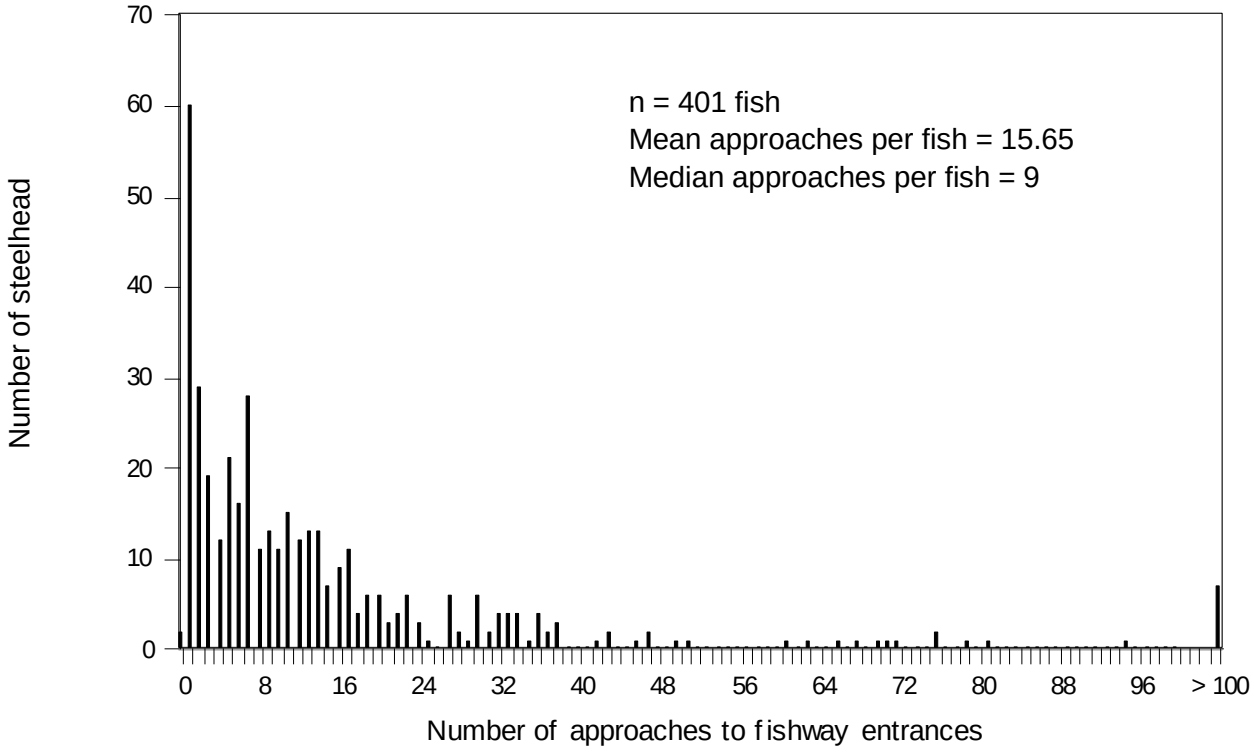

Figure 41. Number of steelhead that approached McNary Dam fishway entrances one or more times in 1996.

fishway 1.23 times on average (median = 1). 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.

Net entry rates (entries minus exits) for fishway entrances ranged from -4 to 93 for first entries and exits, and -32 to 140 for all entries and exits (Figure 45). The south-shore entrance was the most effective (more entries than exits) followed by the north-shore entrance. There were more first and total exits than entries by steelhead at the north-powerhouse entrance. While the north-powerhouse entrance had a negative net entrance rate, it was an important entrance location when last entrance before passage was considered (Figure 46). Thirteen percent (51/397) of last entrance locations were at the north-powerhouse entrance.

Movements Through Transition Pools

We analyzed behavior of 316 steelhead as they moved through transition pools at McNary Dam in 1996. Forty-one percent (130) of these steelhead exited to the tailrace one or more times before they passed through a pool and over the dam. Twenty-six percent (82) moved straight through a transition pool and into a ladder with no downstream movement, and 25% (78) moved downstream in a transition pool but did not exit the pool before passing the dam. The remaining 8% (26) exited the powerhouse transition pool into the collection channel but did not exit to the tailrace.

Seventy-eight percent (247/316) of the steelhead first entered the transition pool at the bottom of the south-shore ladder and subsequently passed over the dam via the south-shore ladder (Figure 47). Ten percent (33) first entered the transition pool at the bottom of the north-shore ladder first and then passed the dam via the north-shore ladder. Another 8% (25) first entered the south-shore transition pool but turned around and exited the fishway, crossed the tailrace, and passed the dam via the north-shore ladder; 4% (11) first entered the north-shore transition pool, but passed the dam via the south-shore ladder.

Of the 247 steelhead that first entered the south-shore transition pool and passed the dam via the south-shore ladder, 65 (26%) moved straight through the transition pool into the ladder and 67 (27%) turned around in the transition pool, moved downstream, but remained in the pool before entering the ladder (Table 9). Eighty-nine fish (36% of 247) traveled downstream into the collection channel after first entering the pool, exited and reentered the fishway and pool before passing the dam. The remaining 26 fish (11% of 247) 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. Fish entered the north-shore pool shortly after entering the fishway and without passing through a collection channel. Of the 33 steelhead that first entered the north-shore pool and passed the dam via the north-shore ladder, 17 (52%) moved straight through the transition pool and entered the ladder, 11 (33%) moved downstream in the transition pool before entering the ladder, and 5 (15%) moved downstream in the fishway and exited into the tailrace at least once before returning and entering the ladder (Table 9).

Steelhead used similar fishway entrances to exit and subsequently reenter the fishways at McNary Dam after leaving a transition pool. The 87 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 30% (62) of 206 exits to the tailrace from south-shore entrances (Figure 48). Approximately 38% (79) of the exits by steelhead were from the north-powerhouse and north-shore entrances. Reentries of these steelhead were distributed among more fishway entrances, but 26% (54) were at shoreline entrances and 28% (61) were from the north-powerhouse and north-shore entrances.

The twenty-five fish that first entered the transition pool in the south-shore fishway and passed the dam via the north-shore ladder, exited the fishways 52 times (Figure 48). The twenty-five fish made 48% (25) of their reentries at the north-shore entrance; the remaining reentries were distributed between orifice gates and the north-powerhouse entrance.

The 5 steelhead that first entered the north-shore transition pool, exited and reentered the fishway, and ultimately passed the dam via the north-shore ladder, made half of their 14 exits and reentries at the north-shore entrance (Figure 49). Eleven steelhead first entered the north-shore transition pool, exited, and then passed McNary Dam via the south-shore ladder. The 11 fish made 18 exits, two-thirds of which were from the north-shore entrance; reentries by the 11 fish were distributed among a variety of fishway entrances (Figure 49).

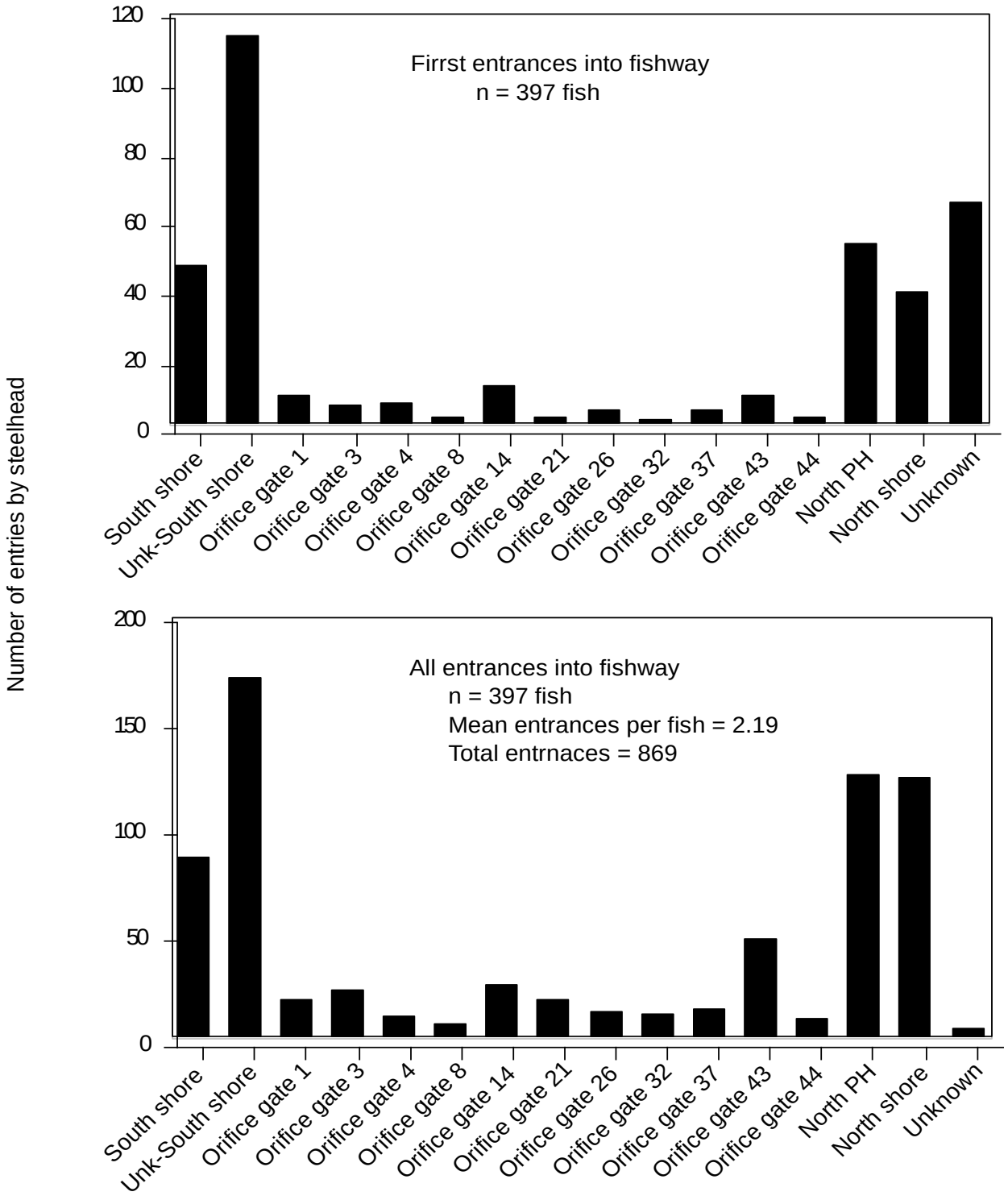

Figure 42. Number of first and total entries at McNary fishway entrances by steelhead in 1996.

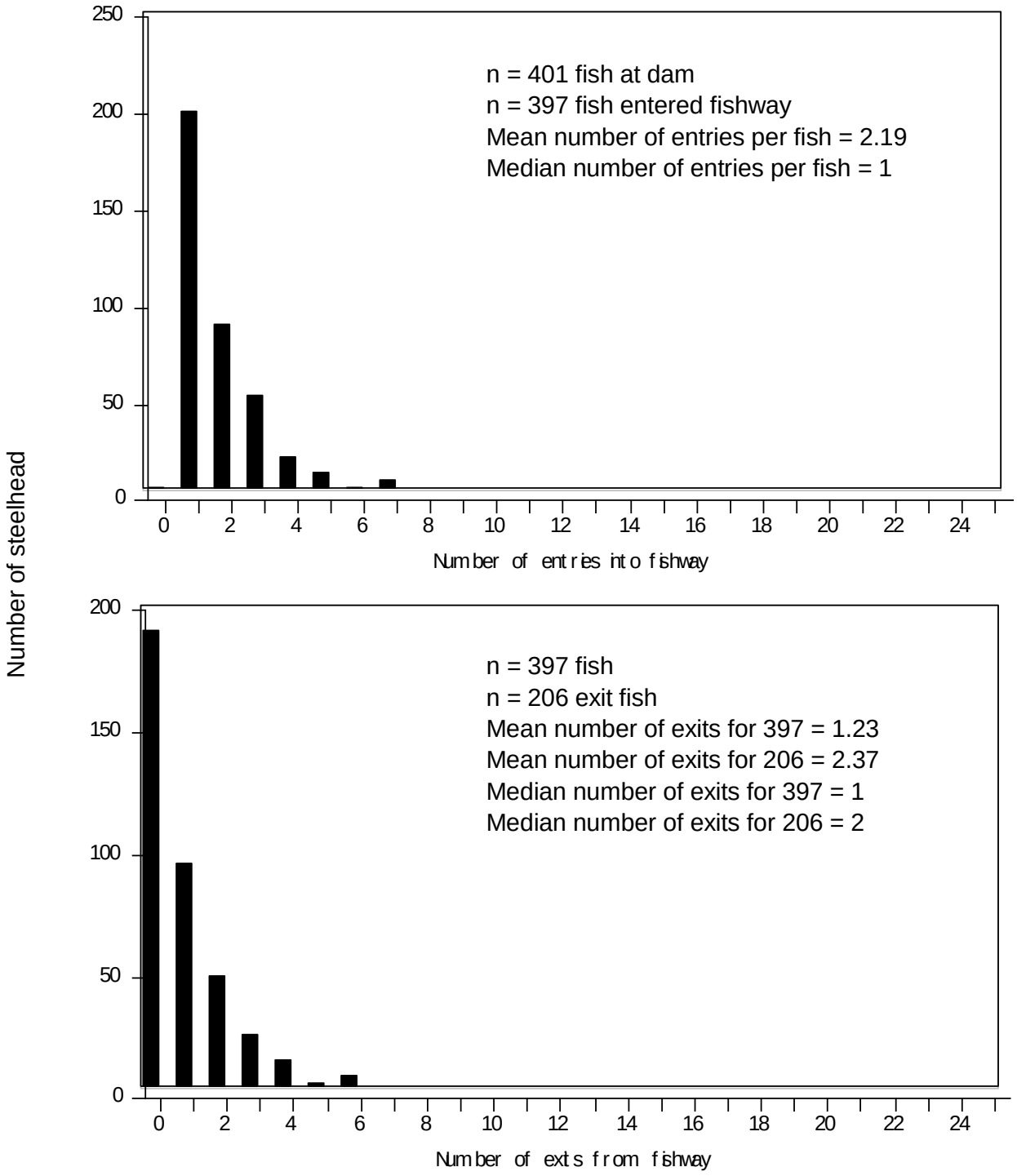

Figure 43. Number of steelhead that entered or exited the fishway, and those with multiple entries and exits into or from the fishway at McNary Dam via the entrances in 1996-97.

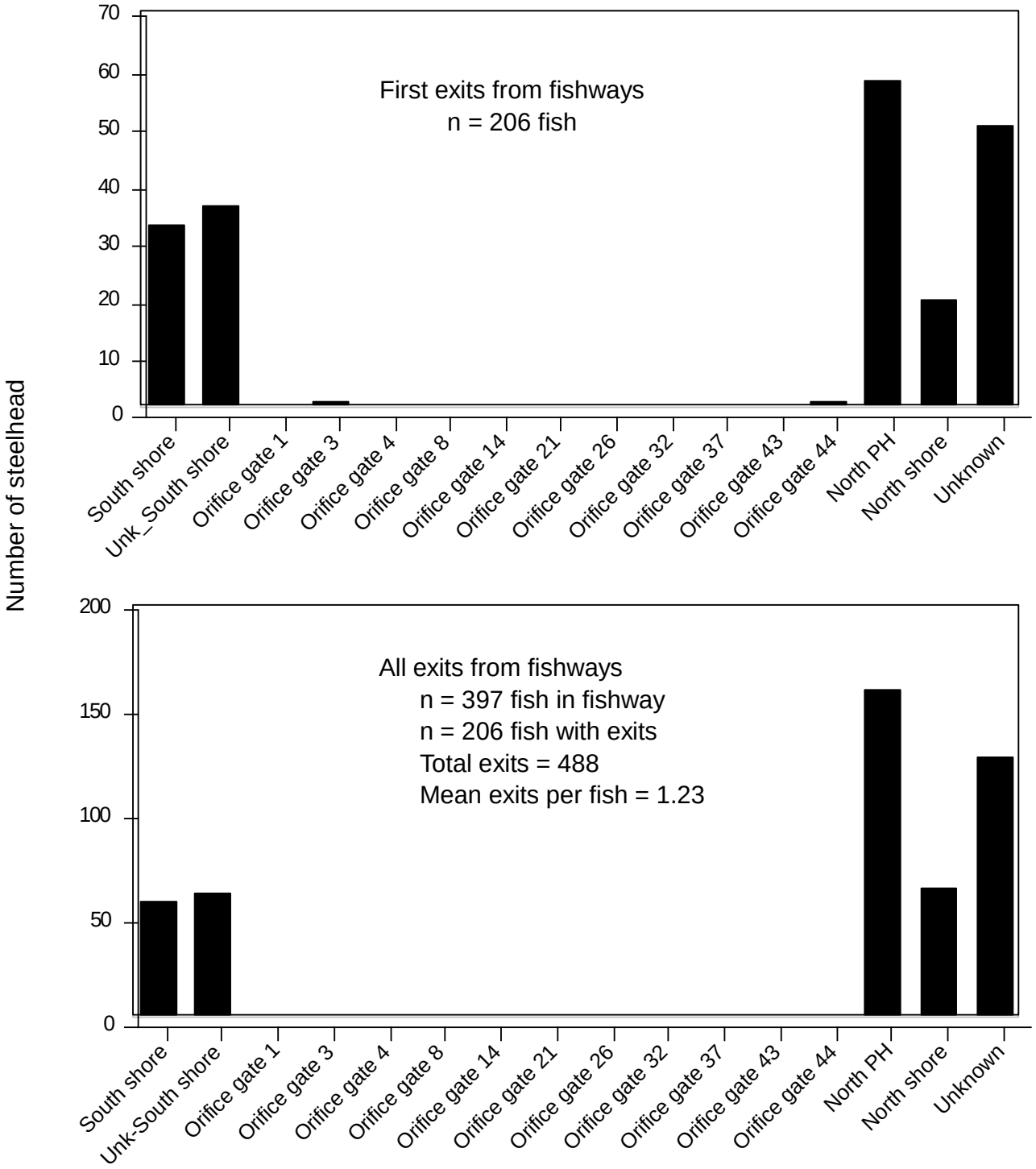

Figure 44. Number of first and total exits from fishway for each entrance by steelhead at McNary Dam in 1996.

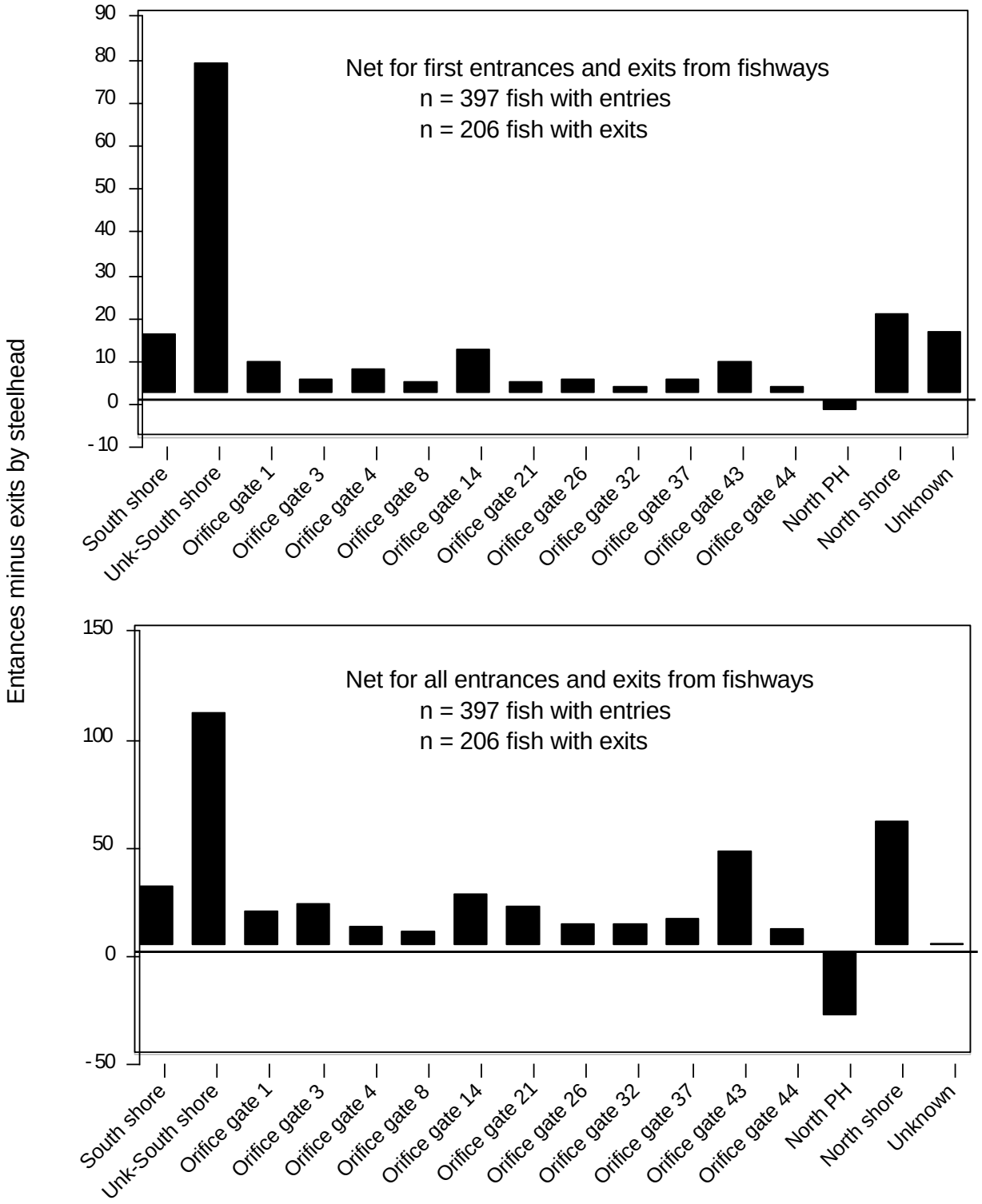

Figure 45. Net number of first and total exits from fishway for each entrance by steelhead at McNary Dam in 1996.

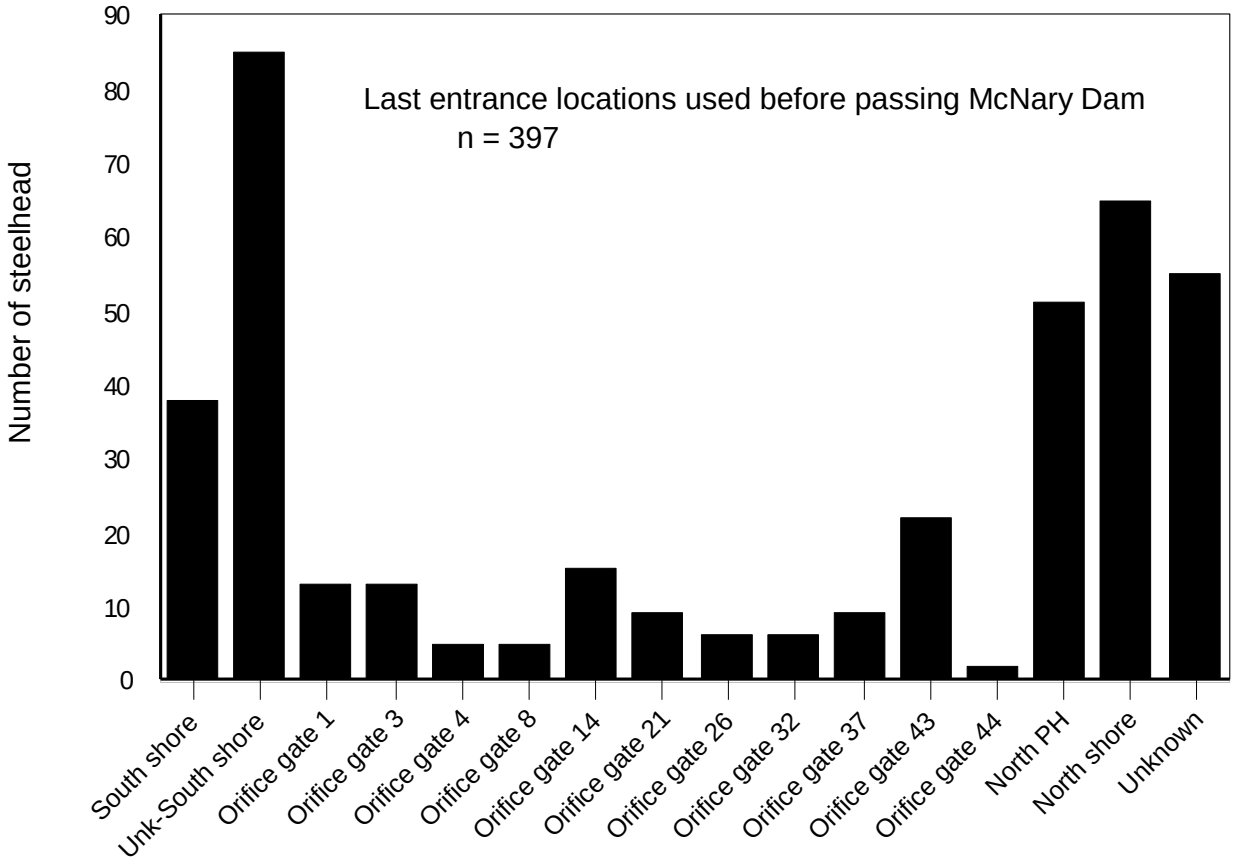

Figure 46. Last entrance locations used by steelhead that passed McNary Dam fishways in 1996.

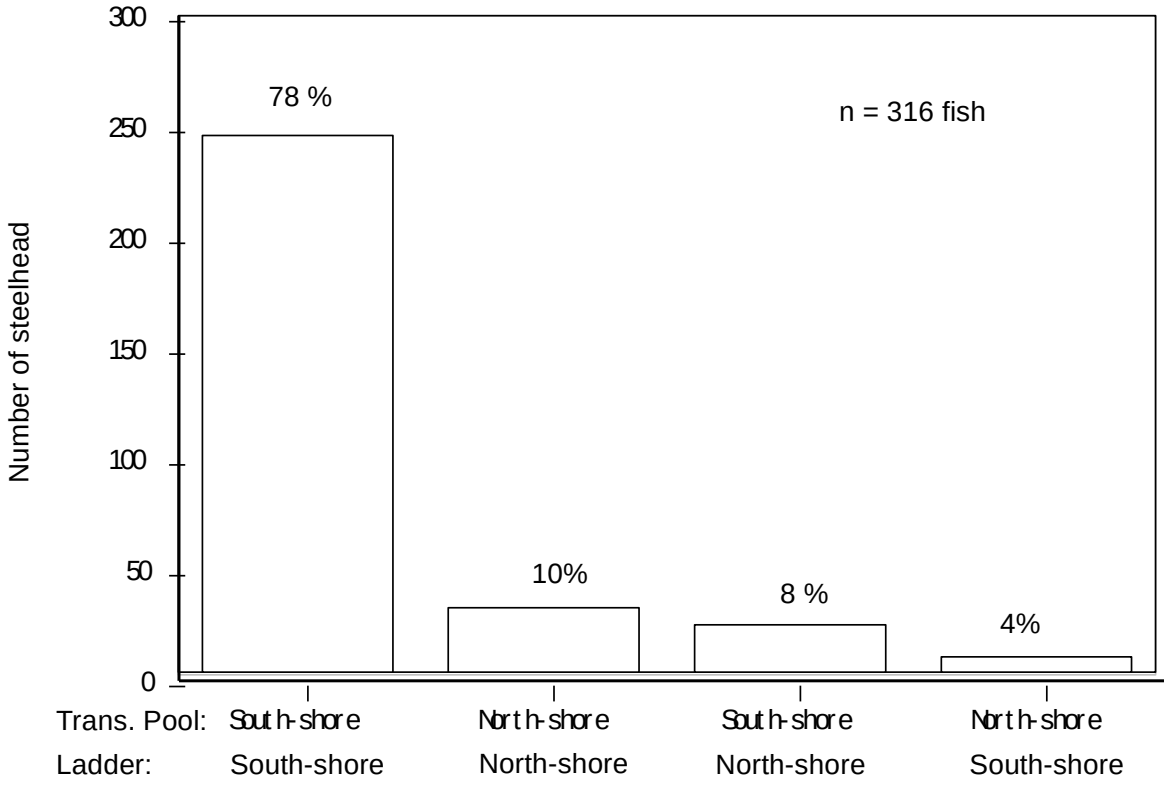

Figure 47. Number of steelhead that passed McNary Dam in 1996, the transition pool first entered, and the ladder used to pass the dam.

Table 9. Number and percentages of steelhead 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.

	South ladder (*N* = 247)		North ladder (*N* = 33)	
Transition pool behavior	N	Percent	N	Percent
Moved straight through	65	26%	17	52%
Moved downstream, but didn't exit	67	27%	11	33%
Exited pool to collection channel	26	11%	N/A	N/A
Exited pool to tailrace	89	36%	5	15%

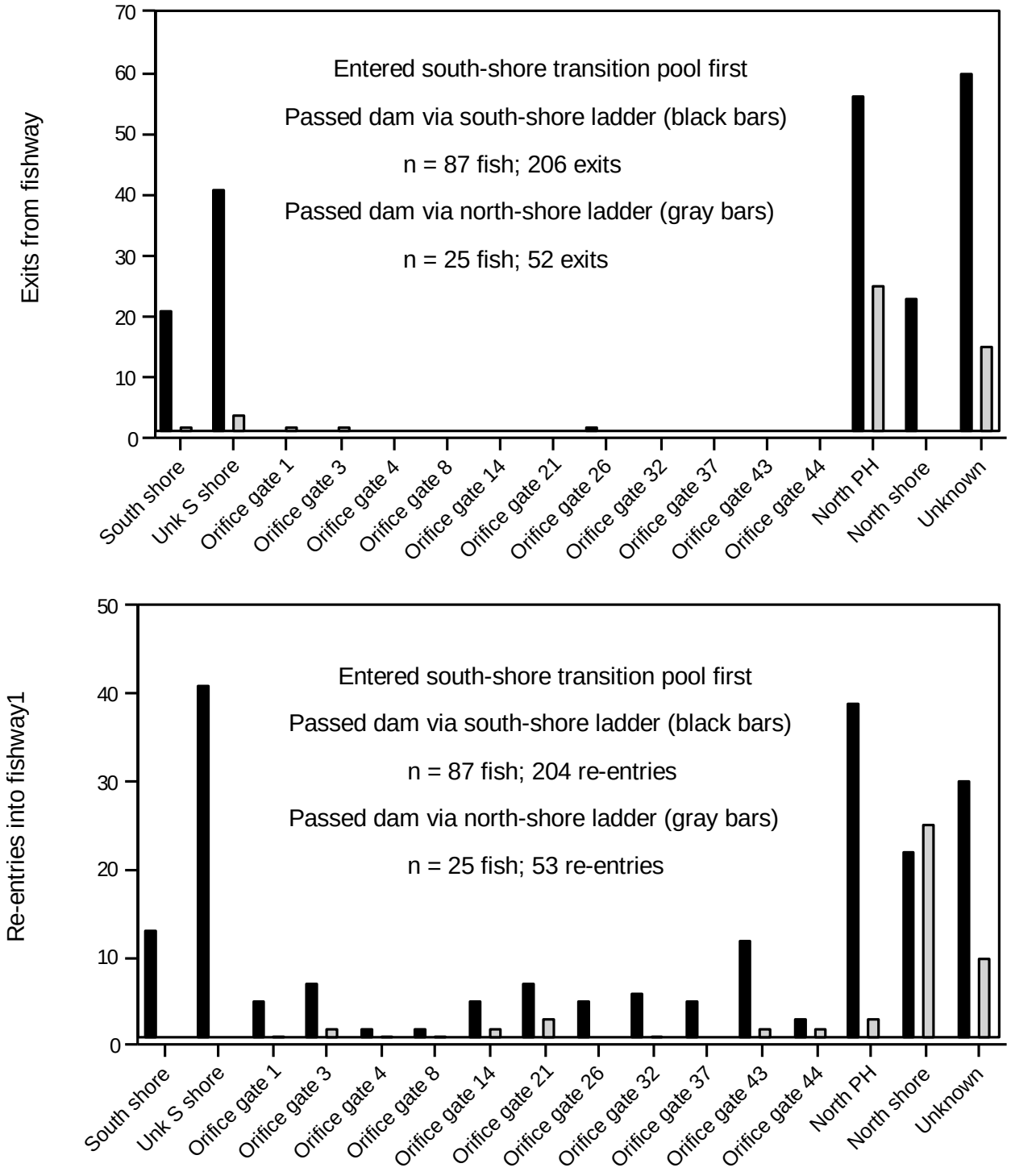

Figure 48. Entrances used to exit and reenter the fishway by steelhead that first entered the south-shore transition pool, exited to the tailrace, and passed over McNary Dam by either the south- or north-shore fishways in 1996.

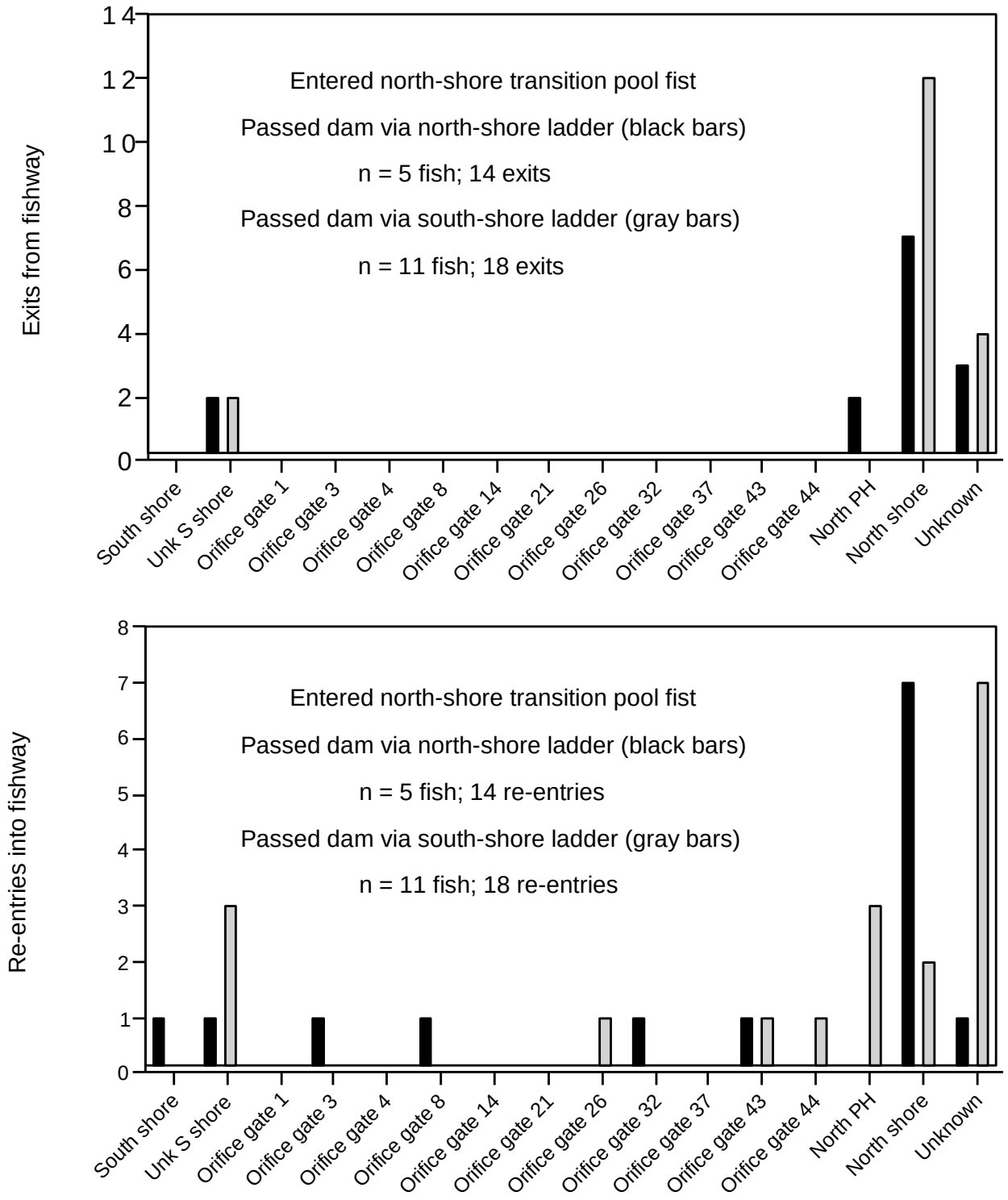

Figure 49. Entrances used to exit and reenter the fishway by steelhead that first entered the north-shore transition pool, exited to the tailrace, and passed over McNary Dam by either the south-shore or north-shore fishways in 1996.

Passage times through transition pools and over McNary Dam were affected by steelhead 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 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 were skewed to the right (Figure 50), and so median values are reported.

Median passage times for the 316 fish that passed through transition pools at McNary Dam were 0.07 h from first fishway entry to first transition pool entry, 0.83 h from first pool to exit into a ladder, 2.23 h to ascend a ladder, and 4.26 h from fish fishway entry to exit from the top of a ladder (Table 10). Median times to first enter a pool and to ascend ladders were similar for all groups of fish regardless of behavior, 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. Steelhead that exited a pool into the tailrace at McNary Dam had median times to pass the dam that were 1.7 to 2.7 times longer than fish that did not exit pools (Table 10).

Median passage time from first fishway entry to first entry in a transition pool were 5 min (0.08 h) for 160 steelhead that moved through a McNary transition pool and entered a ladder on the first attempt, and 4 min (0.06 h) for 156 fish that made more than one attempt to pass (Table 11). Median times from first entry into a transition pool to exit into a ladder were 13 min (0.22 h) and 3.13 h for the two groups, respectively. Median time to ascend a ladder was about 2.2 h for each group. Median times from first fishway entry to exit from the top of a ladder were 2.99 h for fish that moved through a pool on the first attempt and 6.72 h for fish that exited a pool one or more times (Table 11).

For the 247 steelhead that first entered the south-shore transition pool and ultimately passed the dam via that ladder, median times to first enter the transition pool (4 to 6 min), and to ascend a ladder (2.16 to 2.30 h) were similar for all fish (Table 11). For the 115 fish that made more than one attempt, median time to transit the transition pool was 2.48 h, compared to 0.21 h (13 min) for 132 fish that passed through the pool on their first attempt. Median passage time for the 115 fish that made more than one attempt to pass through the south-shore transition pool was 6.03 h to pass the dam after first fishway entry, versus 3.00 h for fish that passed through the pool on the first attempt. Most fish that made more than one attempt to pass through the south-shore pool entered the ladder in less than 2.5 h, but 22% took more than 12 h.

The 26 fish that turned around in the south-shore transition pool and traveled downstream to the collection channel but did not exit the fishway had a median time of 1.09 h from first to last transition pool record and 4.26 h from first fishway entry to exit from the top of the ladder (Table 11). Eighty-nine steelhead that exited the fishway into the tailrace from the south-shore pool had median passage times of 3.78 h to transit the transition pool and 6.42 h to exit the top of the ladder after first entering the fishway (Table 11).

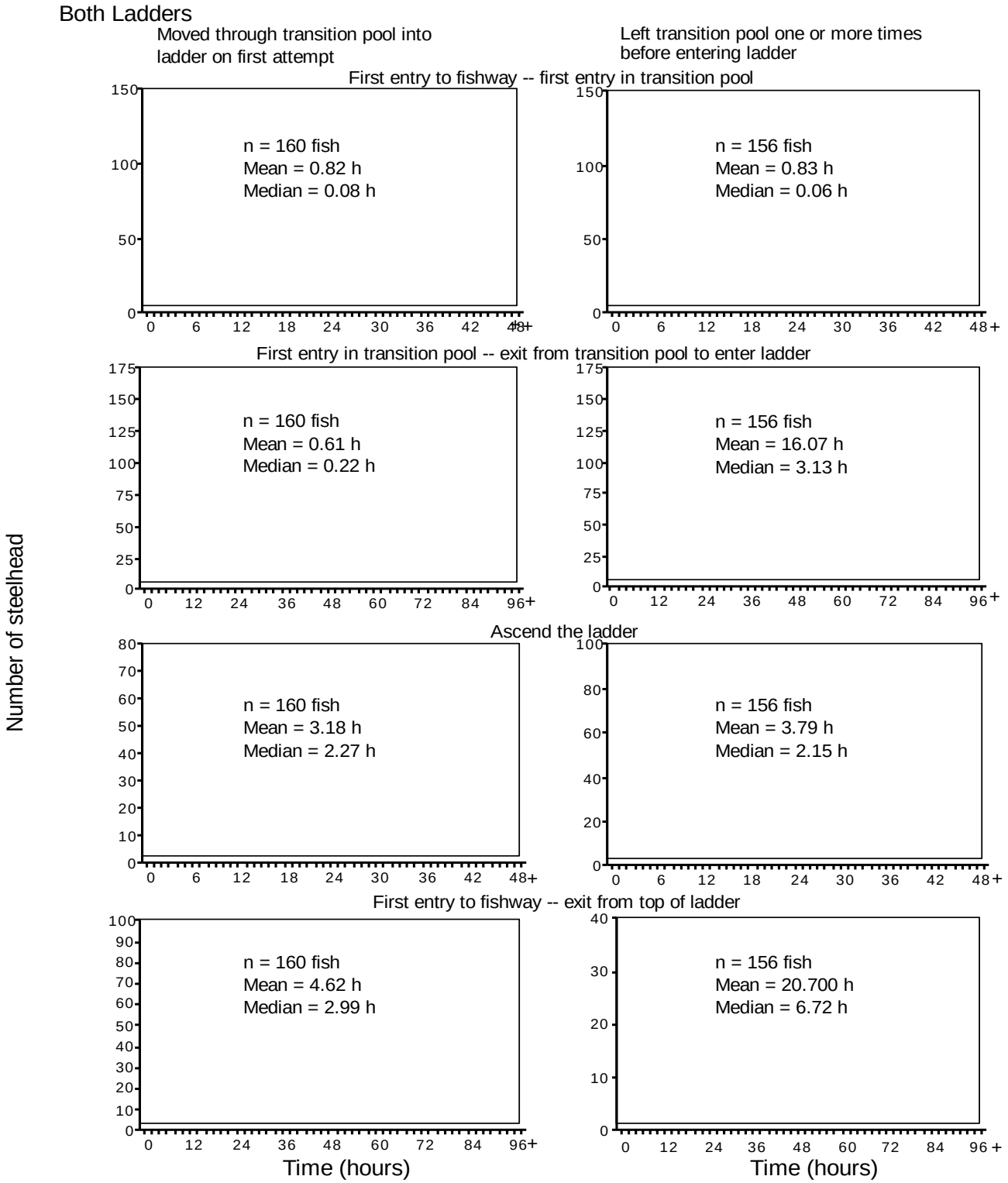

Figure 50. Time to first enter and to pass through a transition pool, to ascend a ladder, and to exit from the top of a ladder at McNary Dam in 1996 by steelhead that passed through the pool on the first attempt and by those that made more than one attempt.

Table 10. Median passage times for steelhead 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	316	0.07	0.83	2.23	4.26
Moved straight through	82	0.04	0.13	2.26	2.68
Moved downstream, but didn't exit	78	0.16	0.44	2.28	3.31
Exited pool to collection channel	26	0.10	1.09	2.30	4.26
Exited pool to tailrace	130	0.06	3.98	2.12	7.36

Of 33 steelhead that first entered the north-shore transition pool and passed the dam via the north ladder, 28 (85%) passed the pool on their first attempt in a median time of 17 min (0.28 h); the median from first fishway entry to exit from the top of the ladder was 2.95 h (Table 11). The 5 fish that made more than one attempt to pass through the north-shore pool had median times of 12.39 h from first pool entry to last entry into the ladder and 14.73 h from first fishway entry to exit from the top of the ladder (Table 11).

Thirty-six steelhead passed McNary Dam via a different transition pool than the one they first entered. Twenty-five (69%) fish first entered the south-shore pool, but passed the dam via the north-shore pool, and 11 (31%) first entered the north-shore pool, and passed via the south-shore pool (Table 11). Median times from first fishway entry to exit from the top of a ladder were 7.47 h and 18.04 h for these two groups (Table 11).

Effects of Spillway Discharge

Radio-tagged steelhead passage at McNary Dam began on 26 June. Spill steadily decreased from 199 kcfs in June and ended on 12 September. Prior to 12 September, passage at the south- and north-shore ladders was nearly evenly split (46% south, 54% north). After spill stopped, most steelhead passed through the south ladder (91% south, 9% north). Approach patterns also changed seasonally as spill rates changed. During spill, 26% of first approaches were at the north ladder entrances. After spill ended only 7% of first approaches were at that ladder. No radio-tagged steelhead passage was recorded at the north ladder after 10 October while 68 passed at the south ladder.

Table 11. Median and mean passage times for steelhead 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.

				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	South	South	132	0.108	0.209	2.287	3.000
pool on first attempt	North	North	28	0.022	0.284	2.320	2.946
	All fish[1]		160	0.075	0.216	2.273	2.992
Exited pool to	South	South	26	0.096	1.086	2.295	4.257
Collection channel							
Exited pool to	South	South	89	0.064	3.778	2.162	6.415
tailrace	South	North	25	0.102	3.386	1.873	7.468
	North	North	5	0.014	12.389	2.324	14.727
	North	South	11	0.040	8.746	2.478	18.038
Exited pool one or more times	All fish[1]		156	0.063	3.126	2.153	6.717

[1] See Figure 50 for passage time distributions

Results - Lower Granite Dam

Passage Times

Fishway entrance use and movements within the fishway at Lower Granite Dam in 1996 were monitored for 264 steelhead (Figure 51). Median passage times were 41.8 d from release at Bonneville Dam to the Lower Granite tailrace and 38.2 d from release to passage over the dam (Figure 52). Median passage times from the Lower Granite 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 2.04 h, 5.06 h, and 1.08 d (Figure 53). Median time from first approach at a fishway to first entrance into the fishway at Lower Granite Dam was 0.72 h, and median time from first fishway entrance to exit from the top of the ladder was 19.44 h (Figure 54).

Most fish entered the fishway within 4 to 20 h after passing the tailrace receiver, but seven fish took more than 4 d to pass the dam. 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. Passage times between the tailrace and passage from the top of the ladder also included time some fish used when making multiple entries into the fishway or ladder and delays resulting from operation of the adult fish trap located in the ladder.

Fishway Use

Approaches to fishways: Steelhead had a tendency to first approach the dam at south- and north-powerhouse entrances, although every entrance had at least one fish first approach (Figure 55). When all approaches at fishway entrances were considered, approaches were most frequent at south-shore entrance-1, and then fairly evenly distributed between orifice-gate entrances, north-powerhouse entrances, and south-shore entrance-2 (Figure 55). The large number of approaches to entrances (average = 16.3, total = 4,301) is an indication that steelhead moved back and forth along the dam before entering the fishway. Of 264 steelhead monitored at Lower Granite Dam, 1 did not approach the dam, 44 (17%) approached the dam once, 135 (51%) approached the dam 2 to 10 times, 125 (47%) approached between 11 and 99 times and 3 (1%) approached 100 or more times (Figure 56). Many steelhead moved back and forth along the dam and approached entrances multiple times; median time between first approach and first entry into the fishway was about 0.7 h (Figure 54).

Entries to and exits from fishway: The majority of first entries into the fishway occurred at the south-shore entrances adjacent to the powerhouse. When all entries were considered, most entries occurred at south-shore entrances and at north powerhouse entrances (Figure 57). 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. 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 discharge of 560 cfs total. As at Bonneville and McNary dams, the location, size and discharge of entrances likely influenced use by steelhead.

Of the 264 steelhead monitored at Lower Granite Dam, one did not enter the fishway. Of those that entered, 139 (53%) entered the fishway at Lower Granite Dam once while the remainder exited and reentered 2 to 16 times (Figure 58). Steelhead entered the Lower Granite fishway 2.5 times on average (median = 1). Of the 263 steelhead monitored in the Lower Granite fishway, 135 (51%) did not exit the fishway, 124 (47%) fish exited from 1 to 10 times, and 4 (2%) exited more than 10 times (Figure 58). Steelhead exited the fishway 1.5 times on average (median = 0). Many fish moved up the collection channel to the transition pool at the bottom of the ladder, returned down the channel, and exited from the fishway one or more times. Steelhead exited the fishway via almost all entrances, but most did so at the north-powerhouse and south-shore entrances. Few exited at orifice gates (Figure 59).

Net entry rates (entries minus exits) for fishway entrances ranged from -1 to 50 for first entries and exits, and -4 to 126 for all entries and exits (Figure 60). The south-shore entrances were the most effective, followed by the north powerhouse entrances. There were more exits than entries by steelhead at the north-shore entrance. The north-shore entrance had a negative net entrance rate, but 3 fish had last entrances there before passage (Figure 61). The remainders of the last entrance locations were similar to net entrances.

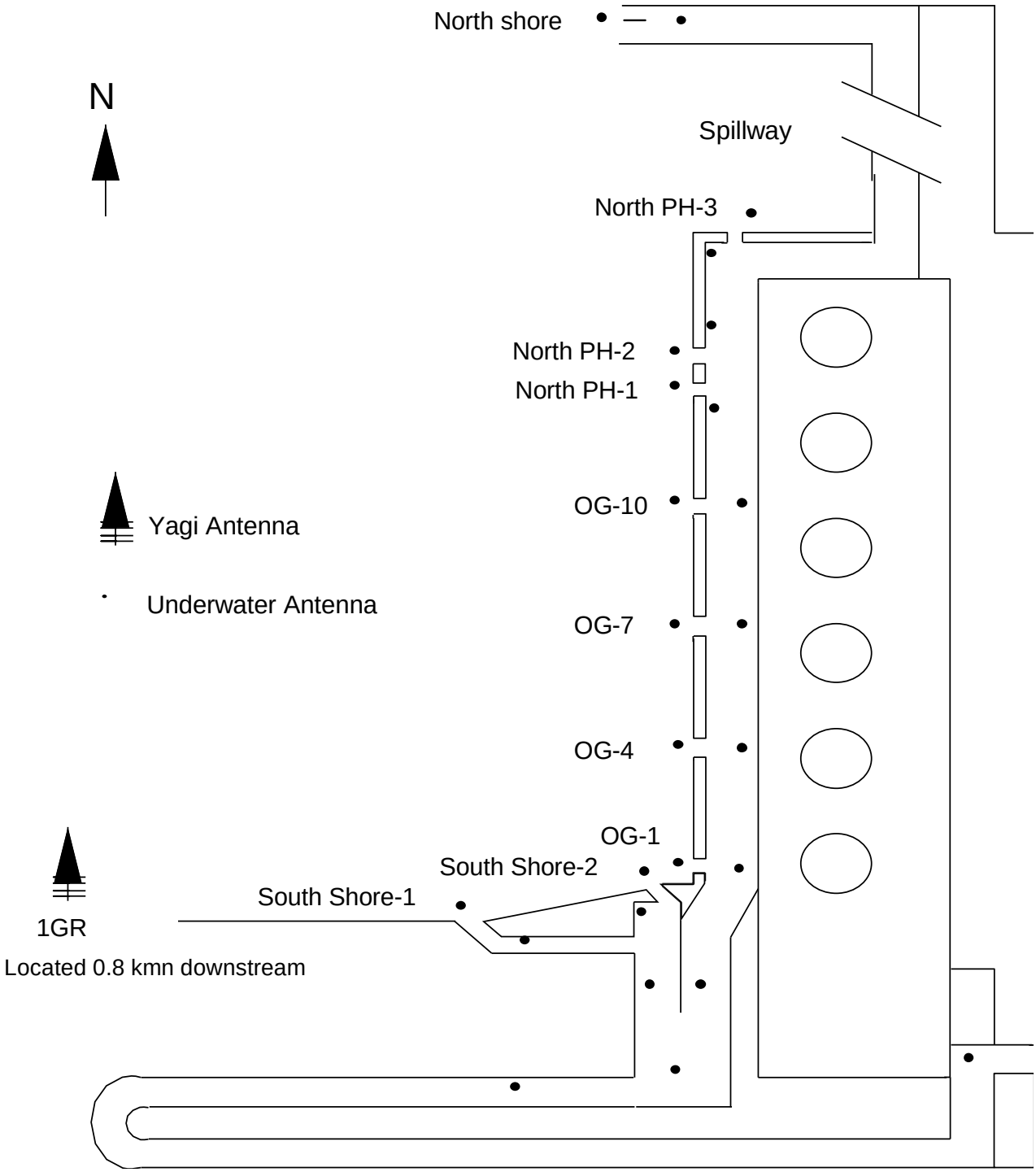

Figure 51. Location of antennas and fishway entrances at Lower Granite Dam in 1996 when steelhead were passing the dam.

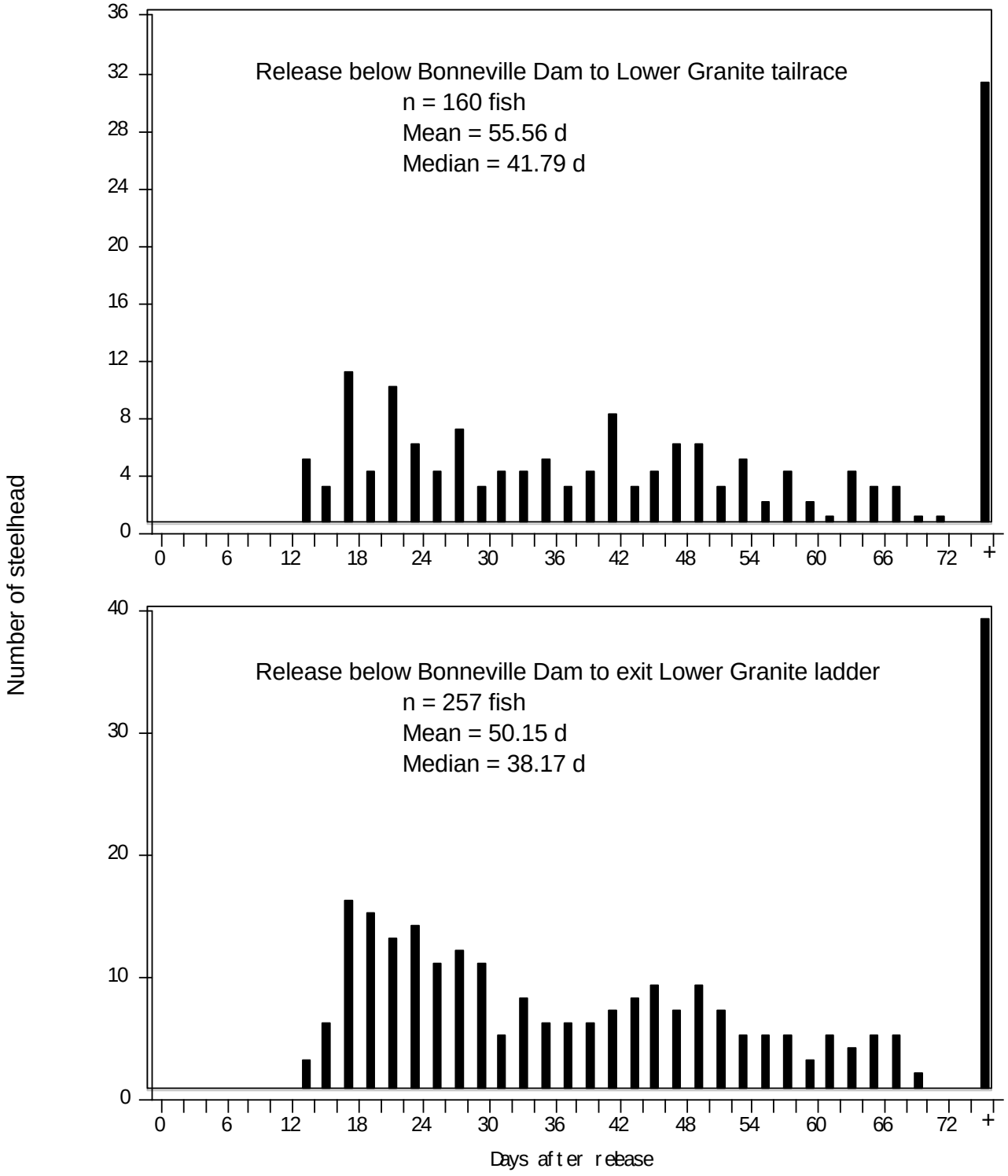

Figure 52. Number of steelhead and days to migrate from the release site below Bonneville Dam to the Lower Granite tailrace and to exit from the top of the ladder at Lower Granite Dam in 1996.

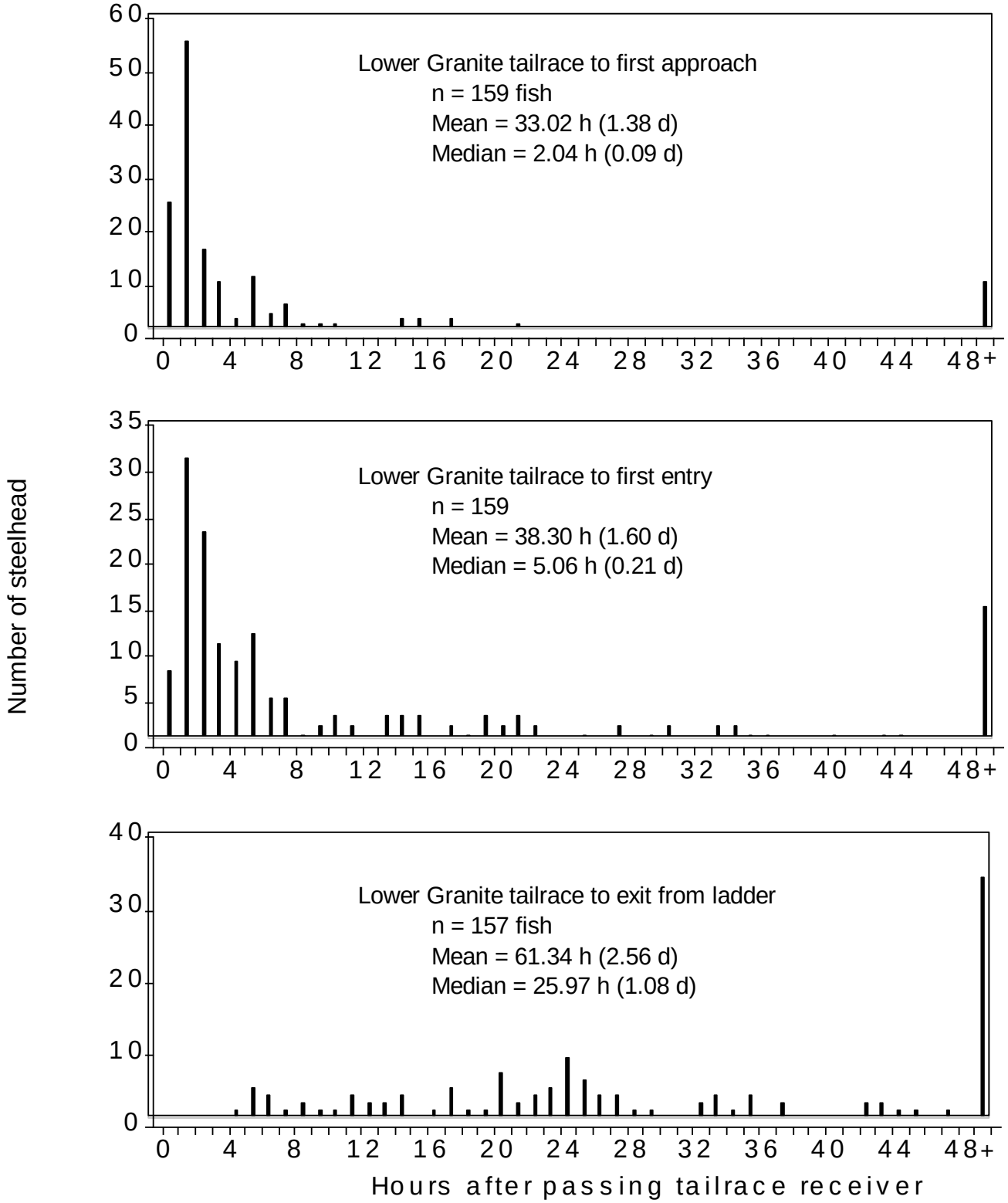

Figure 53. Number of steelhead and time to pass from the Lower Granite Dam tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladder in 1996.

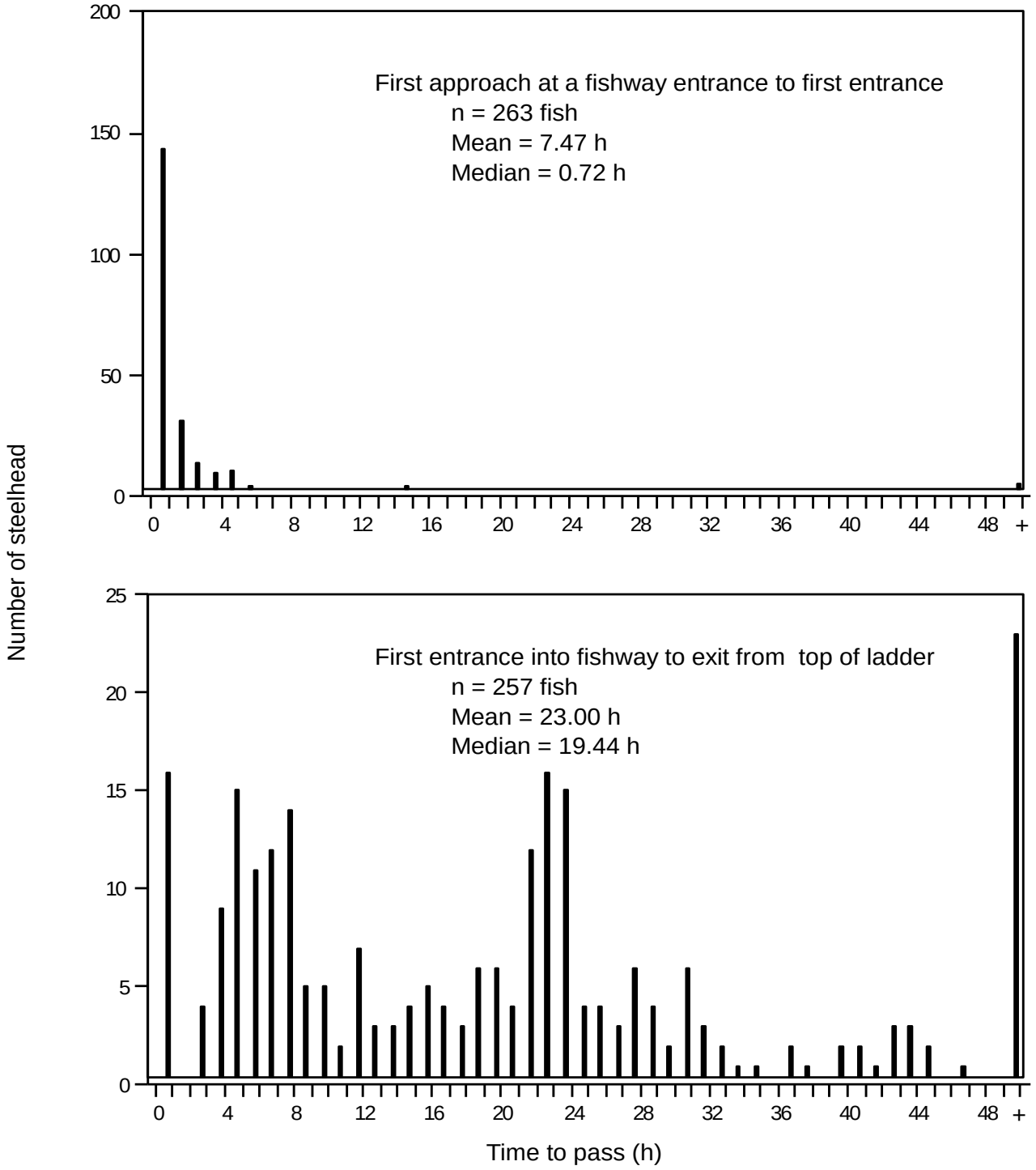

Figure 54. Number of steelhead and time to pass from first approach at a fishway entrance to first entry into a fishway and from first fishway entry to exit from the top of the ladder at Lower Granite Dam in 1996.

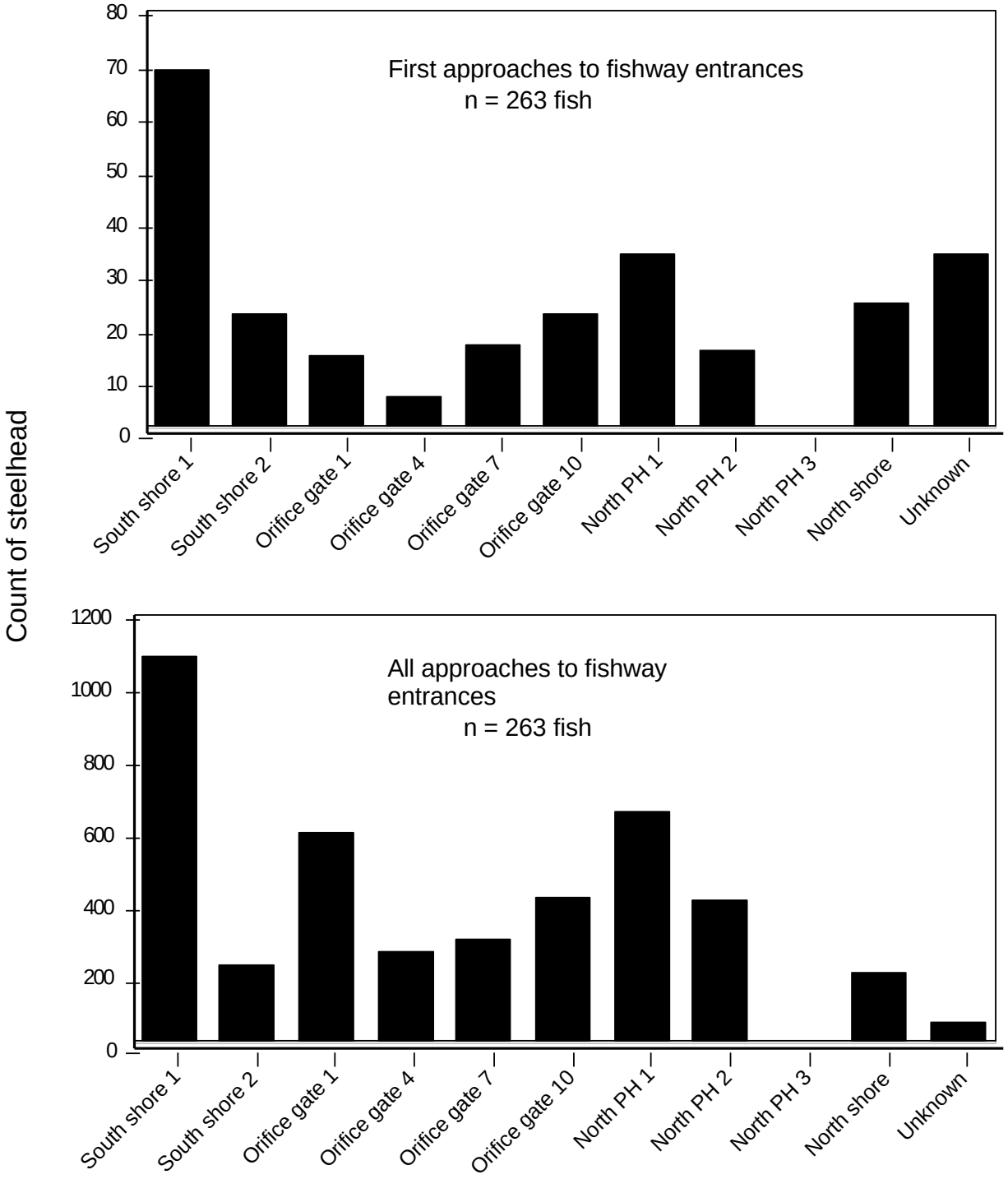

Figure 55. Number of first and total approaches at Lower Granite Dam fishway entrances by steelhead in 1996. See Figure 51 for locations of entrances.

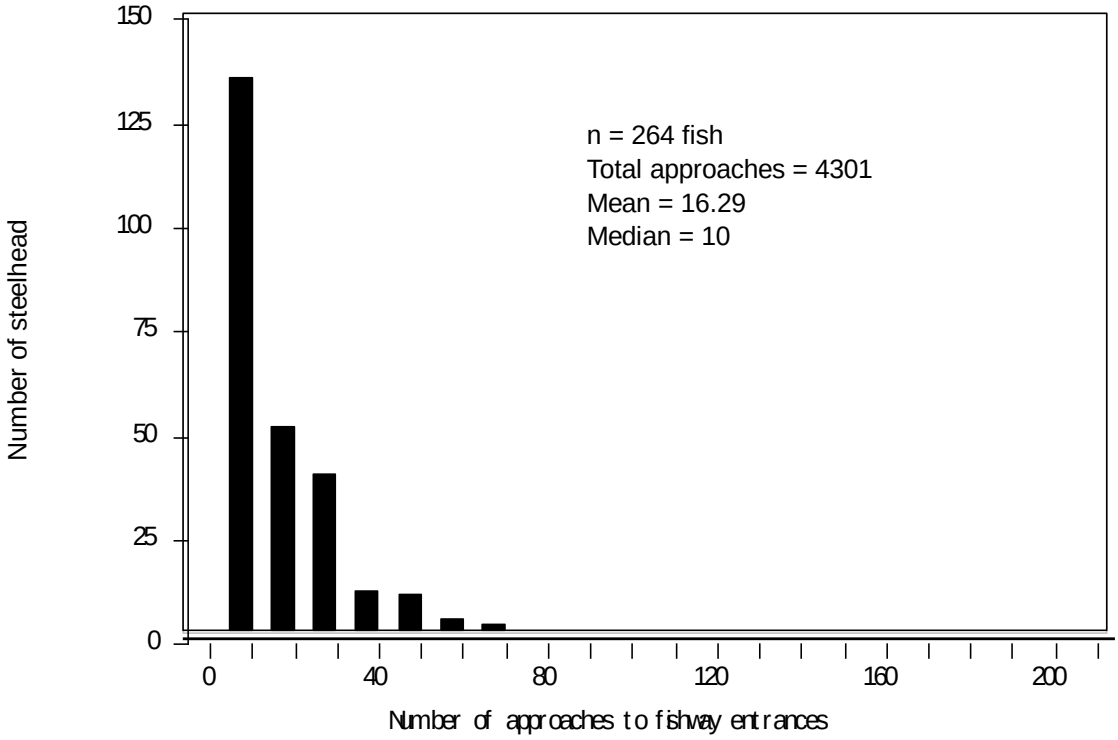

Figure 56. Number of steelhead that approached Lower Granite Dam fishway entrances one or more times in 1996.

Movements Through Transition Pool

We analyzed behavior of 192 steelhead in the transition pool at Lower Granite Dam in 1996. Eight percent (*n* = 16) moved straight through the transition pool and entered the ladder, and 21% (40) turned around in the transition pool, moved downstream but remained in the transition pool before entering the ladder. Seventy-one percent (136) turned around, moved downstream, and exited the transition pool before passing the dam, including fish (23% of 192) that exited the transition pool into the collection channel but did not exit the fishway into the tailrace, and 91 (47% of 192) that exited the fishway into the tailrace.

Fishway entrances used by steelhead to exit the fishway after leaving the transition pool were similar to those used to subsequently reenter the fishway (Figure 62). Approximately 32% of exits were at south-shore entrances, 30% were at north-powerhouse entrances, 3% were at orifice-gate entrances, 2% were at the north-shore entrance, and 34% were at unknown locations. Reentries by steelhead were distributed among fishway entrances, with 50% at south-shore entrances (primarily entrance 1), 10% at the orifice-gates entrances, 29% at north-powerhouse entrances, and 11% at unknown entrances.

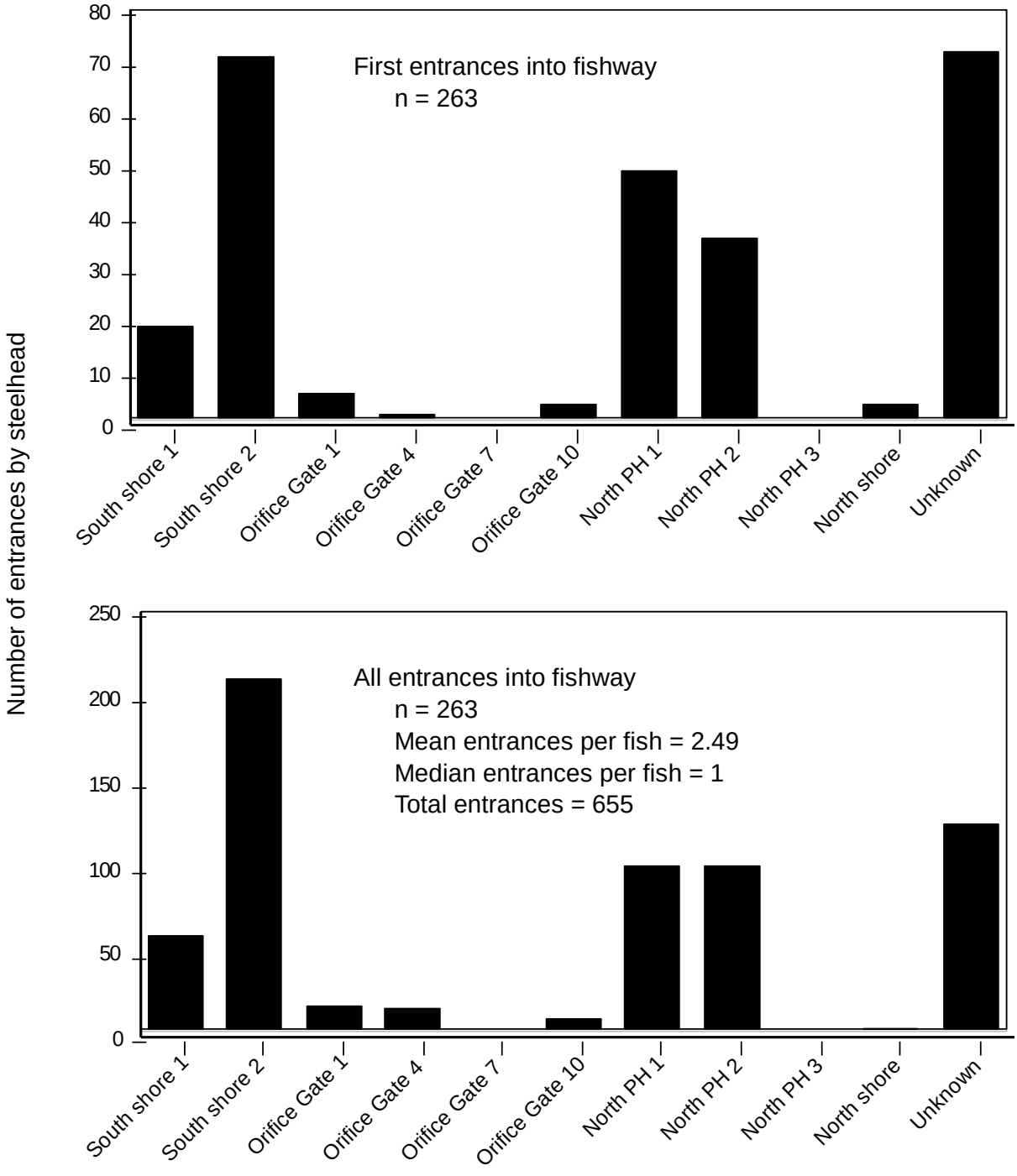

Figure 57. Number of first and total entries at Lower Granite fishway entrances by steelhead in 1996.

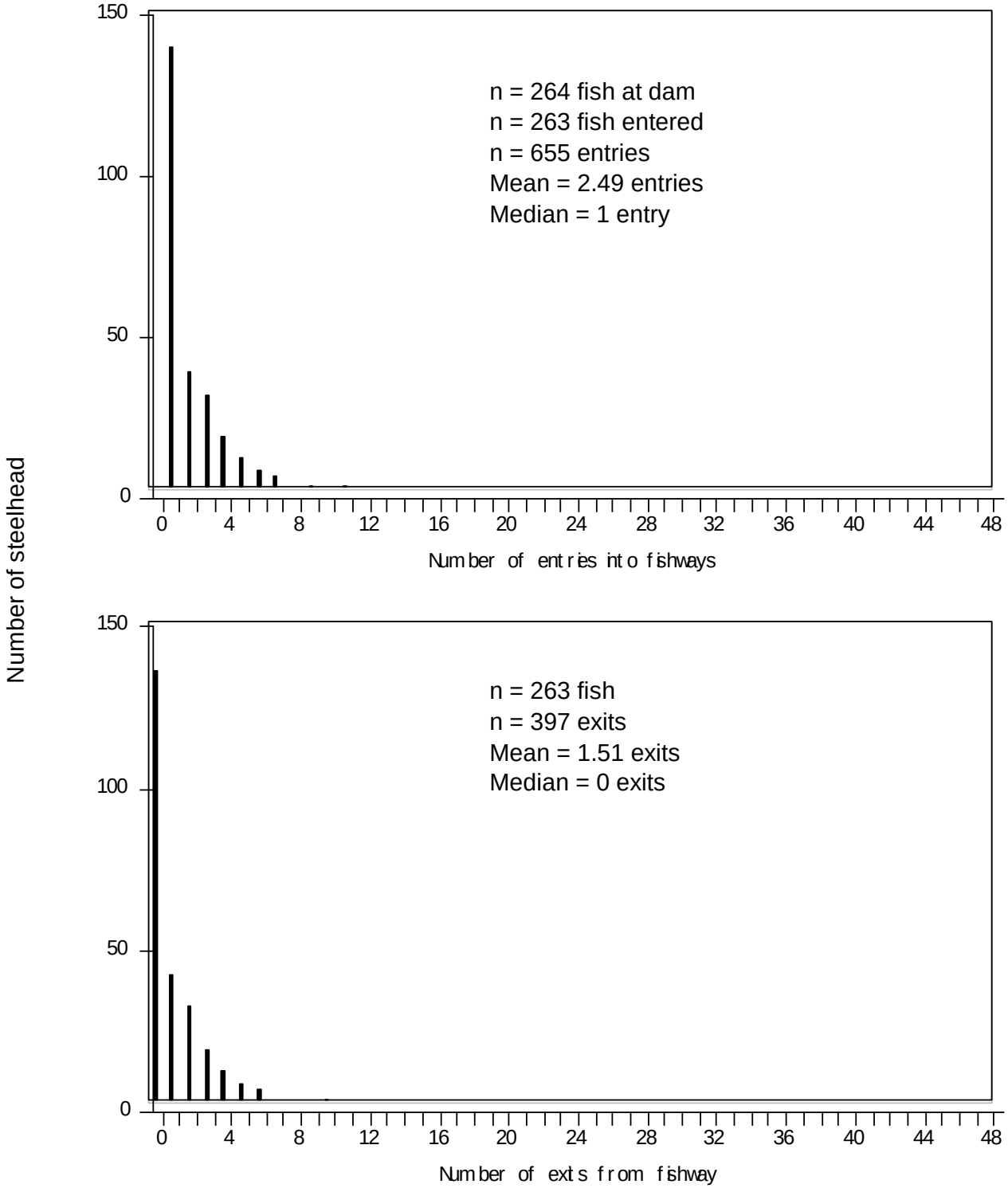

Figure 58. Number of steelhead that did not enter or exit, and those with multiple entries and exits into or from the fishway at Lower Granite Dam via the entrances in 1996.

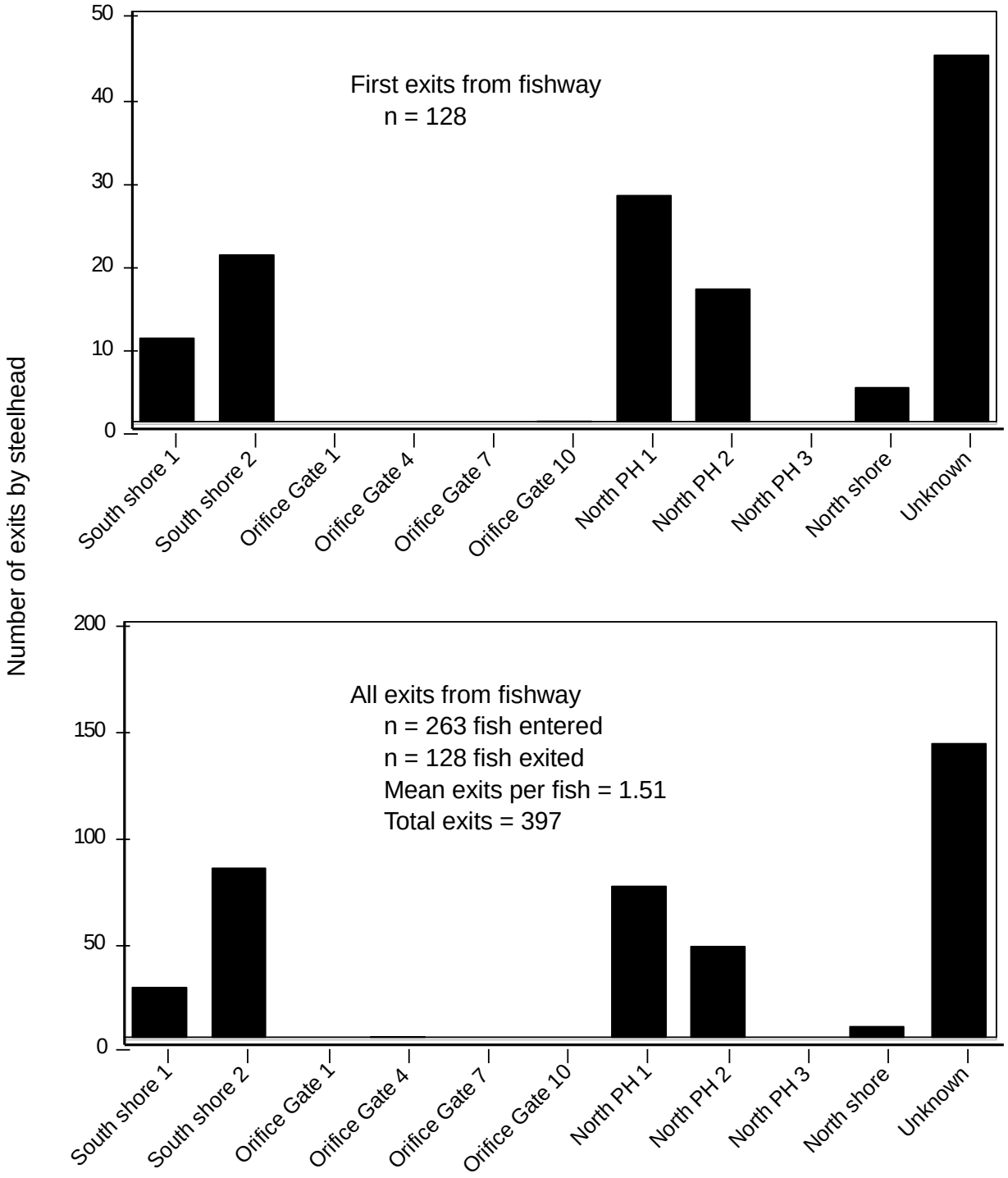

Figure 59. Number of first and total exits from fishway for each entrance by steelhead at Lower Granite Dam in 1996.

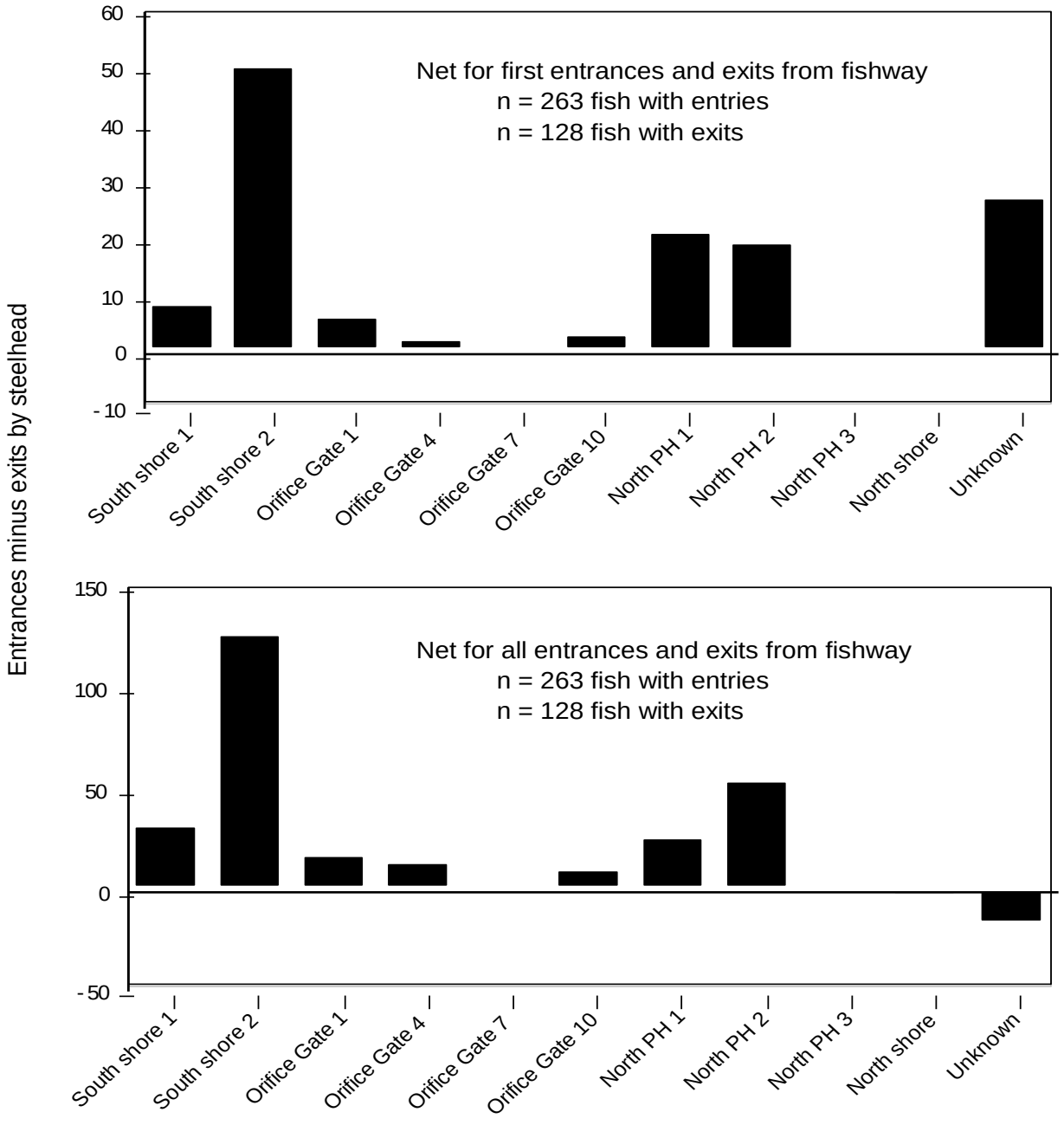

Figure 60. Net number of first and total entries and exits from fishway for each entrance by steelhead at Lower Granite Dam in 1996. of entrances.

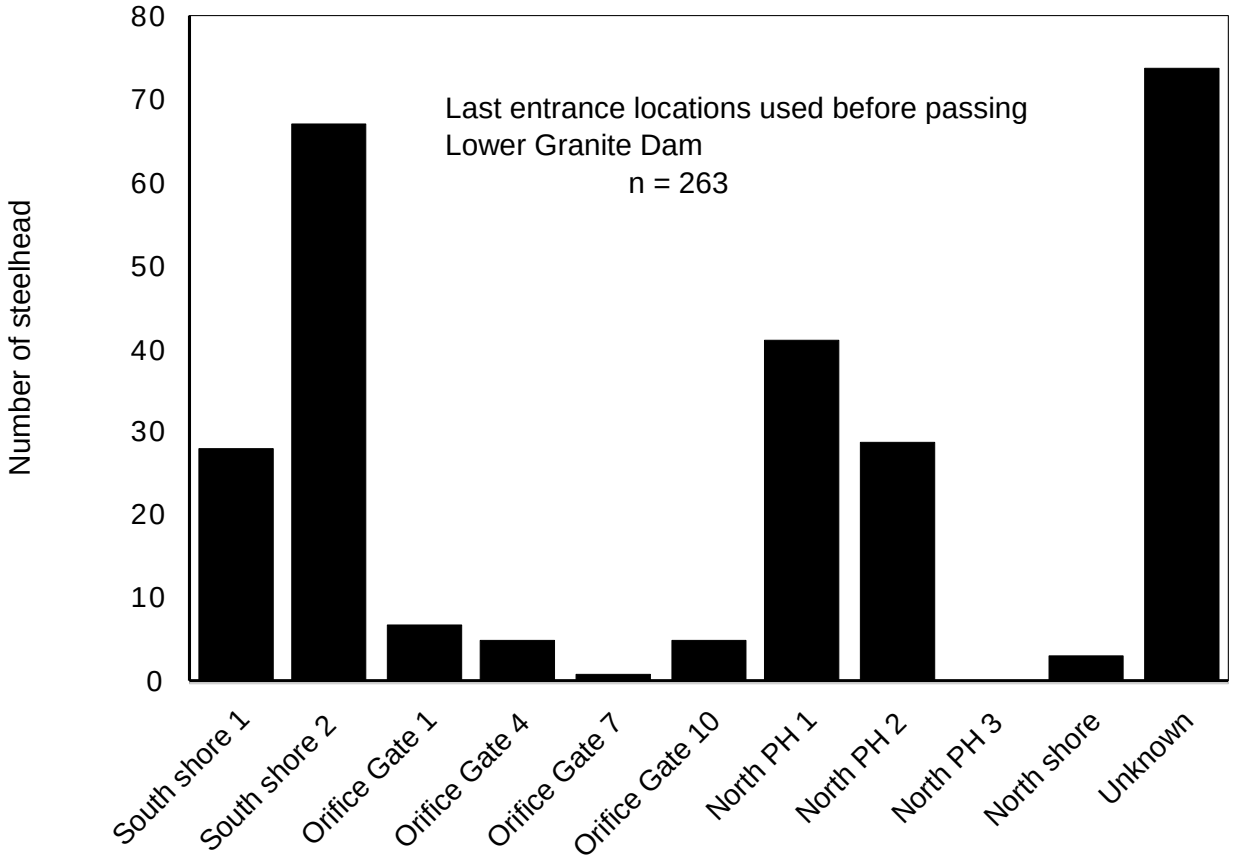

Figure 61. Last entrance locations for steelhead at Lower Granite Dam in 1996.

Fish that passed straight through the transition pool (n = 16) and those that delayed before entering the ladder (n = 40) 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 were skewed to the right, and so median values are reported.

Median passage times from first fishway entry to first transition pool entry ranged from 7 to 10 min (0.11-0.17 h) (Table 12). Median times from first transition pool entry to last entry into the ladder were 9 min (0.15 h) for fish that moved through the pool on the first attempt and 3.17 h for fish that made more than one attempt to pass. Median times to ascend a ladder were 6.84 h (mean = 12.36 h) for fish that passed through the transition pool on the first attempt, and 7.41 h (mean = 12.26 h) for steelhead 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 12.94 h for fish that moved through the pool on their first attempt and 21.57 h for fish that made more than one attempt (Table 12).

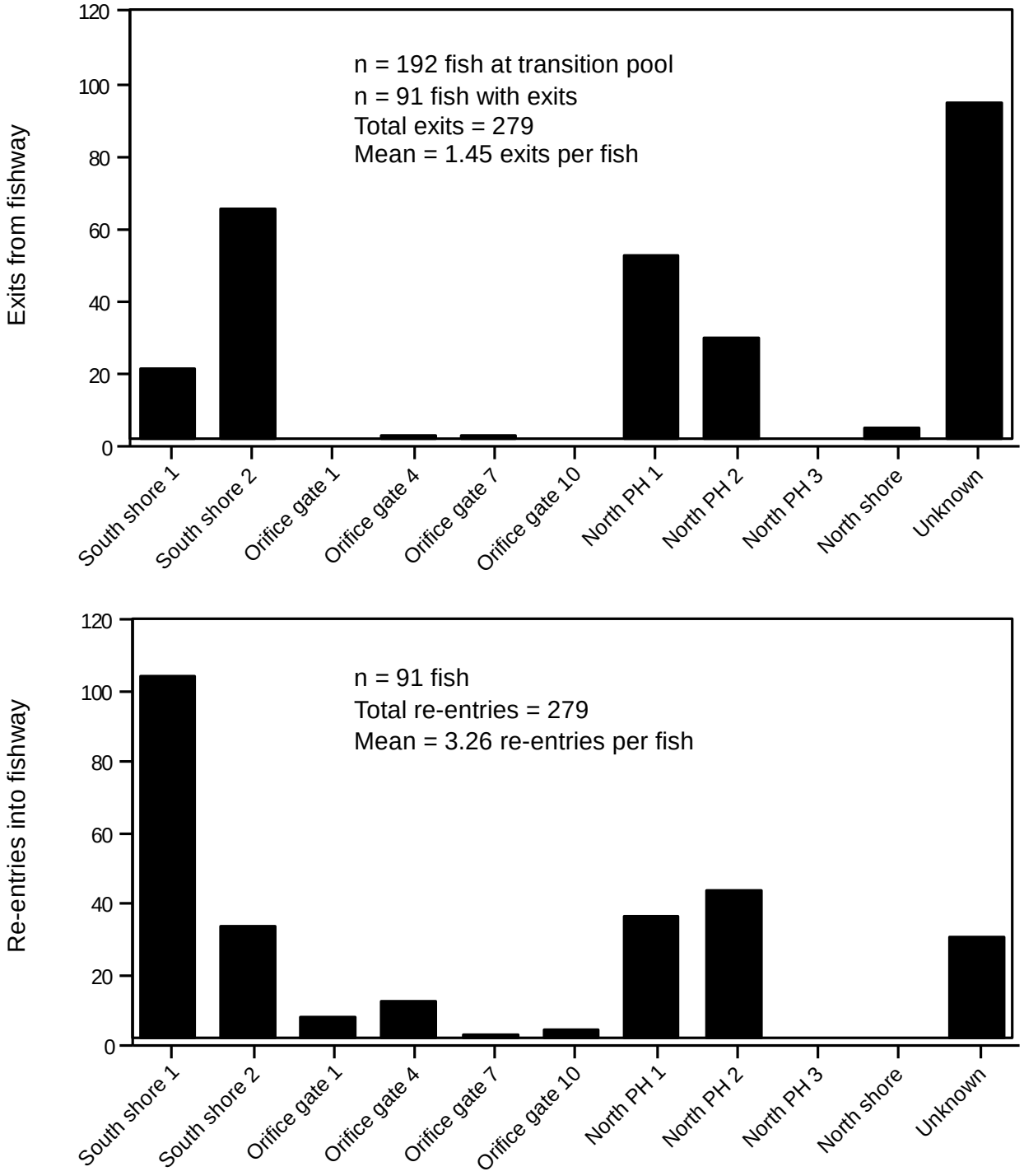

Figure 62. Entrances used to exit and reenter the fishway by steelhead that exited from the transition pool into the tailrace at Lower Granite Dam in 1996.

Table 12. Median passage times for steelhead 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.

		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	192	0.12	0.82	7.32	17.55
Passed through pool on first attempt	56	0.17	0.15	6.84	12.94
Exited pool one or more times	136	0.11	3.17	7.41	21.57
Exited pool to collection channel	45	0.11	0.35	7.15	11.46
Exited pool to tailrace	91	0.09	10.40	7.65	23.89

Slightly more than 60% of the fish that made multiple attempts to pass through the transition pool entered the ladder in less than 8 h, and 15% took more than 24 h. Ten steelhead (7%) that made more than one attempt to pass the transition pool took more than 2 d to pass the dam after first entering the fishway.

The 45 fish that turned around in the transition pool and traveled downstream in the collection channel but did not exit the fishway before passing the dam had median times of 7 min (0.11 h) from first fishway entry to first transition pool entry, 21 min (0.35 h) from first pool entry to last entry into the ladder, 7.15 h to ascend the ladder, and 11.46 h from first fishway entry to exit the top of the ladder (Table 12). Fish that exited the fishway after leaving the transition pool (n = 91) had median times of 10.40 h from first pool entry to last entry into the ladder, 7.65 h to ascend the ladder, and 23.89 h from first fishway entry to exit the top of the ladder (Table 12).

Discussion

Most radio-tagged steelhead approached and entered fishways at the three dams within hours after passing tailrace receivers. Steelhead passed over the dams in median times of 17.02 h at Bonneville Dam and 10.39 h at McNary Dam and 25.92 h at Lower Granite Dam, where fish with transmitters were diverted into the adult trap. Had fish not been diverted into the trap at Lower Granite Dam, their passage times would likely have been shorter. At all dams, passage time distributions were right-skewed, and mean times were higher than medians.

Adult steelhead approached fishways at all available entrances at each dam, but entered and exited mostly at the largest (in size and discharge) entrances. The larger fishway entrances were located at both ends of powerhouse collection channels and at entrances to ladders adjacent to spillways. Relatively few fish used the smaller sluice and orifice gates to enter or exit fishways.

Fish tended to first approach dams at shoreline entrances at Bonneville and Lower Granite dams, while at McNary Dam a large number first approached at orifice gates near the center of the powerhouse (Table 13). When all approaches by steelhead were considered, the highest numbers at Bonneville Dam were at sluice gates at Powerhouse 1 and orifice gates at Powerhouse 2, and at orifice

gates at both McNary and Lower Granite Dams (Table 13). The large numbers of fishway approaches at all dams suggest that many fish move along the downstream face of the dams searching for entrances. Many approaches may not have been attempts to enter fishways, but rather were detections of fish swimming near the fishways while searching for adequate cues.

The tendency for steelhead to first approach Bonneville and Lower Granite dams near shoreline entrances is consistent with our mobile-tracking observations that adult Chinook salmon and steelhead move upstream near the shorelines in the tailrace, as we have observed with Chinook salmon (Bjornn et al. 2000a; Keefer et al. 2002). Fish migrating near shore are most likely to be first attracted to powerhouse discharge, rather than spillway discharge, and to fishway entrances adjacent to the shorelines. Given the configuration of the Bonneville Dam tailrace channels, spill increases attraction flow both at spillway entrances and along the shoreline downstream from Powerhouse 2. Relatively few fish approached at entrances adjacent to spillways even though there was spill for many steelhead during 1996, another indication that shoreline flows are effective at attracting adult migrants. It is also possible that turbulence created during spill discourages fish from approaching or locating adjacent fishway entrances.

First approaches at the fishway entrances adjacent to the Bonneville Dam spillway did not change much when spill stopped (12 percent during spill, 10 percent without spill). However, a significantly higher percentage of fish made their first approaches at the Powerhouse 1 after spill stopped. This may be a further indication that attraction to the Powerhouse 2 is supplemented by spill-channel flows when fish approach the dam on the north side of the river. Daily average discharge from Powerhouse 1 was slightly less then that from the second powerhouse both with and without spill. It is likely that the distribution of entrance use by steelhead would change as powerhouse priority changes at Bonneville Dam, with more fish attracted to Powerhouse 2 sites when a greater percentage of the river is run through that powerhouse.

Steelhead used a more limited number of entrances to enter fishways than they approached. Monitored fish approached and entered all entrances at each dam, but most subsequently entered the larger entrances at shorelines and at the ends of powerhouses (Table 13). At Bonneville Dam, 57% first entered the Bradford Island fishway, primarily at south-shore entrances; 43% first entered at the Washington-shore fishway at Bonneville Dam, mostly at north-shore entrances. At McNary and Lower Granite Dams, most steelhead first and subsequently entered south-shore entrances, again indicating attraction to fishway entrances adjacent to powerhouse discharge. Steelhead entered fishways a median of two times at Bonneville and once at McNary and Lower Granite Dams (2.1 to 3.1 times, on average).

Between 49 and 59% of the monitored steelhead exited fishways back into the tailrace one or more times at all three dams. With the exception at McNary Dam, most steelhead exited from collection channels from the large entrances most distant from the bottom of a ladder (Table 13). This is indicative of the behavior we have observed where fish exiting a transition pool tend to move downstream through the collection channel and exit to the tailrace through powerhouse entrances (or equivalent). Relatively few steelhead exited via orifice- or sluice-gate openings. Steelhead exited a median of once from Bonneville and McNary fishways, and zero times from the Lower Granite fishway (1.2 to 2.2 times, on average).

First and total exits by steelhead from the Bradford Island fishway at Bonneville Dam were primarily from south-shore entrances (Table 13). Monitored fish first and subsequently exited the Washington-shore fishway mostly from the south-shore entrances, but many also exited from the north-

shore entrance. First and total exits by steelhead at McNary Dam were primarily from south-shore and north powerhouse entrances. At Lower Granite dam, first and subsequent exits were mostly from north-powerhouse and shoreline entrances. Use of fishway fences at downstream powerhouse entrances has been shown to be effective at reducing exits of fish at those sites (Bjornn et al. 1999), although using fences does not address the probable cause of many exits—when fish turn around in transition pools and subsequently move downstream in fishways.

Table 13. Percentage of first and total approaches to fishways, entrances into fishways, and exits from fishways by steelhead at Bonneville, McNary and Lower Granite dams in 1996. (Entrances combined by location or type.)

	Percentage of:					
Location	First Approaches	Total Approaches	First Entries	Total Entries	First Exits	Total Exits
Bonneville, Bradford Is. fishway						
S Shore Powerhouse 1	**49**	18	**32**	**35**	**55**	**59**
Sluice Gates	27	**51**	23	28	3	4
N Shore Powerhouse 1	9	26	14	11	10	10
B-Branch (S Spillway)	11	4	17	14	14	11
Unknown	4	1	14	12	18	16
Bonneville, WA-shore fishway						
Cascades Island (N Spillway)	13	3	13	13	10	11
S Shore Powerhouse 2	14	27	27	29	**39**	**39**
Orifice Gates	15	**49**	6	11	9	9
N Shore Powerhouse 2	**53**	20	**44**	**38**	31	30
Unknown	5	1	10	9	11	11
McNary Dam						
S Shore	17	7	**41**	**35**	**34**	25
Orifice Gates	**53**	**78**	19	30	4	3
N Powerhouse	14	9	13	17	28	**33**
N Shore	10	4	10	17	10	13
Unknown	6	2	17	1	24	26
Lower Granite Dam						
S Shore	**35**	31	**34**	**41**	25	28
Orifice Gates	24	**37**	5	8	1	3
N Powerhouse	19	25	32	31	**35**	31
N Shore	9	5	2	1	4	2
Unknown	13	2	27	19	**35**	**36**

Most fishway entrances at all dams had more entries than exits throughout the study. The number of exits exceeded the number of entries at the powerhouse 1 south-shore entrance at Bonneville Dam, at

the north powerhouse entrances at McNary Dam, and the north-shore entrance at Lower Granite Dam. Although steelhead had negative net entry rates at these sites, fish also successfully used the shoreline and powerhouse entrances most often. We believe near-shore and powerhouse entrances were favored by steelhead due to their location, larger size, greater depth, higher flow volumes, and the distribution of flows (powerhouse versus spillway) during the migration. We caution against misinterpretation of negative net entry rates. Fish appear to be more likely exit at sites which are located at fishway collection or transition points (*i.e.* the ends of collection channels, or entries closest to transition pools). The south shoreline entrance at Bonneville's Powerhouse 1, for example, may have had a negative net entry rate because fish that entered at the north end of the powerhouse or via orifice gates moved up to the end of the collection channel, encountered confusing of unfavorable conditions near the transition pool, and then exited at the nearest site—the high discharge south-shore entrance.

After first passing tailrace receiver sites, steelhead approached and entered fishways relatively quickly, although some fish took more than 24 h to first enter fishways at each dam. Median times for steelhead to first approach fishway entrances in 1996 were between 2 and 2.5 h at the three dams. After first passing tailrace sites, median times for steelhead to first enter fishways were 3.62 h at Bonneville, 3.34 h at McNary, and 5.06 h at Lower Granite dams. It was not clear why steelhead took longer to first enter the Lower Granite fishway.

Transition pools at Columbia and Snake River dams include submerged weirs and 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. 1998; Keefer et al. 2002). Between 8 and 26% of steelhead passed through transition pools with no downstream movement, and another 7 to 25% moved downstream in a pool but did not exit. Overall, 26% of the fish monitored at Bonneville Dam, 51% at McNary Dam, and 29% at Lower Granite Dam passed through transition pools on their first attempt. Eight to 28% of the monitored fish moved downstream into a collection channel, and from 41% to 48% exited into the tailrace after having been in a transition pool (Table 14).

Regardless of transition pool behavior, median passage times from first fishway entry to first transition pool entry were similar at all transition pools (0.02 to 0.41 h) . Similarly, transition pool behavior did not appear to affect the time steelhead took to ascend ladders at Bonneville or McNary dams (medians = 1.9 to 4.0 h). Steelhead took longer to ascend the ladder at Lower Granite Dam (medians = 4.8 to 7.6 h) because fish were diverted into the adult trap, but those times did not appear to be related to transition pool behavior.

Median times to pass through transition pools were less consistent among the different behavior-groups. All steelhead that moved through individual transition pools on the first attempt or that turned around in a transition pool and traveled downstream in the fishway but did not exit into the tailrace had median passage times of about 1 hr or less. Fish that exited a fishway into the tailrace after first entering a transition pool had the longest median times to pass through pools, reflecting the additional time required to re-approach and re-enter fishways and transition pools. At Bonneville Dam, steelhead that exited the fishway had median passage times from 1.06 to 16.27 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 to the tailrace had median times from 3.39 to 12.39 h to pass through transition pools.

Table 14. Number of steelhead monitored in the transition pools at Bonneville, McNary, and Lower Granite Dams and the percent that fell into each of the four transition pool behavior groups.

	Bonneville (n = 615)	McNary (n = 316)	Lower Granite (n =192)
No downstream movement in pool	19%	26%	8%
Moved downstream but did not exit	7%	25%	21%
Exited pool to collection channel	28%	8%	23%
Exited pool to tailrace	46%	41%	48%

Temporary 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. Median times from first fishway entry to pass the dam were mostly < 4.1 h at Bonneville Dam for steelhead that did not exit a transition pool into the tailrace. By comparison, fish that exited into the tailrace at Bonneville Dam had median times from 7.6 to 27.8 h, two to seven times longer than fish that did not exit. Patterns were similar at McNary and Lower Granite dams. Using medians, delays associated with exiting a transition pool into tailrace areas were 3 to 23 h at Bonneville Dam, 2 to 15 h at McNary Dam, and 8 to 16 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 (median times approximately 1 h less than the fish that passed transition pools on their first attempt). These consistent patterns suggest that prevention of transition pool exits to the tailraces of dams could substantially reduce overall dam passage times. More detailed investigations of the factors that affect transition pool behavior, and particularly transition pool exits, are underway.

At Bonneville Dam, the vast majority of fallback events were by fish that had passed the dam using the Bradford Island fishway. Fallback fish that reascended and passed the dam a second time approached, entered, and passed fishways differently on their first and second passages. First passages for fallback fish more closely matched patterns by all tagged fish. On their second passage, fish tended to have fewer approaches and entrances, but slightly longer passage times than on their first passage. These behaviors reflect the tendency of adult fish to fallback over the spillway and then approach near the spillway at Bonneville Dam (Bjornn et al. 2000b). Reduced numbers of fishway entrances and approaches following fallback may indicate familiarity with fishways, while longer second passage times may reflect time spent recovering from fallback or time spent overnight in tailrace areas.

In summary, it appeared that adult steelhead readily located fishway entrances at the three study dams. Steelhead mostly used those entrances where those approached most often, although this was not always the case (i.e. submerged orifices at McNary Dam). Entrances with greatest use were the larger openings with greater attractive flow and those nearest shorelines, as would be predicted by the tendency for adult fish to move upstream along shorelines. Most steelhead that exited fishways into tailraces turned around in transition pools prior to exiting a fishway, though many fish also exited before entering pools. Behavior of fish while transiting the transition pool was the best predictor of passage times at dams for adult steelhead, primarily because those that exited to the tailrace had longer passage times. Although mechanisms have been tested to reduce the likelihood of fishway exits (e.g. Bjornn et al. 1999), these types of strategies have primarily treated the symptom of a problem apparently created largely by transition pool behavior. Managers seeking to improve adult steelhead passage at the study dams (*i.e.*, reducing passage times) should consider modifications to transition

pools that would encourage more fish to pass through transition pools on their first attempt. Possible strategies include improving attraction flow through transition pools, ensuring favorable passage conditions (*e.g.*, water temperature) in the pools, or other modifications to the existing transition pool environment.

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