Technical Report 2002-2

MIGRATION OF ADULT STEELHEAD PAST COLUMBIA AND SNAKE RIVER DAMS, THROUGH RESERVOIRS AND DISTRIBUTION INTO TRIBUTARIES, 1996

A report for Project MPE-P-95-1

by

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Preface

Recent studies of adult salmon and steelhead migrations past dams, through reservoirs, and into tributaries with radio telemetry began in 1990 with planning, purchase and installation of equipment for studies at the Snake River dams. Adult steelhead were outfitted with transmitters at Ice Harbor Dam in 1991 and 1992, at John Day Dam in 1993 and reports of those studies are available (Bjornn et al. 2002; 1992; 1994; 1995; 1998). The focus of adult passage studies was shifted to the lower Columbia River dams in 1995 when telemetry equipment was set up at the dams and tributaries and spring/summer chinook salmon and steelhead were outfitted with transmitters at Bonneville Dam in 1996. In this report we present information on the overall migration of steelhead from release, past each of the dams in the Columbia and Snake Rivers and into tributaries in the run-year 1996-97. Additional reports will be issued on detailed analysis of passage at dams that had a full complement of receivers and antennas to monitor use of fishway entrances and passage through transition pools. Reports will also be produced that cover studies of passage of chinook and sockeye salmon.

Acknowledgments

Many people assisted in the fieldwork and data compilation for this project and the successful completion was made possible by Bob Dach and Teri Barila, the Corps of Engineers project officers. Michelle Feeley, Brian Hastings, Michael Jepson, and Jay Nance played important roles in the study. Alicia Matter and Sarah McCarthy assisted with the telemetry database management.

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Abstract

We captured 770 steelhead *Oncorhynchus mykiss* in the adult trapping facility at Bonneville Dam in 1996, released them with radio transmitters, and studied their passage past dams, through reservoirs and into tributaries. Radio receivers were set up at Columbia and Snake River dams and at the mouths of major tributaries to monitor movements of steelhead. Recaptures of steelhead at hatcheries, weirs and traps, and data from mobile tracking were used to complete the migration history.

Of 765 steelhead with transmitters released downstream from Bonneville Dam, 487 were classified as A-group steelhead (tagged before 29 August) and 278 as B-group steelhead (tagged after 29 August). We believe 739 fish retained transmitters beyond the release site and migrated upstream. Of the 739 fish, >99% passed through the tailrace and reached Bonneville Dam and 97.4% were known to have passed the dam. Seventy-nine percent of the 739 fish passed The Dalles Dam, 62% passed John Day Dam, 53% passed McNary Dam, 43% passed Ice Harbor Dam, 35% passed Lower Granite Dam, and 2% passed Priest Rapids Dam.

Median times for steelhead to pass individual lower Columbia River dams ranged from 0.43 d at McNary Dam to 0.85 d at John Day Dam. Median passage times at the lower Snake River dams were between 0.61 d at Ice Harbor Dam and 1.08 d at Lower Granite Dam, where operation of the adult trap extended passage times for fish diverted into the trap. Adult steelhead passed most tailrace receiver sites throughout the day and night, but typically moved through fishways and past top-of-ladder receivers during daylight hours. Most fish that were in fishways at nightfall did not pass the dam until the next day.

Median passage rates through reservoirs were between 24 and 43 km/d through the lower Columbia River pools, which included time steelhead temporarily strayed into tributaries. Median times to pass through reservoirs ranged from 1.2 d to 2.9 d. From first passage of the tailrace at Bonneville Dam, median passage times past multiple dams were 16.1 d to the top of McNary Dam, 26.2 d to the top of Ice Harbor Dam, 35.0 d to the top of Lower Granite Dam, and 22.0 d to the top of Priest Rapids Dam.

B-group steelhead tended to migrate more rapidly than A-group steelhead, with median passage times past multiple projects about half those for A-group steelhead. However, median passage times past some individual dams and reservoirs were shorter for A-group fish.

In 1996, peak counts of steelhead at dams occurred during no-spill conditions. When spill did occur, it did not significantly affect passage times at dams. Total flow and turbidity also had limited impact on passage times, although there was a tendency for times to increase with increased flow. Passage times at dams decreased with increasing water temperature, but correlations between pasage times and temperatures were low.

Cumulative passage times past multiple projects were best predicted by the time steelhead temporarily strayed into lower Columbia River tributaries. The date fish were released was also correlated with passage time, with early migrating fish migrating at lower rates than those later in the migration. The number of times steelhead fell back over dams was also a good predictor of passage times, because fish with one or more

fallbacks during their migration had significantly longer migration times. Exits from fishways into tailrace areas also contributed to longer times to pass upriver. Turbidity, spill, and flow at lower Columbia River dams explained relatively low proportions of the variability in passage times past multiple dams.

The incidence of marine mammal injuries or descaling at time of tagging had a limited impact on fish passage times. Marine mammal and descaling injuries did not appear to have a detectable effect on fallback rates.

At least 143 steelhead, 20% of the fish with transmitters that passed Bonneville Dam, fell back at Bonneville or other dams 207 times in 1996 or 1997 before spawning. Most fallback events occurred at John Day (25%), The Dalles (19%), or Bonneville (18%) dams. About 22% of A-group and 16% of B-group steelhead fell back. Between 4.9 and 10.1% of fish fell back at lower Columbia River dams, and 5.6 to 8.4% fell back at Ice Harbor and Lower Granite dams; none fell back at Priest Rapids Dam. Fallback rates tended to be higher during high flow and spill, but correlations were not strong; most analyses were qualitative due to small sample sizes. Although most steelhead passed dams during no-spill conditions, a disproportionate number of fallback events occurred during spill, especially at lower Columbia River dams.

Fallbacks at any dam added significantly to overall passage time past multiple dams. Using median passage times, one or more fallbacks at any dam added 12 to 21 days to most overall passage times when compared to fish that did not fall back, differences that were significant. Differences in median passage times past multiple dams between fish that did and did not fall back were slightly greater for B-group steelhead than for A-group steelhead. Fish that fell back multiple times had the longest median passage times.

About 57% of steelhead that fell back subsequently reascended all dams where they fell back. Of fish that did not reascend, about 37% subsequently entered tributaries downstream from the location of the fallback. About 56% of steelhead that fell back at lower Columbia River dams eventually returned to tributary sites up- or downstream from the dam where they fell back. Less than 40% of those that fell back at lower Snake River dams returned to tributaries. Steelhead that fell back escaped to tributaries at lower rates than fish that did not fall back, but differences were not strongly significant.

Fish that fell back over dams and then reascended ladders added mostly positive biases to fish counted at the dams. Using weighted adjustment factors, steelhead counts reported in the USACE annual fish passage report were inflated by an estimated 6,000 to 12,700 fish at The Dalles, John Day, and McNary dams. Positive biases were 7,800 to 8,300 fish at Ice Harbor and Lower Granite dams. Passage through the navigation lock at Bonneville Dam more than compensated for fallback and reascension behavior at the dam; the estimated escapement was about 1,300 higher for Bonneville Dam than that reported by USACE. Weighted escapement adjustment factors for counts at dams were from 0.93 to 1.01 at lower Columbia River dams, 0.92 at Ice Harbor Dam, and 0.91 at Lower Granite Dam.

About 5% of the steelhead that passed Bonneville Dam had mainstem overwintering behavior. A significantly higher proportion of B-group fish overwintered than A-group fish. Overwintering fish fell back at significantly higher rates than fish that did not overwinter, temporarily strayed into lower Columbia River tributaries at relatively high rates, and tended to move downstream during the overwintering period. We estimated average overwintering times to be around 140 d. The highest number of fish overwintered at least some of the time between The Dalles and John Day dams; overall, 73% spent overwintering time in the lower Columbia River, 41% spent time in the lower Snake River, and 25% spent some time overwintering in lower Columbia River tributaries other than their final destination. A significantly higher proportion of overwintering fish were unaccounted for than fish that did not overwinter in the mainstem hydrosystem. The steelhead that did not overwinter in the Columbia and Snake rivers hydrosystem (95% of the radio-tagged steelhead) entered tributary streams or passed Priest Rapids and Lower Granite Dam reservoir before the onset of winter.

Migrations into individual tributaries started during July of 1996 and continued through April of 1997. Median arrival dates were in August and September at most lower Columbia River tributaries, in October at the John Day, Yakima, and Snake River tributaries, and were in November or December at the Umatilla and Walla Walla rivers. Fish were first recorded at tributary mouths mostly during daylight.

In 1996, about 48% of A-group steelhead with transmitters were last recorded in the lower Columbia River and its tributaries and 28% were last recorded in the Snake River basin upstream from Lower Granite Dam. About 48% of B-group steelhead were last recorded upstream from Lower Granite Dam and 42% were last recorded in the lower Columbia River or its tributaries.

About 65% of steelhead that passed Lower Granite Dam and 61% that passed Priest Rapids Dam made temporary excursions into one or more lower Columbia River tributaries. Snake River fish mostly entered the Little White Salmon (32%), Deschutes (30%), and White Salmon (23%) rivers. A significantly higher proportion of Snake River A-group fish (74%) entered lower Columbia tributaries than B-group fish (55%). Fish stayed in tributaries for a median of 7.7 d (mean = 11.6 d). A-group fish stayed in tributaries significantly longer (median = 15.3 d) than B-group fish (4.7 d), and fish without fin clips stayed significantly longer (20.7 d) than fin-clipped fish (6.0 d). Peak proportions of Snake River fish were in lower Columbia River tributaries when mainstem water temperatures were high (20?C or higher) and tributary temperatures were relatively low in late August. Between 22 and 43% of Snake River fish were in lower river tributaries from early August through mid-September.

Fish bound for lower and mid-Columbia River tributaries also strayed into tributaries other than their final destinations. The proportion temporarily straying was ? 50% for the steelhead that ended up in the Deschutes (67%), John Day (81%), Umatilla (100%), Yakima (50%), and Walla Walla (50%) rivers. Less than 8% of the fish that entered the Wind, Little White Salmon, and White Salmon rivers were last recorded at those sites.

Reach survival estimates within the mainstem Columbia/Snake river hydrosystem were lowest through the Bonneville-The Dalles reach (0.920), and through the Lower Granite pool (0.901). Reach survival estimates in the remaining lower Columbia River reaches were approximately 0.94, and the estimate from the top Ice Harbor Dam to the top of Lower Granite Dam was 0.922.

Although there were limitations in our ability to monitor detectable escapement to tributaries, we calculated that approximately 63% of all steelhead that retained transmitters ended up in tributary streams, a rate that included fish recaptured in tributary fisheries. Tributary return rates were similar for A-group and B-group fish and for fin-clipped and unclipped fish. Of 261 fish (37% of those that retained transmitters after release) that did not enter tributaries, about 27% were recaptured in mainstem fisheries and reported to us, and the fates of the remaining 73% (27% of all steelhead that retained transmitters) were mostly unknown.

About 32% of tagged fish were reported recaptured in fisheries, at hatcheries, weirs or traps (not including the Bonneville or Lower Granite traps), at spawning grounds, or their transmitters were found along river corridors. Forty-six percent of reported recaptures were in sport fisheries, 21% in tribal fisheries, 26% at hatcheries, weirs or traps and 19% at spawning grounds or along migration routes. About 47% of all recaptures were in the Snake River basin, 45% were in the lower Columbia River or its tributaries, and 8% were upstream from Priest Rapid Dam.

Our best estimate of the final fate for all radio-tagged A-group and B-group steelhead in 1997 was 6.0% downstream from Bonneville Dam, 44.4% between Bonneville and McNary dams, 8.2% in the mid-Columbia upstream from McNary Dam, and 41.3% in the Snake River basin. Escapements were 37.9% in tributaries (excluding tributary harvests) and 5.2% to hatcheries; when we included fish last recorded upstream from Priest Rapids Dam, at or near Ringold Trap, or at Lower Granite Trap without transmitters, total escapement was 47.5%. About 21% were reported recaptured in mainstem and tributary sport or tribal fisheries, 6.9% of transmitters were known or presumed regurgitated in non-spawning areas, and 24.8% were unaccounted for. We found no significant differences in escapement rates or unaccounted-for rates for A-group and B-group fish. Fish without fin clips escaped at higher rates than fin-clipped fish, probably because a significantly lower proportion of unclipped fish (8.8%) were harvested compared to fin-clipped fish (23.3%).

Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated transmitters that were not recovered or located, may have entered tributaries undetected, may have spawned at mainstem locations, or may have died and were not detected as mortalities. The largest proportion of unaccounted for fish were last detected between Bonneville and The Dalles dams. About two-thirds of unaccounted for fish were A-group steelhead, but we found no significant differences in the overall proportion of unaccounted for A-group or B-group fish; we also found no differences in unaccounted for rates for fin-clipped and unclipped fish.

Introduction

Studies of the passage of adult chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* at the lower Columbia River dams began in 1995 with the setup of radio telemetry equipment, and fish were outfitted with transmitters in 1996. In this report we present information on passage of steelhead at each of the dams, beginning with Bonneville Dam, and their migrations through reservoirs and into monitored tributaries throughout the basin in the run-year 1996-97. (Run-year was from 1 June 1996 to 31 May 1997). Data presented in this report can be compared to migration rates and passage success of adult steelhead at dams and through reservoirs in the lower Snake River that were assessed in 1991-1994 (Bjornn et al. 2002 (Part 2). As in the Snake River studies, radio telemetry was used to monitor salmon movements at the dams, up the rivers, and into tributaries.

The study described herein was undertaken because of concerns of the U.S. Army Corps of Engineers (USACE), state and federal fish agencies and tribes, those expressed in section 603 of the Northwest Power Planning Council's (NPPC) 1987 Columbia River Basin Fish and Wildlife Program, and later reflected in the Biological Opinions issued in 1995, 1998, and 2000 for operation of the Federal Columbia River Power System, that studies were needed to ensure that passage of adult salmon and steelhead past the dams and through reservoirs was as efficient as possible. Specific to the 2000 Biological Opinion (NMFS 2000) these studies address assessments of survival, unaccounted for loss, fallback, delay, tributary turnoff and effects of river environment on passage, as outlined in Action 107.

Study plans were developed in consultation with USACE personnel, and with biologists in other federal, state, and tribal fish agencies. Research was conducted by personnel of the Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU) and National Marine Fisheries Service with logistical support, cooperation, and funding from the U.S. Army Corps of Engineers, Bonneville Power Administration and U.S. Geological Survey.

Passage of chinook salmon and steelhead at dams and through reservoirs in the lower Snake River was studied in 1991-1993 (Bjornn et al. 1992; 1994; 1995; 1998; 2002), and the telemetry equipment and procedures developed for those studies were used at the lower Columbia River dams starting in 1996. Because larger numbers of fish were tagged and more receiver sites were used in the 1996 studies, we developed new ways to process the millions of records obtained, and to code the records to identify the migration behavior of fish that would facilitate data analysis.

In 1995, as we started planning for the studies at the lower Columbia River dams, we, and others, were concerned that adult salmon and steelhead taken from the Washington-shore ladder at Bonneville Dam might not be a representative sample of the fish runs that passed the dam. We also wanted to study passage at Bonneville Dam and believed that use of naive fish that had not already passed the dam would be preferred. In the spring of 1995, we attempted to capture adult salmon downstream from Bonneville Dam in trap nets, but with little success. With little hope of capturing adequate numbers of adult salmon downstream from the dam, we decided to use the facilities in the Adult Fish Facility (AFF) at Bonneville Dam and determine if fish trapped there were representative of the runs, and if the use of non-naive fish to study passage at Bonneville Dam biased our results in any discernible way. In 1996, we captured steelhead in the AFF, outfitted them with transmitters and transported them to release sites on both sides of the Columbia River about 9.5 km downstream from the dam. We report herein on tracking of steelhead as they migrated back upstream to Bonneville Dam and our assessment of the use of fish trapped at the dam.

We set up receivers/antennas in 1996 in tributaries downstream from Bonneville Dam, at dams and major tributaries in the lower Columbia River, at Priest Rapids Dam , at Ice Harbor and Lower Granite dams in the lower Snake River, and at the lower end of the Clearwater River and Snake River near Asotin, WA (Figure 1). Fish with transmitters returned to tributaries, dams, traps, and hatcheries upriver from Priest Rapids Dam and our uppermost sites in the Snake River, and we used recaptures of those fish to gain additional information about fish distribution.

Counts of steelhead at Columbia River dams in 1996 were 12% to 20% below the previous 10-year average, with the exception of John Day Dam, where counts were about average (Table 1) (USACE 1996; DART 2000). The 1996-1997 run-year counts at Ice Harbor and Lower Granite dams were close to the 10-year average, while the count at Priest Rapids Dam was about 23% below average (Table 1). Fish in the A-group at Bonneville Dam, fish that passed between 1 January and 25 August, were 86% as numerous as the previous 10-year average and B-group fish were 69% of the average (Table 1). Differentiation between A- and B-group fish was not defined at upriver dams because some A-group fish have a tendency to delay migration and pass upstream dams at the same time as B-group fish. We classified steelhead tagged prior to 29 August as A-group fish and those tagged after 2 September as B-group; each fish retained its group designation regardless of passage timing at upriver sites. We did not tag fish on the five days 29 August to 2 September.

A higher proportion (49.4%) of steelhead counted at Bonneville Dam in 1996 were later counted as the 1996-1997 run at Ice Harbor Dam than the average for the previous 10 years (39.7%). The number of steelhead that passed Priest Rapids Dam in 1996 (8,375 fish) was lower than the previous 10-year average by almost 2,500 fish, but the proportion they made up of the count at Bonneville Dam was only 0.1% less than the 10-year average (4.1% in 1996 versus 4.2% average).

For the 1986 to 1995 period, the distribution of counts indicating when steelhead passed Bonneville Dam varied from that at upstream dams (Figure 2). At Bonneville Dam, average counts increased during late June and July and persisted at consistently high levels from late July through mid-September with no well defined nadir in counts to separate A- and B-group fish (Figure 2). At The Dalles, John Day, and McNary dams the mean daily counts in late July and August were progressively smaller, followed by peak counts in late September.

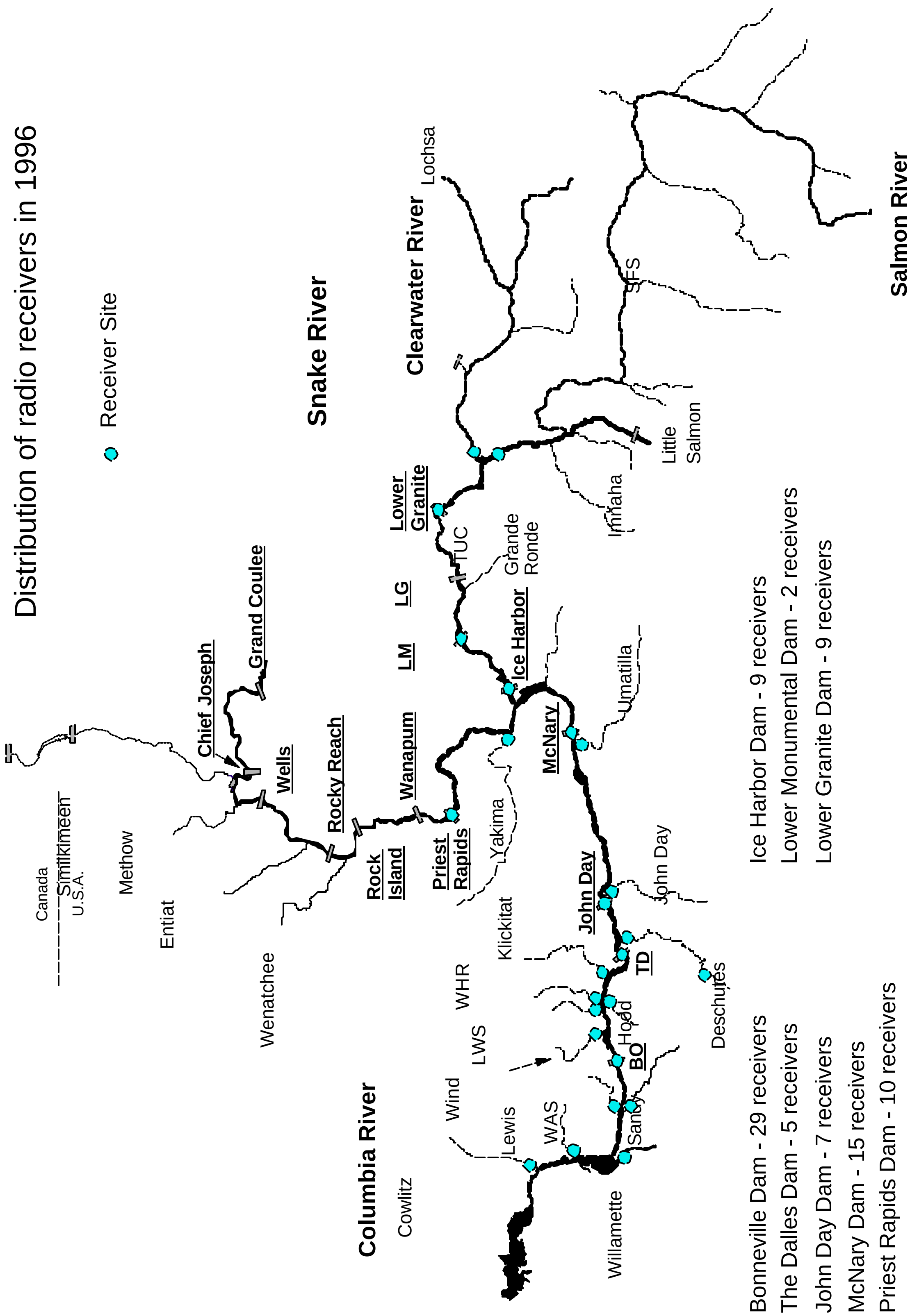


Figure 1. Location of radio receivers at dams and major tributaries within the Columbia River study area in 1996.

Table 1. Adult steelhead counted at mainstem dams in run-year 1996-97, the previous 10-year mean count (1986 to 1995) and the 1996 counts as a percentage of the 10-year mean. Data compiled from annual USACE fish passage reports, with A-group fish those that were counted at Bonneville Dam 15 March through 25 August and B-group fish those that passed after 25 August.

	All Steelhead		A-group steelhead		B-group steelhead	
Dams	1996 count	Percent of 10-year mean	1996 count	Percent of 10-year mean	1996 count	Percent of 10-year mean
Bonneville[1]	205,213	80	136,677	86	68,536	69
The Dalles	162,447	87				
John Day	156,924	102				
McNary	124,820	88				
Ice Harbor	101,384	99				
Lower Granite	86,898	98				
Priest Rapids	8,375	77				

[1] run-year at Bonneville Dam was from 15 March to 31 November, 1996

In 1996 at Bonneville Dam, steelhead counts peaked in mid August and there were significantly more fish counted before 1 September than after (Figure 2). At the other lower Columbia River dams, the number of fish counted in 1996 was higher than the 10 year average during August and lower than average after September. At Priest Rapids Dam in 1996, peak counts during early September were higher than average, but counts during late September and October were lower than average (Figure 2). At Ice Harbor and Lower Granite dams, steelhead counts peaked a little earlier than average, with more fish counted in August and early September, but fewer in October. The steelhead count distribution at Ice Harbor Dam in the Snake River was significantly later then the count distribution at Priest Rapids Dam for fish that continue their migration up the Columbia River (Figure 2).

Flow and spill in the Columbia and Snake rivers in 1996 were higher than the prior 10-year averages (1986 to 1995) throughout the summer, and flow was slightly higher than average during the fall (Figure 3). During spring and summer 1996, Secchi depth visibility was lower than average at all dams, but by fall turbidity levels were close to average, although Secchi disk reading were not taken at some locations (Figure 4). Water temperatures were 1 to 2° C colder than the 10-year average during much of the 1996 migration, particularly at Lower Granite Dam, where releases of cool water from Dworshak Dam during late August and early September reduced the temperature noticeably (Figure 5).

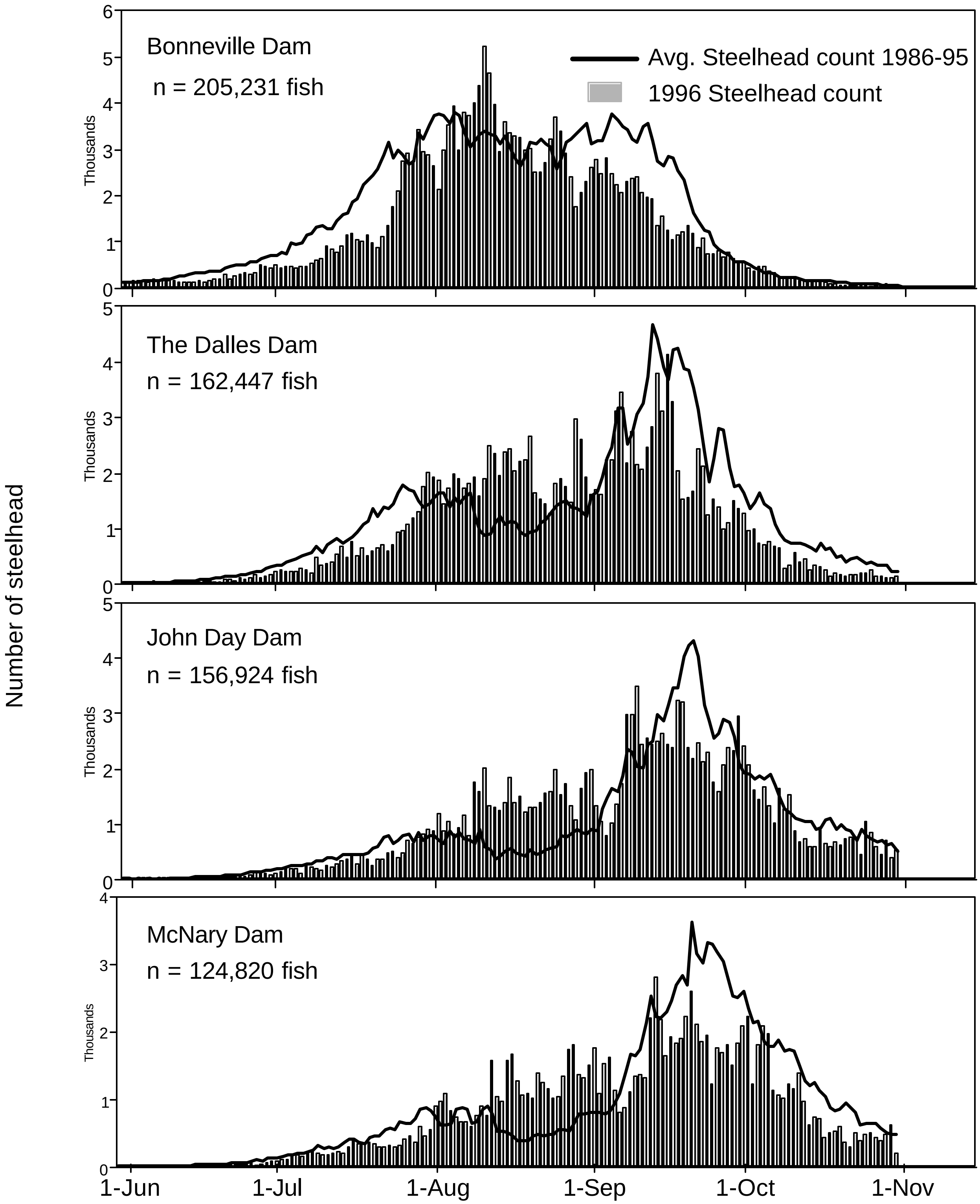
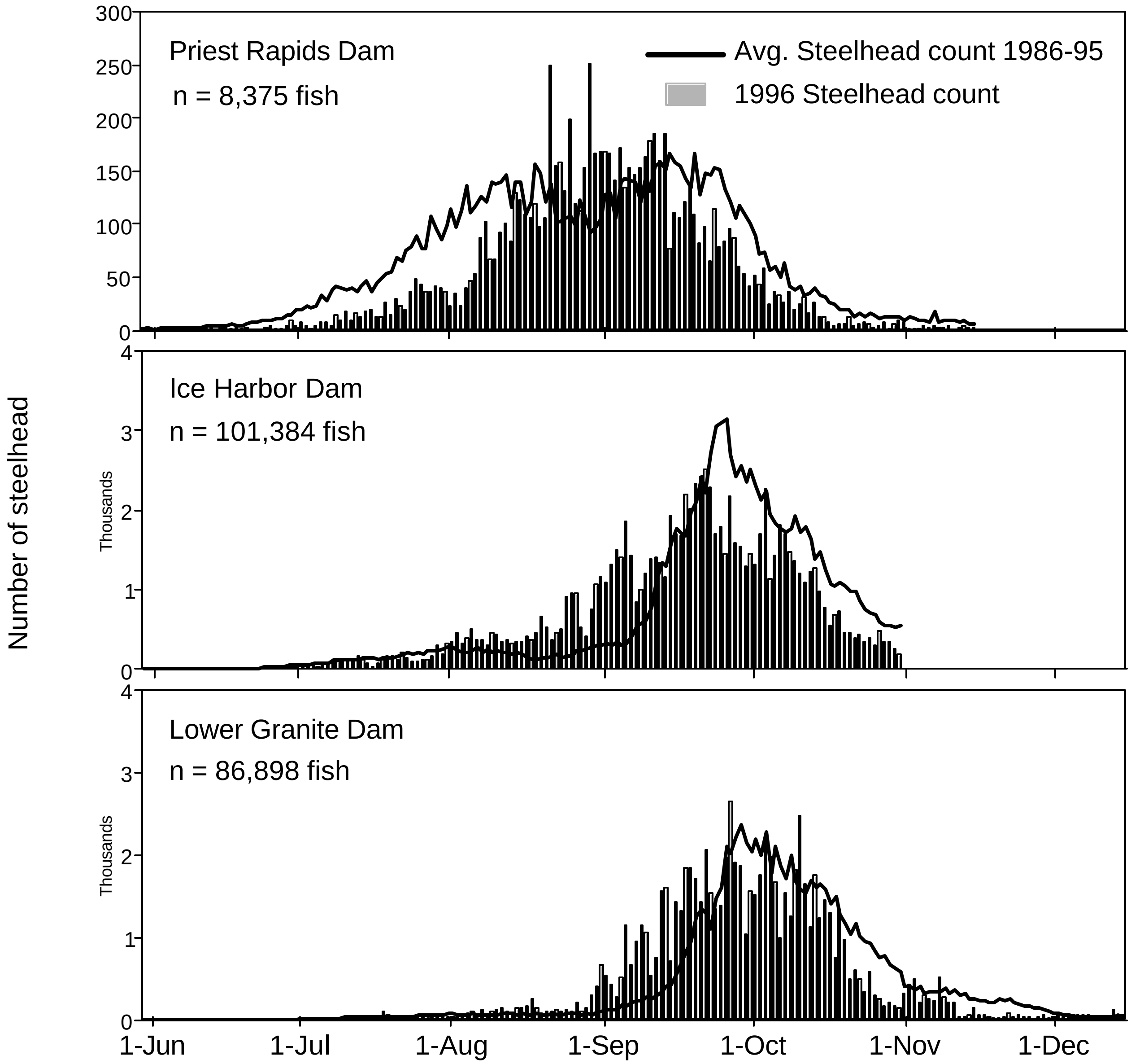


Figure 2. Number of steelhead counted at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996 with 10-year average counts (1986 to 1995).



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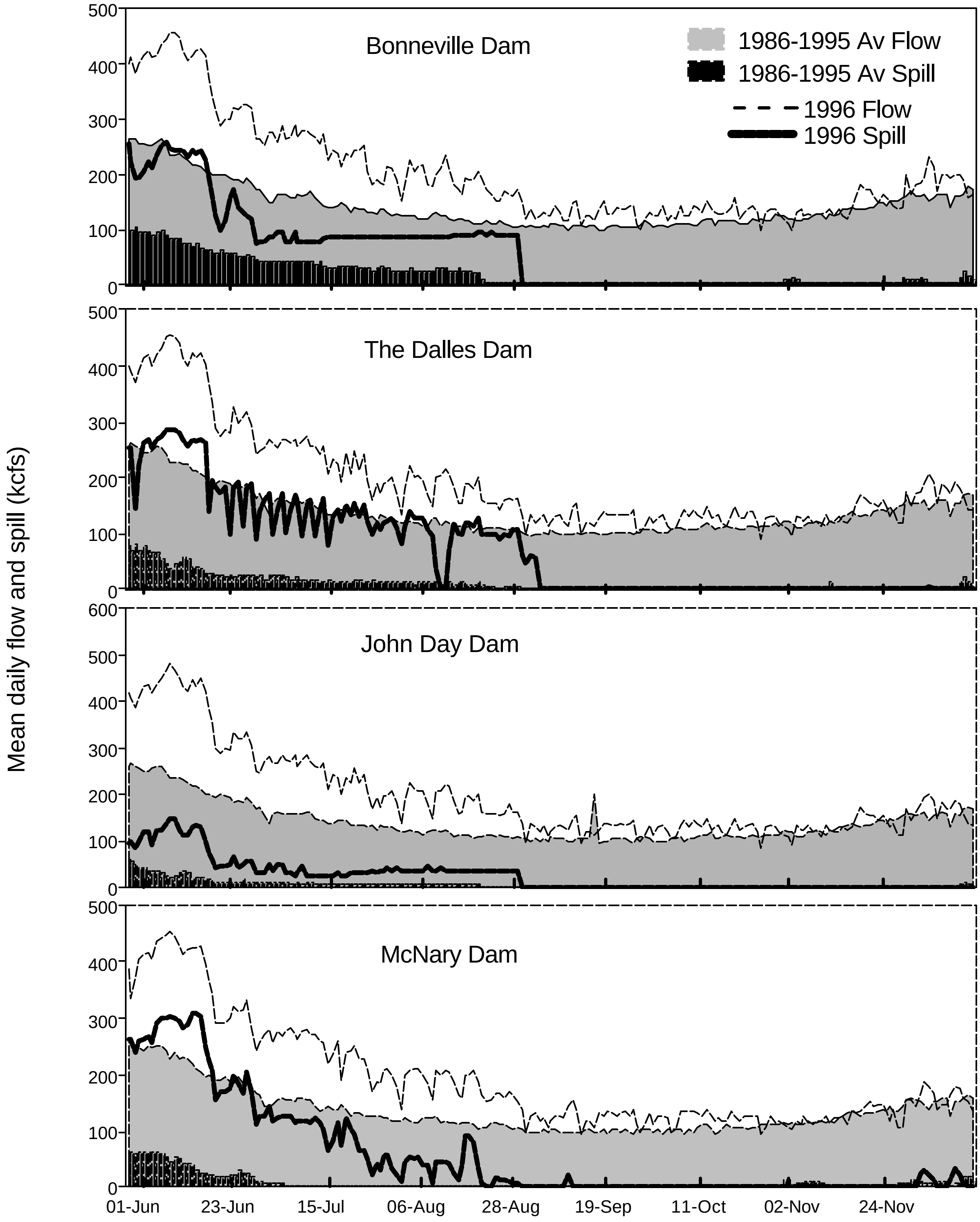
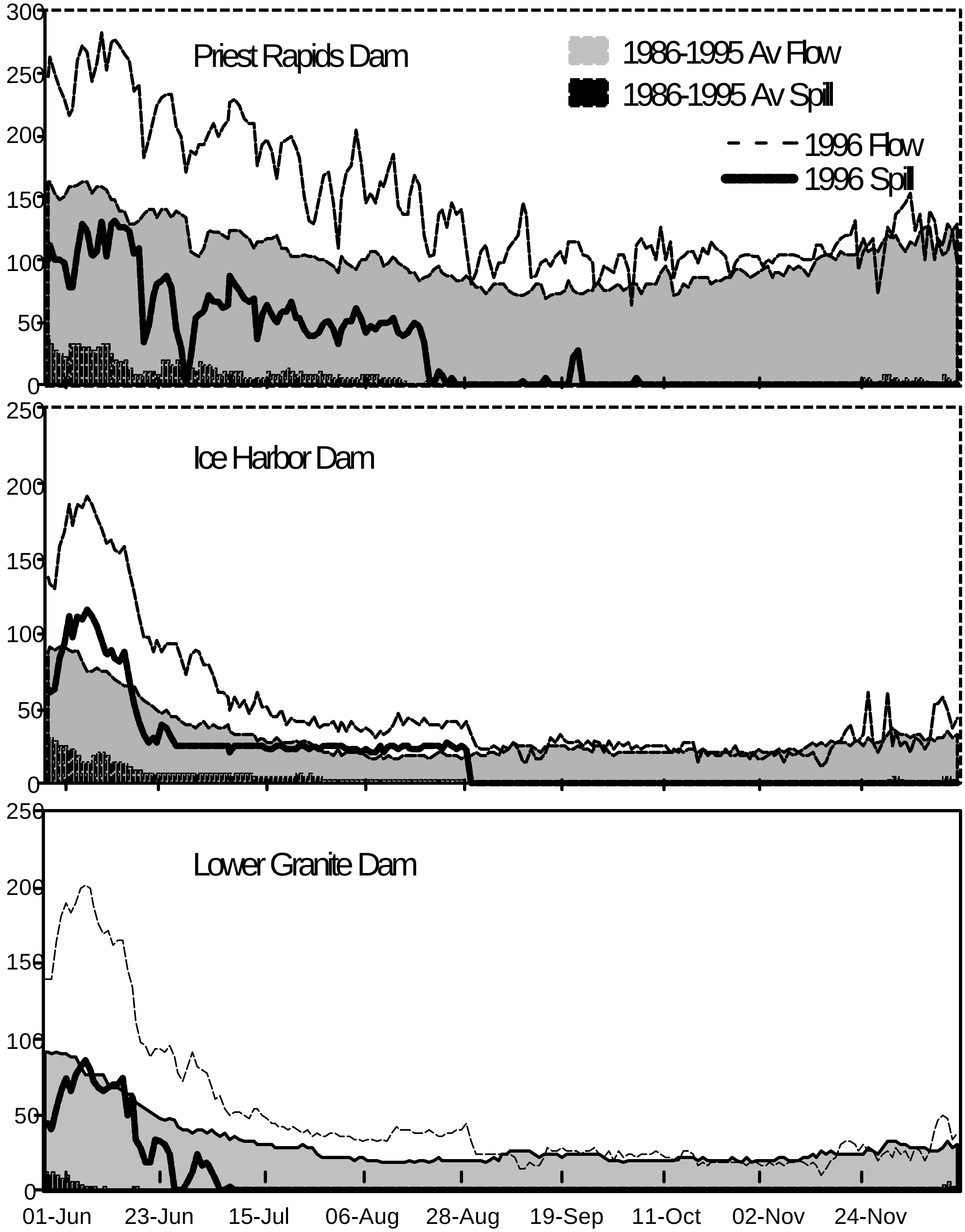


Figure 3. Mean daily flow and spill volumes at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996 with 10-year averages (1986 to 1995).



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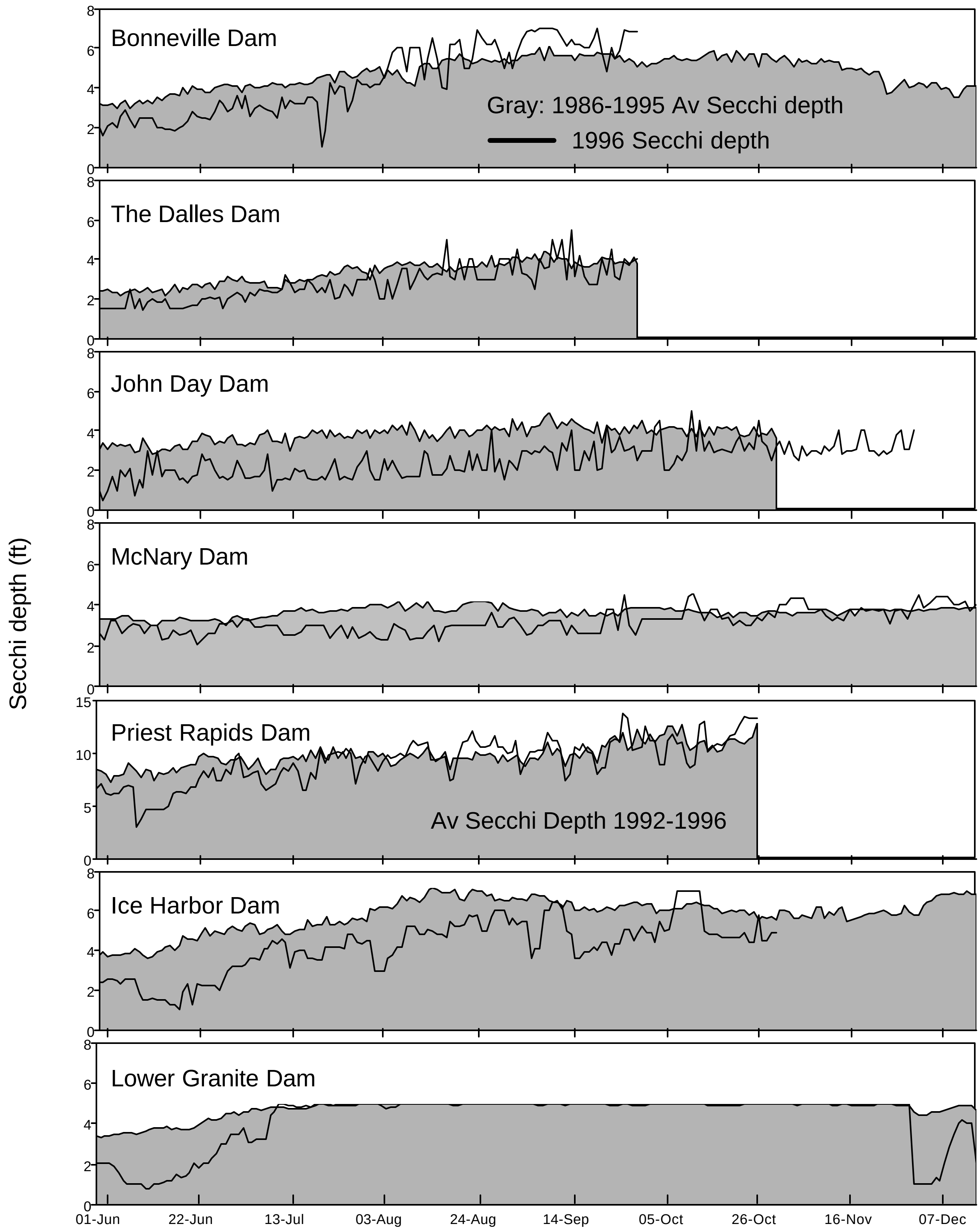


Figure 4. Mean daily Secchi disk visibility at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996 with 10-year averages (1986 to 1995).

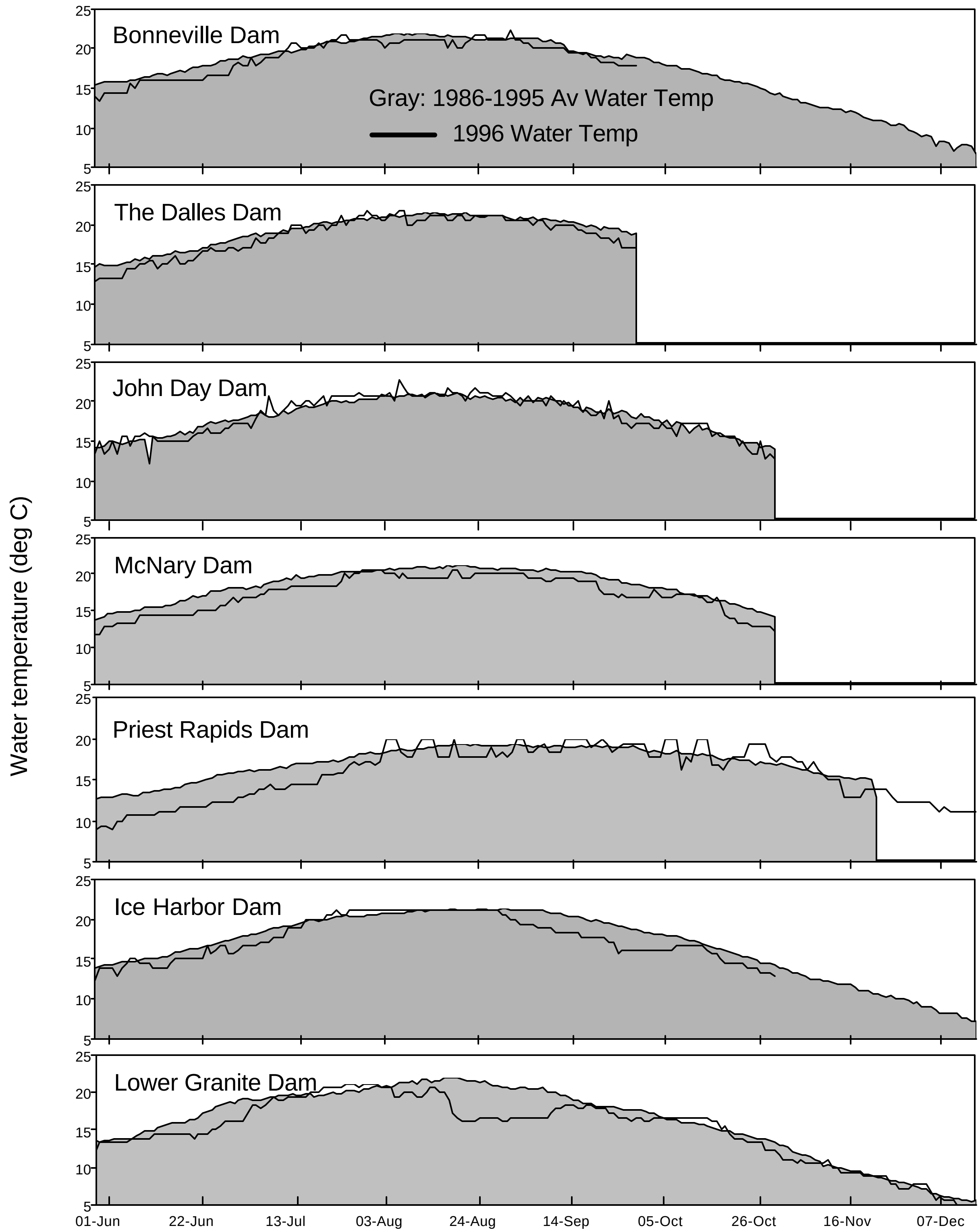


Figure 5. Mean daily water temperature at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996 with 10-year averages (1986 to 1995).

In 1996 we used radio telemetry on a large scale (770 steelhead outfitted with radio transmitters) to assess the proportion of adult steelhead that successfully passed dams in the lower Columbia River, and their passage times at the dams and through reservoirs. Cumulative passage times and minimum survivals from Bonneville past multiple dams were also estimated. The influence of flow and spill on migration and fallback rates, relations between fallback and passage, final distributions for fallback and non-fallback steelhead, overwintering and straying behavior, and survival rates to major tributaries were studied for steelhead outfitted with transmitters in 1996.

General Methods

Radio telemetry was the primary means of assessing movements and passage rates of adult steelhead in the Columbia River in 1996. In 1995, we began planning and installation of the telemetry setups that would be required at each dam and at the mouths of tributaries. Priority dams for intensive study in 1996 were Bonneville, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams. We fully outfitted those dams with receivers and antennas to monitor all fishway entrances and exits, as well as the tailraces to determine when steelhead with transmitters approached dams (See Figure 1 and Table 3 in Bjornn et al. (2000a) for locations of receivers used in 1996). At The Dalles, John Day, and Lower Monumental dams, we installed receivers and antennas at tailrace sites, tops of ladders, and at selected (but not all) fishway entrances. Passage of steelhead with transmitters was not monitored at Little Goose Dam, or at the mid Columbia River dams upriver from Priest Rapids Dam. Coverage during the steelhead migration was not continuous at some receiver sites. A number of antennas and receivers primarily installed to monitor the passage of A-group and summer chinook salmon in 1996 were removed during the steelhead migration. We removed most of the telemetry setups at Ice Harbor and Priest Rapids dams relatively early in the steelhead migration, and most fishway receivers were removed at Lower Granite Dam in December. Tailrace and top-of-ladder monitoring was continuous at all dams monitored.

Receivers and aerial antennas were installed at all major tributaries upstream from Bonneville Dam, and in selected tributaries downstream from the dam (Figure 1; also see Table 3 in Bjornn et al. (2000a) for complete documentation of receiver/antenna locations at dams and on tributaries in 1996). We set up receivers/antennas in tributaries near the mouths, but far enough upstream so that transmitter signals from fish in the Columbia or Snake rivers would not be picked up and recorded. At some tributaries we installed receivers/antennas upstream or downstream from tributary mouths to monitor steelhead with transmitters as they approached and proceeded upstream past a tributary.

Receiver and Antenna Outages

During 1996, individual sequentially scanning receivers (SRX) and Yagi antennas installed at tailrace sites down river from dams operated satisfactorily 81.4% to 97.9% of the time (mean of 91.0%) that they were in place (Table 4 in Bjornn et al. 2000a). SRX/DSP (SRX connected to a digital spectrum processor) receivers that were used to monitor the tops of ladders operated satisfactorily 85.2% to 99.9% of the time (mean of 93.1%), and SRX receivers at tributary mouths operated satisfactorily 89.6% to 100% of the time (mean 95.6%). Antennas and receivers that monitored entrances to fishways and within fishways operated at similar or slightly lower rates, but data from those receivers were typically not used for the passage studies in this report. (Note: during the steelhead migration, we removed some receivers and antennas at Ice Harbor, Lower Granite, and Priest Rapids dams that were in place principally to monitor the A-group and summer chinook salmon migration in 1996. Reported efficiency values were not restricted to the steelhead migration, but were for the entire time receivers were in place in 1996.) Receiver outages occurred primarily because of power loss, receiver malfunction, vandalism, and full memory banks (Bjornn et al. 2000a). In a few additional cases, receivers were operating but were not accurately recording data or were recording data incompletely. Cut antenna wires, malfunctioning receivers or downloading errors accounted for most data gaps not explained by receiver outages (Table 5 in Bjornn et al. 2000a).

Outfitting Steelhead with Transmitters (Tagging)

Radio transmitters were placed in 770 adult steelhead collected in the Adult Fish Facility at Bonneville Dam from 17 June to 9 October, 1996 as they migrated upstream to natal streams or hatcheries. Steelhead were transported to release sites at Dodson and Skamania landings about 9.5 km downstream from Bonneville Dam; 765 were released with transmitters and 5 regurgitated transmitters during transport to the release sites. We followed an approximate rotation of ten days of tagging followed by four days without tagging (Figure 6). Tagging was temporarily stopped in late July/early August due to high water temperatures.

On each day that we tagged fish, a diversion weir was lowered into the Washington-shore ladder in the morning to divert fish from the main ladder into the Adult Fish Facility via a short bypass ladder. Steelhead then entered a large tank with two false weirs leading to chutes. As steelhead passed over the false weirs and slid down the chutes, a person would divert fish into an anesthetic tank if they were to be tagged; other fish continued down the chute and entered a channel that led back to the main fishway. Handling stress was thus minimized since fish collected at the Adult Fish Facility are not handled until anesthetized. We had no steelhead mortalities during tagging, transport, or release in 1996. Steelhead not diverted into the anesthetic tank were those too small to receiver radio transmitters.

Tricane-methanesulphonate (MS-222) was used to anesthetize fish at a concentration of 100 mg/L. When fish were anesthetized, we moved them to a tagging tank in a wet plastic sleeve and recorded length and sex (if possible), and examined them for injuries, old scars, and fin clips. We then outfitted fish with a transmitter that had been dipped in glycerin, by inserting it into the stomach through the mouth. The transmitter antenna was bent at the corner of the mouth and allowed to trail along the

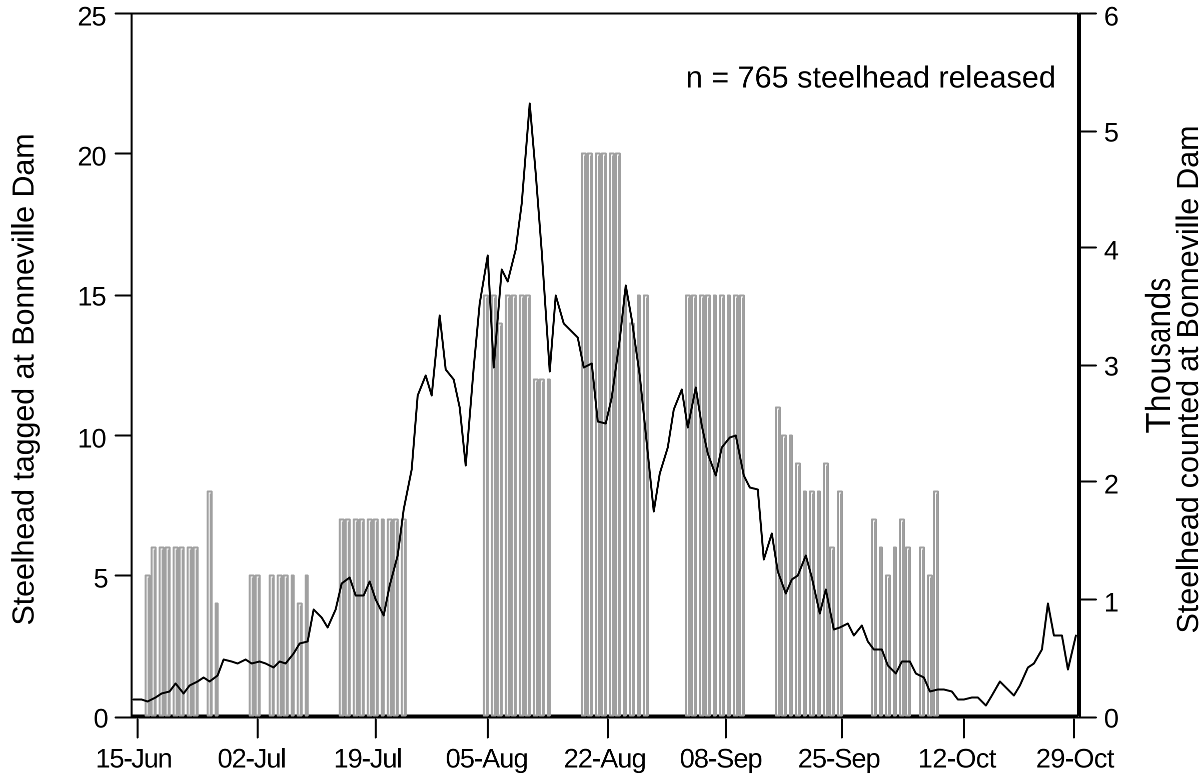


Figure 6. Number of steelhead outfitted with radio transmitters at the Bonneville Dam adult trap (bars), and the number counted passing the dam at the counting stations during the migration in 1996 (line).

side of the fish. We used a mixture of 3- (43 mm by 14 mm diameter, 11 g in air, 4.1 g in water) and 7-volt (80 mm by 16 mm diameter, 29 g in air, 13 g in water) transmitters developed and supplied by Lotek Engineering that transmitted a digitally coded signal every 5 s that included the frequency and code of the transmitter. The code set we used allowed us to monitor up to 170 fish on each frequency. Transmitters were powered by a lithium battery and had a rated operating life of 270 d, but usually lasted a year or more.

We inserted a unique secondary visual implant (VI) tag into the clear tissue posterior to the eye (left usually), and a 1 mm-long piece of magnetic wire was inserted into the muscle near the dorsal fin to trigger the coded-wire detector at Lower Granite Dam. Fish were then placed in the wet sleeve and moved to the transport tank were they were held until released (usually less than 3 hours). The length of the trapping period each day depended on the number of steelhead to be outfitted with transmitters and the number of fish moving up the ladder. The transport tank was a 300 gal, insulated, fiberglass tank with a large trap door on the end for fish release. Air stones on the tank bottom supplied oxygen from bottles mounted on the side of the tank. An overhead crane was used to move the transport tank in and out of the fish facility. Once trapping was finished each day, we removed diversion weir pickets from the ladder and fish in the trapping system were allowed to proceed up the ladder.

Of 770 steelhead outfitted with transmitters in 1996, we designated 490 (64%) as A-group steelhead because they were tagged before 29 August, and 280 (36%) as B-group steelhead that were tagged after 29 August. Over the course of the tagging period, 194,976 adult steelhead were counted passing Bonneville Dam of which the 770 radio-tagged fish represented 0.4% (1 in 253) of the counted run passing the dam. For the A-group steelhead migration period (17 June to 28 August), 143,922 steelhead passed Bonneville Dam, and 0.3% (1 in 294) were tagged. During the B-group tagging period (3 September to 9 October), 51,054 steelhead were counted at Bonneville Dam, and 0.5% (1 in 182) were tagged. The A-group or B-group designations applied to steelhead at Bonneville Dam were kept for analysis purposes regardless of date of passage at upriver dams. (Note: A-group steelhead are usually classed as those fish that pass Bonneville Dam prior to 26 August; our designations were essentially the same, as we tagged no steelhead between 29 August and 2 September). As in previous years, we unselectively outfitted fish with transmitters in a manner we believe provided a representative, but not strictly random sample of adult steelhead. The sample was not truly random because only fish passing via the Washington-shore fishway were sampled, the proportion of the run sampled each day varied but was more or less constant, more fish were collected in the morning than afternoon, and no fish were collected at night when steelhead passage is typically very limited. Fish were tagged as they were trapped, and we tagged almost all fish regardless of minor injury or fin clip; seven steelhead with serious injuries were rejected for tagging in 1996.

Our overall sampling effort was evaluated by calculating the proportions of total counts of steelhead passing ladders for consecutive 5-d blocks that were radio tagged. Between 15 June and 31 October we outfitted 0.38% of the steelhead counted at Bonneville Dam. We tended to tag disproportionately more fish in the earliest and latest portions of the run and proportionally fewer fish were tagged during peak counts (Figure 7).

The proportions of radio-tagged fish that passed upstream dams reflected the disproportionate tagging rates with proportionately more fish early and late in the run, and fewer during run peaks. The break in tagging due to high water temperatures in late July created the most significant undersampling, and low proportions of tagged A-group steelhead persisted through the early peak counts at all dams. At Lower Granite Dam, 0.32% of the steelhead counted at the project were radio-tagged, and the undersampling was mostly of fish passing the dam from late August to mid-September (Figure 8).

In 1996, 645 (84%) steelhead outfitted with transmitters had adipose, ventral or a combination of fin clips and 125 (16%) had no clips; 12% of A-group fish and 36% of B-group fish had no clips. Juvenile hatchery steelhead of the year classes returning as adults in 1996 should all have been adipose-clipped when released from Washington and Oregon; fish with coded-wire tags for specific projects had additional fin clips. Idaho fisheries personnel clipped fins on all juvenile steelhead released for the year classes returning as adults in 1996, with ventral clips for hatchery fish used to

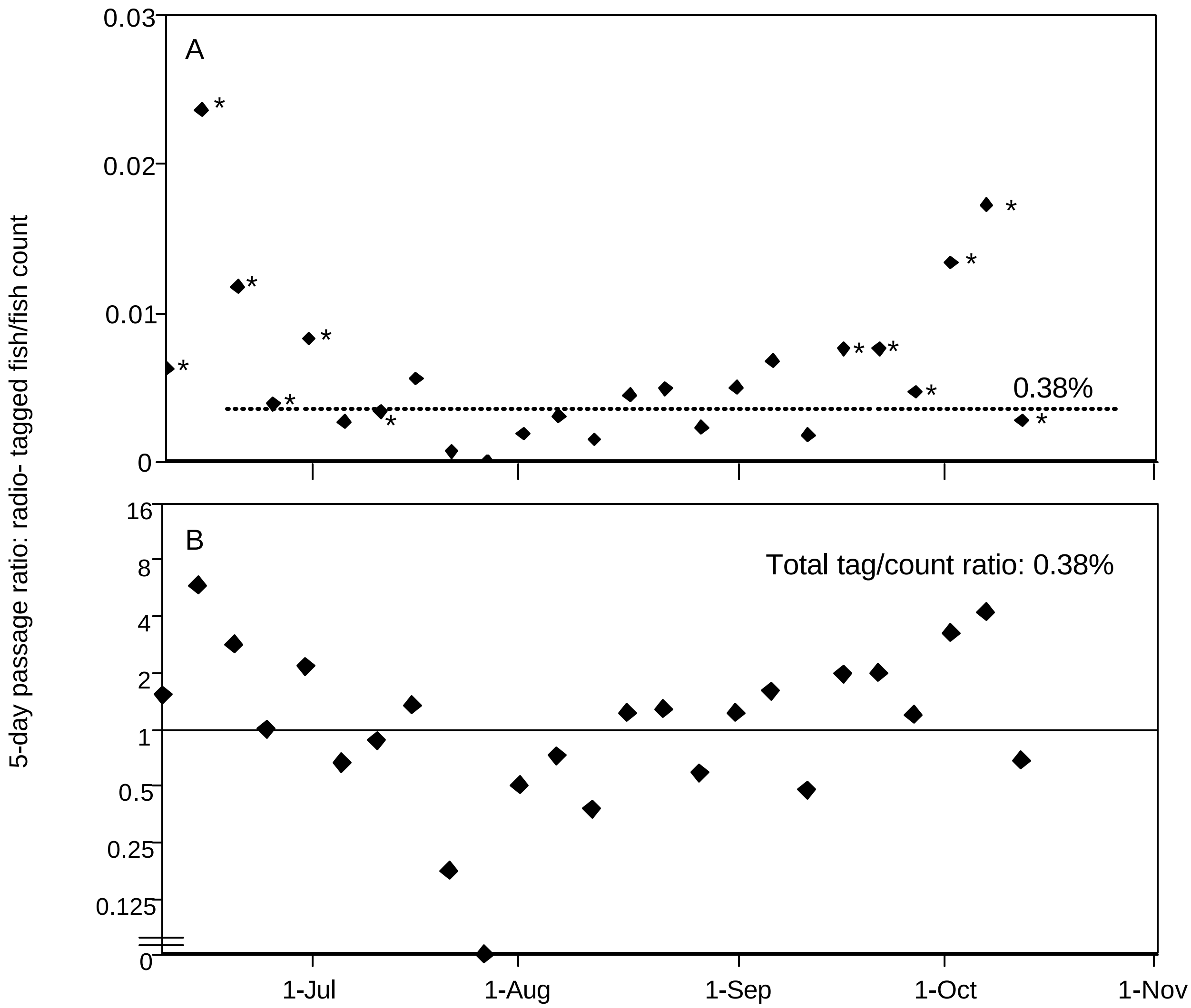


Figure 7. (A) Proportion of radio-tagged steelhead that passed Bonneville Dam to the total counts at the dam during 5-d blocks in 1996. Blocks that include less than 2.5% of the total run noted with an asterisk. (B) Standardized proportions of the total counts steelhead that passed Lower Granite Dam during 5-d blocks that were radio-tagged in 1996. Log (~base 2) scale used to show relative distance from the overall sampling rate.

supplement wild stocks and adipose clips for production fish. Adult steelhead outfitted with transmitters in 1996 were classified as 36.3% female and 63.7% male. Fork lengths of fish outfitted with transmitters ranged from 51.0 to 97.0 cm with a median length of 67 cm. Median fork lengths were 62.5 cm for A-group and 77.5 cm for B-group steelhead (Figure 9); median lengths were 66.0 cm for steelhead with fin clips and 71.0 cm for unclipped fish. Fish weights were not collected.

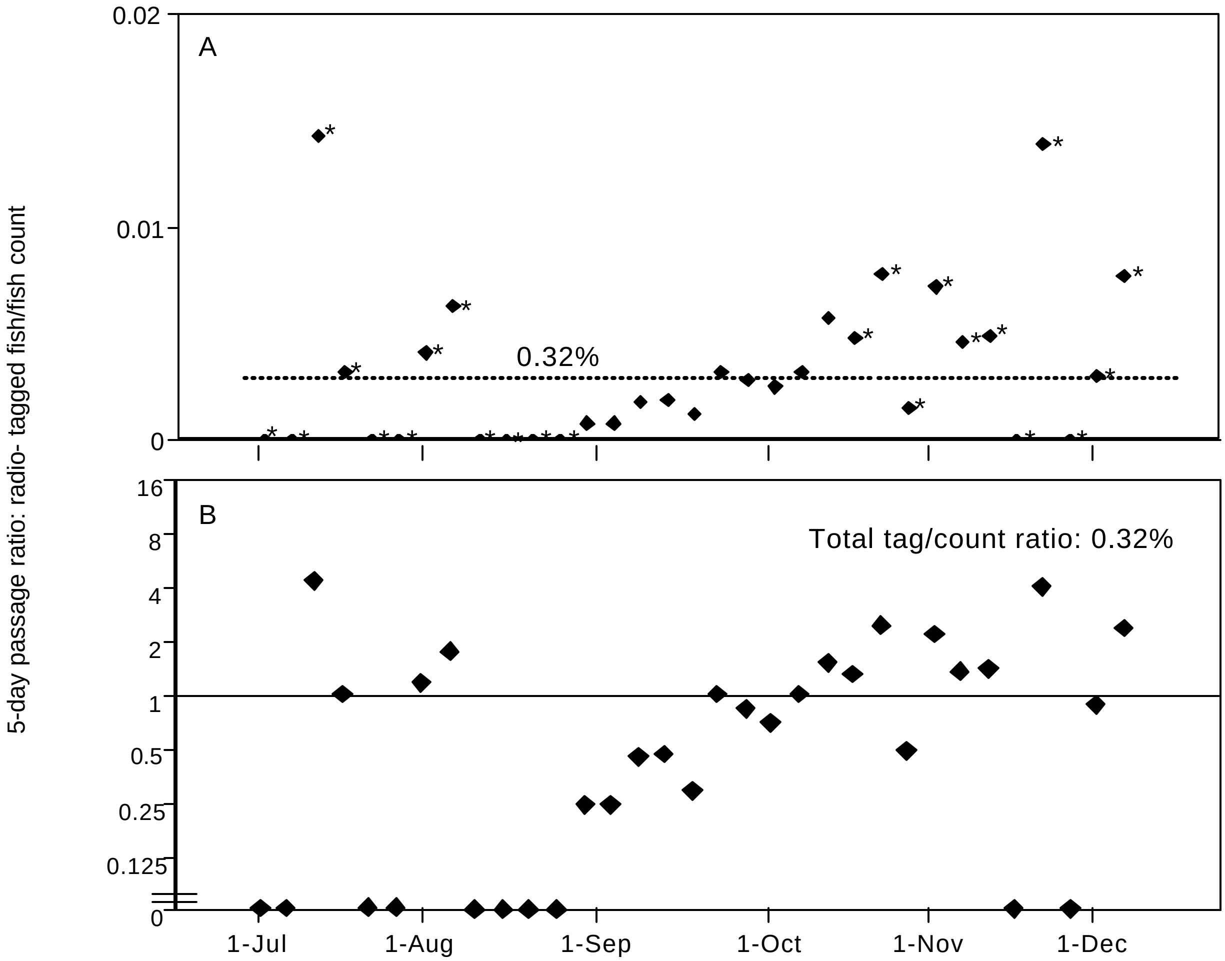


Figure 8. (A) Proportion of radio-tagged steelhead that passed Lower Granite Dam to the total counts at the dam during 5-d blocks in 1996. Blocks that include less than 2.5% of the total run noted with an asterisk. (B) Standardized proportions of the total counts steelhead that passed Lower Granite Dam during 5-d blocks that were radio-tagged in 1996. Log (~base 2) scale used to show relative distance from total sampling rate.

Forty-seven percent of the 770 steelhead tagged had no descaling, 48% were less than 10% descaled, 4% were 10-25% descaled, and < 1% were more than 25% descaled. Twelve percent had no marks from marine mammals, 63% had fresh scrapes, and 25% had fresh bite injuries. For head and mouth injuries, 91% of the steelhead had none, 3% had scrapes, cuts, or skinned areas, about 4% had sores or hook marks, < 1% had eye injuries or fungal infections, and about 3% had some head or jaw deformity. Less than 1% of the fish had what we thought were gillnet marks.

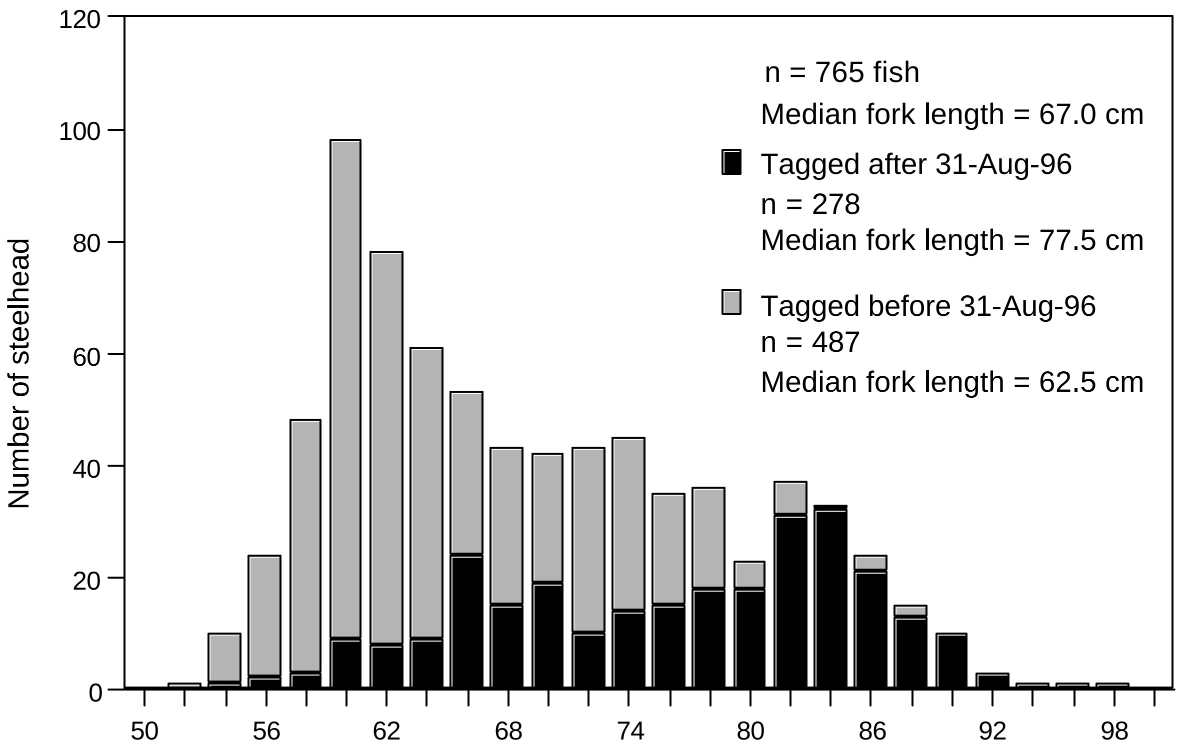


Figure 9. Length frequency distribution of A-group and B-group steelhead outfitted with transmitters at the Bonneville Dam adult trap in 1996.

Monitoring Fish Movements

We monitored steelhead with transmitters using fixed-site radio receivers at each dam and at the mouths of major tributaries, and by mobile trackers in areas not covered by fixed-site antennas. Additional information was collected at upriver dams, traps and weirs and from fishers that returned transmitters. In addition, because of the concern that fish from the Washington-shore ladder might not be representative of the total run passing the dam, we tracked a small number of steelhead with transmitters by boat as they migrated from the release sites back up to the dam to evaluate if they mostly returned to pass the dam via the same ladder or if location of passage was closer to random.

We used SRX receivers with Yagi antennas to determine when fish first entered the tailrace area of a dam. Digital spectrum processors (DSP) added to SRX receivers could simultaneously monitor several frequencies and antennas; DSPs were particularly helpful in monitoring movements of adults into and through fishways at the dams. SRX/DSP receivers were connected to underwater antennae made of coaxial cable and were positioned near all fishway entrances, exits, and inside fishways at dams where fish were monitored intensively.

We also installed SRX receivers connected to Yagi antennas near the mouths of most major tributaries to the Columbia River, from the Cowlitz River 225 km downstream from Bonneville Dam to Priest Rapids Dam and at the mouth of the Clearwater River and on the Snake River upstream from the confluence with the Clearwater River (Figure 1). For more details on receiver and antenna installation and the evolution of monitoring techniques for the adult passage project, see Bjornn et al. (2000a).

Three trucks were outfitted with 4-element Yagi antennas and SRX receivers to track fish in areas not covered by fixed-site receivers. Two boats were similarly outfitted to facilitate mobile tracking in reservoirs, as well as the free-flowing section of the Columbia River between Pasco and Priest Rapids Dam. In 1996, sections of the lower Columbia River were mobile-tracked approximately once each week during most of the steelhead migration by ICFWRU personnel or the National Marine Fisheries Service. Segments of the Wind, White Salmon, Little White Salmon, Deschutes and Klickitat rivers were also mobile-tracked occasionally, as were small segments of tributaries downriver from Bonneville Dam. The Washington Department of Fish and Wildlife (WDFW) mobile-tracked the Tucannon River during the migration and also tracked segments of the lower Snake River. ICFWRU personnel tracked the Clearwater, Salmon and Upper Snake rivers periodically during late fall 1996 and early winter 1997.

Data Collection and Processing

Members of the study team downloaded data from receivers into portable computers periodically, with the frequency depending on the number of fish passing a site. Some sites were downloaded daily during the peak of the run, and some every two weeks. Each night files of downloaded data were transmitted to a computer at the NMFS lab in Seattle and added to databases. Records consisted of transmitter frequency (channel), code, date, time, power of signal received, and site. We created databases for all the records of each fish at each dam and each species. After each day of tagging, a member of the tagging crew transmitted a file with records of fish tagged that day to the Seattle computer. During the initial screening process all records were evaluated and good records were added to the databases and bad records were placed in a bad-record table. Bad records were those with channels and codes for fish that had not been released. As the season progressed, files of data for each dam were sent to the University of Idaho for coding by study team members.

Coding of the records consisted of going through all the records for a fish at a dam and assigning codes to identify fish activity. For example, the first record of a fish at the tailrace site downstream from a dam was coded as an ‘F1’, and the last record at the tailrace site was coded as an ‘L1’. Similarly each approach and entry into the fishways was coded as were exits back into the tailrace and exits from the top of ladders. When all fish had been coded for a dam, coded records were returned to Seattle and added to the databases. A semi-automated software program was developed to assist in the coding. The program incorporated a decision tree a coder would use to code records manually and facilitated the coding process, but was not a substitute for evaluation of fish behavior by an experienced coder.

When all fish had been coded at each dam, all coded records for each steelhead were combined into a file that also contained records from tributary receivers, records of fish found by mobile trackers, and records of fish that were recaptured at weirs, hatcheries or in fisheries. Records in the file that had not been previously coded were then coded to create the 'general migration' file, the file that contains most of the data presented in this report.

Statistical Methods

Our sampling effort was restricted in space and time due to the location of the trapping facility, the trapping schedule (daytime only with approximately 10 d of sampling and 4 d no sampling every two weeks), and interruption of the schedule by high water temperatures in August. From mid-June to early October, we unselectively outfitted steelhead with transmitters, but sampling rates varied (see Figures 7 and 8) due to fluctuations in the run. We believe our sample behaved like a random sample, although it was not random in a strict statistical sense. We used stratified sampling methods to address sampling variability and variability over time (i.e. in calculations of fallback rates and escapement estimates), but we did not have replicate releases to better validate such estimates. (See tagging methods for additional comments on tagging effort and limitations).

Analyses were performed to relate passage times and migration rates to existing river conditions of flow, spill, temperature and water clarity (Secchi disk readings). Most environmental conditions varied continuously at monitored dams during the study period and several were correlated through time and thus were not independent random variables (i.e. total flow and spill). We used reported daily mean values of environmental variables for analyses, but conditions encountered by individual fish likely differed from means and some fish likely encountered a range of conditions at a given dam.

As with all Columbia River adult salmonid runs, behavior (e.g. fallback, fishway use), stock composition (e.g. proportion of Snake River fish), and response to river environment (e.g. slowed migration during high river temperatures) by the 1996 steelhead run varied continuously through time. As a result, any grouping of fish violated some assumptions about independence. To address variation through the migration and simplify interpretation, however, we grouped fish using several methods. Grouping into A- and B-components was provided for managers using the established separation of the two runs in late August at Bonneville Dam (USACE 1996). The separation may not reflect biologically significant differences between fish, particularly those that passed close to the separation date, but there are recognized differences in final distribution of the two groups. Grouping fish based on the tagging schedule or month of passage was also used to evaluate the continuum of changes through the migration and to compare early and late portions within the A- and B-groups. We also aggregated all data for the run-year for comparison to other years and species.

Because steelhead passage times tended to be right-skewed, we used nonparametric Wilcoxon scores and Kruskal-Wallis chi-squared (K-W X^2) tests (PROC NPAR1WAY, SAS Institutes Inc., 2001) for comparisons of steelhead migrating during different time periods (e.g. A- versus B-group steelhead). If distributions were near normal we used parametric tests in addition to nonparametric tests. We used standard Z tests, chi-squared (X^2) tests of independence or X^2 goodness-of-fit tests for comparisons of proportional data (e.g. to compare survival for fallback versus non-fallback fish). All tests were two-tailed unless otherwise noted.

We initially used graphical methods for exploring univariate regression data to identify linear and non-linear trends, using loess and other data smoothing techniques. We examined residuals from univariate models for outlying data points and for non- normality of residuals; non-normal errors were relatively common due to covariance and autocorrelation in environmental variables. Prior to building multiple regression models, we created scatterplot matrices of independent variables and identified outlying data groupings using SAS/INSIGHT. We chose forward stepwise regression to identify the most influential variables affecting passage times past projects and through reservoirs, and also compared groups of models using subsets of independent variables (PROC REG, SAS Institutes Inc., 2001). We chose a P cutoff value of 0.10 for inclusion of variables to multiple regression models because univariate correlations were relatively low in many cases. Because steelhead behavior was highly variable and the resolution and selection of independent variables were limited, our objectives in model building were to identify general trends and influential variables rather than to produce fully predictive models. The study was not designed to experimentally test hypotheses related to in-river conditions (i.e. using discreet spill or flow patterns).

Evaluation of the use of Steelhead Trapped at Bonneville Dam

Introduction

There was a concern that adult salmon and steelhead trapped in the Adult Fish Facility as they migrated up the Washington-shore fishway might not be representative of the runs or may not behave the same as naive fish. For example, if disproportionate numbers of fish that used the Washington-shore ladder were destined for Washington- shore tributaries (Wind, Little White Salmon, White Salmon, and Klickitat rivers) there would be an under-representation of fish destined for south-shore tributaries (Hood, Deschutes, John Day, and Umatilla rivers) and of fish destined for the mid-Columbia and Snake rivers. To evaluate that concern, we monitored the migration paths of adult A-group steelhead with transmitters as they returned back to Bonneville Dam from the release sites about 9.5 km downstream from the dam, and the approaches, entries, and ladders used to pass the dam. We also evaluated Bonneville Dam ladder preference for steelhead that returned to different lower Columbia River and Snake River tributaries. The goals of the study were to determine routes used by chinook salmon and steelhead as they migrated in the river, if fish trapped from the Washington-shore fishway returned in disproportionate numbers to that fishway, and if fish passing the Washington-shore ladder returned to lower Columbia River tributaries in disproportionate numbers. (See Bjornn et al. 2000a for summary of chinook salmon monitoring downstream from Bonneville Dam.).

Methods

From 17 June to 9 October 1996, we released 765 steelhead with transmitters, equally divided between the north-shore (Skamania Landing, WA) and south-shore (Dodson, OR) release sites (Figure 10). We tracked 31steelhead after release as they migrated upstream using a boat outfitted with a radio receiver and aerial antenna. Fish were located by moving the boat short distances up and downstream in the vicinity of fish, and by rotating the antenna until the power of the signal from a transmitter was maximum. Fish locations and times were noted on maps of the stretch of river downstream from Bonneville Dam (Figure 10). Typically, several fish were monitored each day by repeatedly locating fish as they progressed in their migration back to Bonneville Dam. This monitoring of steelhead was limited to about 10 d in late June and several days in September due to high water and time restrictions; our downstream tracking of chinook salmon was more extensive (Bjornn et al. 2000a).

Radio receivers connected to aerial antennas, one on each shore, were used to determine when steelhead with transmitters entered the tailrace of Bonneville Dam (Figure 10). The south-shore antenna was located 1.1 km downstream from powerhouse 1 and the north-shore antenna was 3.2 km downstream from powerhouse 2. Underwater coaxial cable antennas were used to monitor when and where steelhead approached and entered fishway entrances at powerhouse 1, the spillway, and powerhouse 2. A receiver and aerial antenna was also used to monitor fish that entered the tailrace portion of the navigation lock channel.

Results

Of the 765 adult steelhead outfitted with transmitters and released downstream from Bonneville Dam, 27 were tracked as they returned to Bonneville Dam. Complete paths from release until fish entered restricted areas at Bonneville Dam were observed for 23 of the 27 fish tracked. Of the 27 steelhead tracked, 11 (41%) were released on the north shore and 16 were released on the south shore. Eight steelhead moved from release to Bonneville Dam along the same shoreline released, three along the north shore and five along the south shore (Figure 11). The remaining 19 steelhead crossed the river one or more times between release sites and the dam (Figure 12). Of those 19 steelhead, 10 crossed the river once, six crossed the river twice and three steelhead crossed the river three times for a total of 31 crossings. Direction of channel crossings were evenly divided between north-to-south crossings (15) and south-to-north crossings (16). Areas where steelhead crossed the river included near the release sites, the main river channel from the east end of Pierce Island up to about the middle of Hamilton Island, and in the vicinity of the new navigation lock and Robins Island (Figure 13). Transmitter signals were lost or became weak when the steelhead crossed the river (with exceptions noted above), which is an indication that the fish moved deeper, possibly following the river bottom, when crossing the channel.

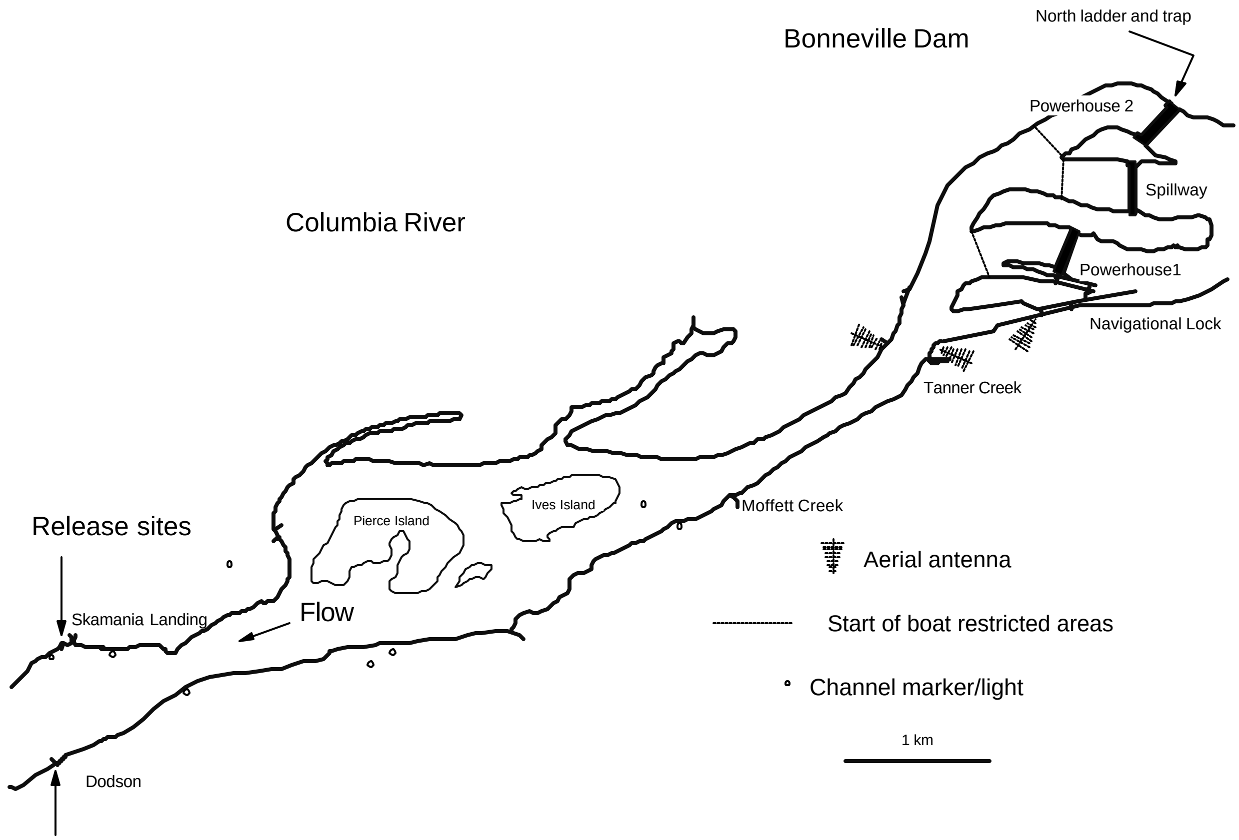


Figure 10. Columbia River downstream from Bonneville Dam where radio-tagged steelhead were tracked in 1996, showing location of north- and south-shore release sites and tailrace receivers. Restricted areas near Bonneville Dam, where steelhead could not be tracked by boat, are delineated with dashed lines.

In general, other then when crossing the river channel, the steelhead tended to migrate upstream close to shorelines, but there were exceptions. We observed what might be described as erratic or random movement events by some steelhead. On eight occasions steelhead moved from a shoreline to a mid-channel position and then either moved upstream or downstream for some distance before returning to a shoreline. One steelhead moved over a flooded section of Pierce Island while crossing from the south to the north shores.

Twelve (44%) of the tracked steelhead first approached a fishway entrance at Powerhouse 2, 3 (11%) at the spillway, 11 (41%) at Powerhouse 1, and one steelhead passed through the navigation lock without first approaching a fishway entrance. Passage times for 25 of the radio-tagged steelhead from release until their first record at the tailrace receiver sites were a median of 6.8 h and mean of 14.2 h (± 7.8 h). Passage times from release until first approach at the dam for 25 steelhead were a median and mean of 19.5 h and 21.2 h (± 7.7 h). Eighteen (67%) steelhead eventually crossed the dam using the Washington-shore fishway, eight (30%) used the Bradford Island fishway and one steelhead passed through the navigation lock. Sixteen (59%) of

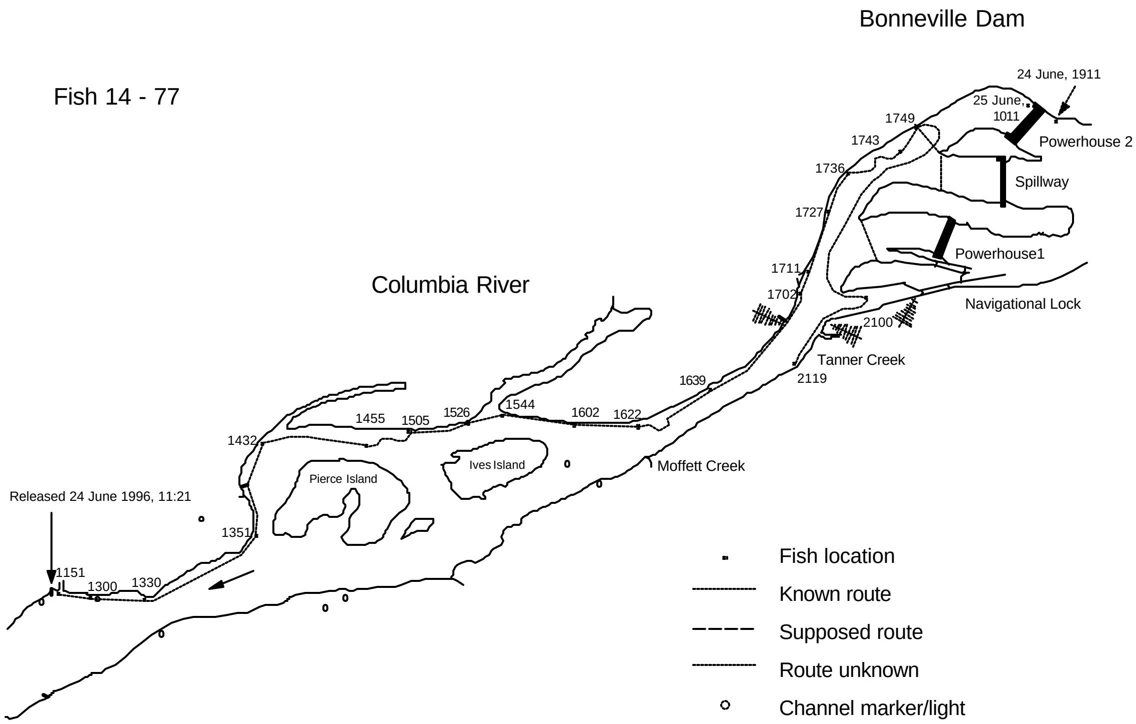


Figure 11. Example of a steelhead with a transmitters that migrated from release sites on the north shore to Bonneville Dam without crossing the river. Times are shown to the side of fish locations. Fish is identified by channel and code of their transmitter.

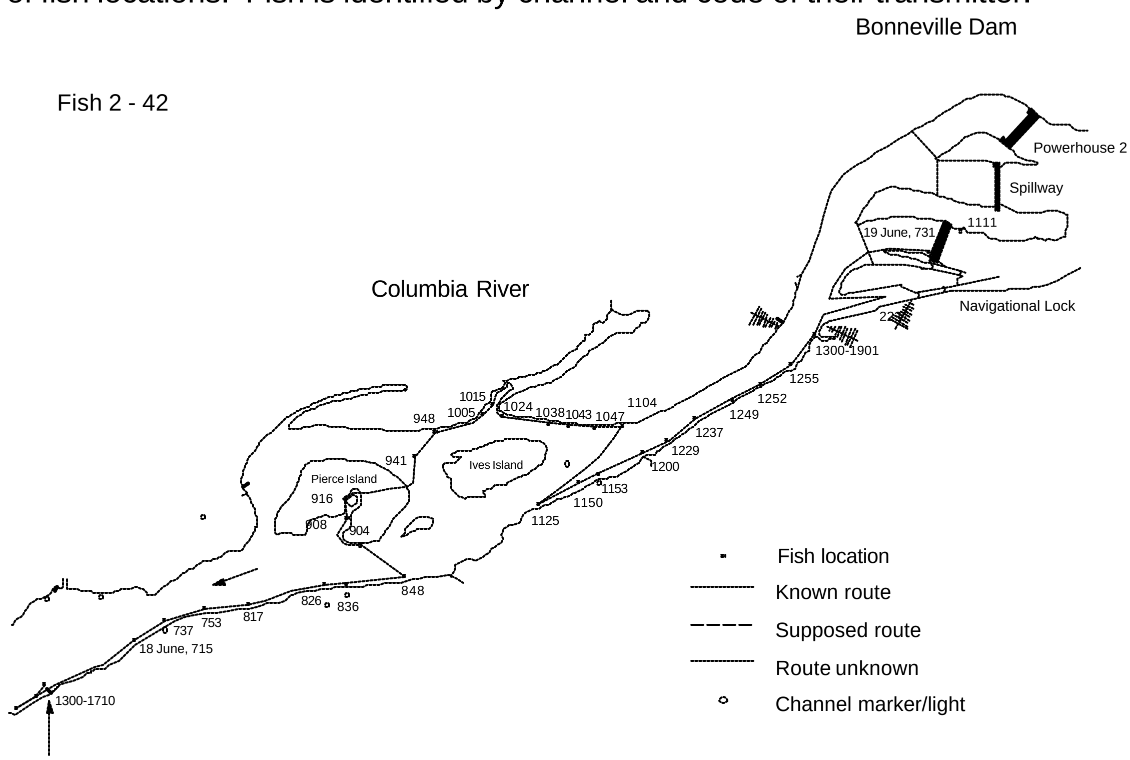


Figure 12. Examples of steelhead with transmitters that crossed the river once between release and Bonneville Dam. Times are shown to the side of fish locations. Fish are identified by channel and code of their transmitter.

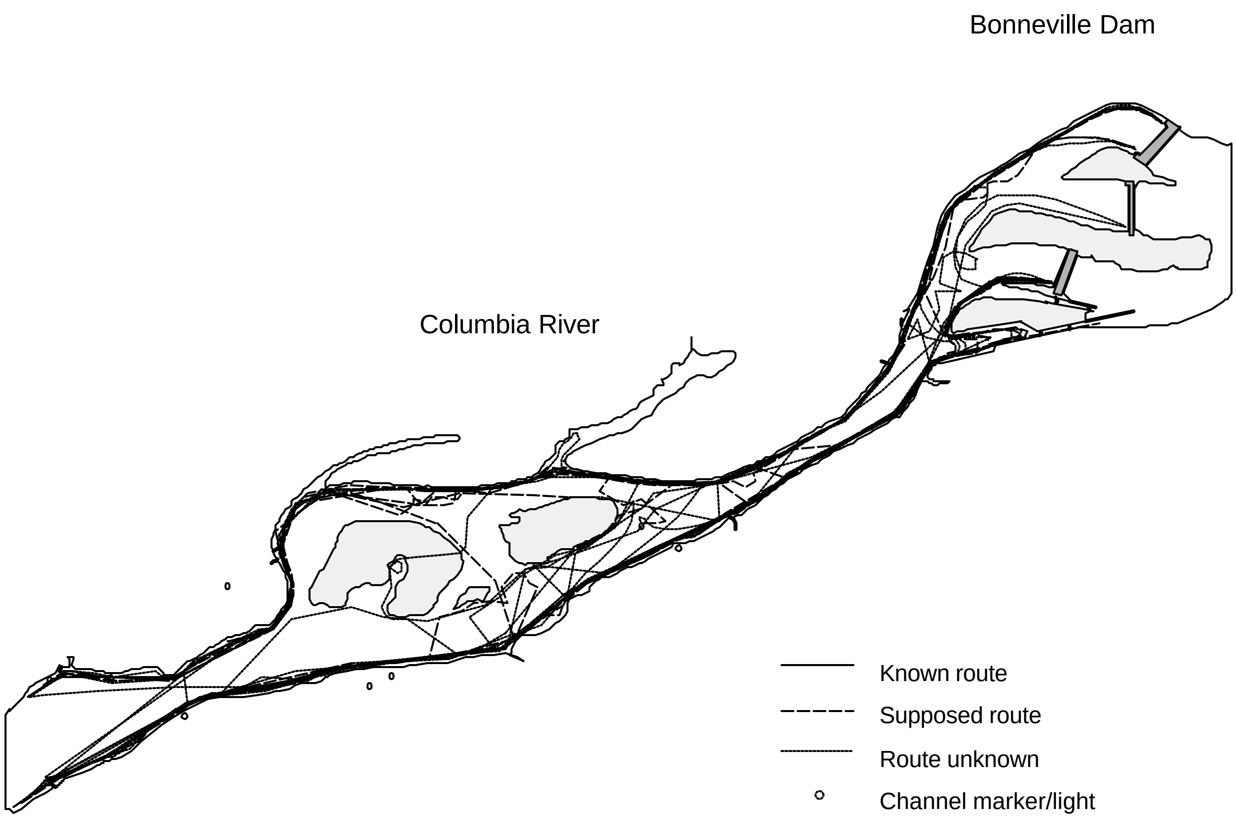


Figure 13. Composite of routes taken by radio-tagged steelhead tracked in the Columbia River downstream from Bonneville Dam in spring 1996.

the 27 steelhead we tracked were recorded in the tailrace portion of the navigational lock channel at least once while at Bonneville Dam.

For all steelhead tagged (765), 49% were released on the north shore, 51% on the south shore. Median and mean travel times from release until first reaching the tailrace receiver sites were 7.4 and 25.5 h (± 7.9 h, n = 680). Steelhead with transmitters traveled from release until their first approach at the dam in a median of 20.6 h and mean of 33.6 h (± 8.8 h) and ranged from 2.9 h to 85.3 d. Migration times were clumped at 24 h intervals following release. River flow and water temperature on day of release were the two variables significantly related to steelhead times to reach the tailrace and to approach the dam (Table 2). Flow was more important than temperature, however the two variables combined accounted for less than 29% of variation in steelhead migration times in the two analyses. Regression analysis was not completed for steelhead we tracked because of low sample size.

More than 80% of fish from both release sites were first recorded at the south-shore tailrace antenna (Table 3). About 53% of all steelhead with transmitters first approached Bonneville Dam at powerhouse one, 35% first approached at powerhouse two and 12% first approached at entrances adjacent to the spillway; proportions were similar for fish from both release sites (P = 0.62, X^2 test). Forty-four percent of all radio-

Table 3. Number of steelhead with transmitters released downstream from Bonneville Dam by location, percentage that were first recorded at south- and north- shore tailrace receivers and percentage recorded passing the Bradford Island and Washington-shore ladders in 1996. Total ladder counts provided for comparison.

	Number released	First tailrace (%) south	First tailrace (%) north	First approach (%) PH1	First approach (%) PH2	First approach (%) spill	Ladder passed (%) Bradford	Ladder passed (%) WA-shore
Steelhead with transmitters								
All	765 (100%)	81.2	18.8	53.0	34.6	12.4	53.4	46.6
Dodson	388 (50.7%)	80.5	19.5	52.9	35.9	11.2	49.2	50.8
Skamania	377 (49.3%)	81.9	18.1	53.1	33.2	13.6	57.1	42.9
Total steelhead counts in ladders								
All steelhead 24 March to 31 October							43.5	56.5
All steelhead 15 June to 15 October[1]							43.1	56.9
All wild steelhead							39.3	60.7

[1] time period that radio-tagged fish were passing Bonneville Dam

tagged steelhead first entered fishways at powerhouse one, 37% first entered at powerhouse two, and 18% first entered ladders adjacent to the spillway; proportions were similar for both release sites (P = 0.21, X^2 test) (see Keefer et al. 2002a for details on fishway use by steelhead). About 43% of radio-tagged steelhead known to pass Bonneville Dam in 1996 were recorded in the tailrace portion of the navigation lock at least once.

For steelhead that eventually passed Bonneville Dam via ladders, 46.6% used the WA-shore ladder and 53.4% used the Bradford Island ladder (Table 3). About 49% of the fish released at Dodson landing and 57% of those released at Skamania landing passed the dam via the Bradford Island ladder, a difference between release sites that was significant (P = 0.04, X^2 test). We also compared total ladder passage by fish with transmitters to passage proportions for all steelhead counted at the dam based on daily ladder passage reports (USACE 2000, Technical Management Team electronic database). During the time that radio-tagged fish were passing the dam (15 June to 15 October), 43.1% of counted steelhead and 53.4% of radio-tagged steelhead passed via the Bradford Island ladder (Table 3).

Radio-tagged fish passed via the Bradford Island ladder at significantly higher than expected rates (P < 0.0001, X^2 goodness-of-fit test). Fish released at Dodson landing passed Bradford Island ladder at higher than expected rates (P = 0.03), as did fish released at Skamania landing (P < 0.0001, X^2 goodness-of-fit test).

Although not always significantly higher, the proportion of radio-tagged steelhead passing via the Bradford Island ladder was higher than the proportion of fish counted passing the ladder during most of the migration (Figure 14). Proportions were more

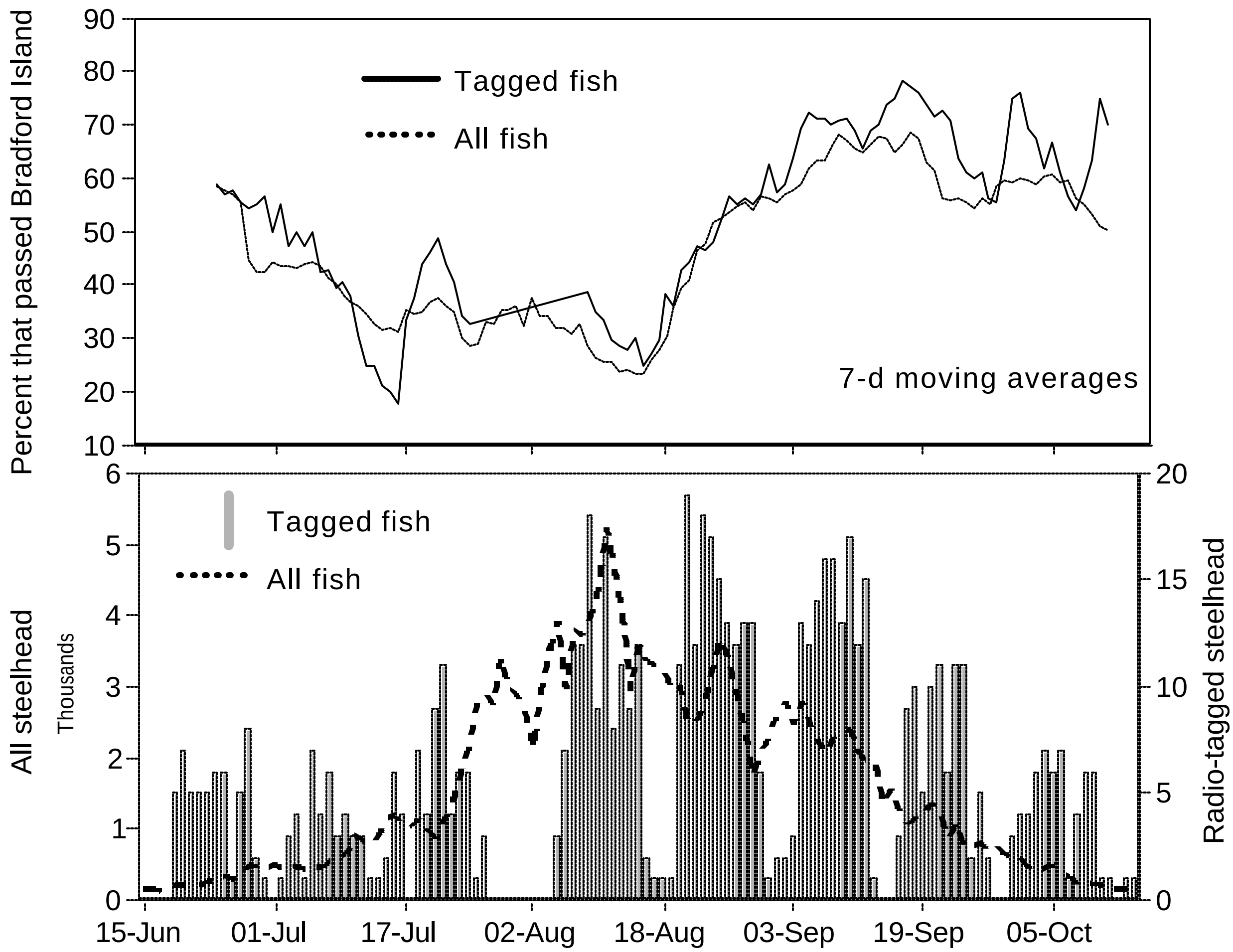


Figure 14. Proportion of radio-tagged steelhead and of all steelhead that passed Bonneville Dam via the Bradford Island ladder in 1996, based on 7-d moving averages (top). Number of radio-tagged steelhead and all steelhead counted passing Bonneville Dam via ladders in 1996 (bottom).

variable for radio-tagged fish early and late in the migration when relatively few tagged fish passed the dam. We separately tested proportions passing during each month, and found radio-tagged fish passed the Bradford Island ladder at significantly higher than expected proportions in August and September ($P < 0.03$, X^2 goodness-of-fit test), but not in June ($P = 0.22$), July ($P = 0.98$), or October ($P = 0.09$) (Table 4).

Ladder preference at Bonneville Dam by radio-tagged steelhead suggests that use of non-naive fish may have influenced fish behavior at the dam. However, we found little evidence that ladder preference affected upstream passage or final distribution of steelhead with transmitters. For example, similar proportions of radio-tagged fish passed upstream dams as untagged fish, based on ladder counts adjusted for fallback and reascension (Figure 15). Differences between tagged and untagged proportions passing dams were less than 3.3% at McNary, Ice Harbor, Lower Granite, and Priest

Table 4. Number and percentage of all steelhead and steelhead with transmitters that passed the Bradford Island ladder at Bonneville Dam during each month that radio-tagged fish were passed in 1996. For returns to specific tributaries, proportions that passed via the Bradford Island ladder were compared to expected proportions based on total counts using X^2 goodness-of-fit tests.

	Jun to Oct	Jun	Jul	Aug	Sep	Oct
Number that passed Bradford Island ladder						
All fish	**81,072**	**3,882**	**12,803**	**31,572**	**29,628**	**3,187**
All tagged fish	378	32	37	117	155	37
Bonneville pool tribs[1]	20	4	2	7	7	0
All lower Columbia tribs	71	9	10	24	22	6
Deschutes	34	3	5	16	8	2
John Day	12	1	2	1	5	3
Passed L. Granite Dam	140	3	4	39	76	18
Clearwater	42	1	1	3	33	4
Salmon	43	0	1	17	22	3
Percent that passed Bradford Island ladder						
All fish	**43.1**	**59.0**	**35.8**	**34.7**	**62.3**	**54.8**
All tagged fish	**53.2	57.1	35.9	**42.9	*69.5	66.1
Bonneville pool tribs[1]	51.3	50.0	50.0	38.9	77.8	n/a
All lower Columbia tribs	49.0	64.3	38.5	38.1	66.7	66.7
Deschutes	43.6	100.0	29.4	41.0	53.3	50.0
John Day	†63.2	100.0	50.0	33.3	71.4	75.0
Passed L. Granite Dam	**56.0	60.0	36.4	38.2	*73.1	64.3
Clearwater	**65.6	50.0	50.0	50.0	71.7	50.0
Salmon	**62.3	n/a	50.0	47.2	*84.6	60.0

[1] only includes north-shore tributaries: Wind, Little White Salmon, White Salmon, Klickitat

† $P < 0.10$; * $P < 0.05$; ** $P < 0.005$, X^2 goodness-of-fit test

Rapids dams, and were likely closer than indicated because some fish that regurgitated transmitters probably passed upstream dams undetected.

We also tested whether fish last recorded in specific tributaries passed the Bradford Island ladder in different than expected proportions. We derived expected proportions from counts of all fish counted passing the Bradford Island ladder each month. Proportions ranged from 34.7% in August to 62.3% in September. The shift in ladder preference from August to September may have been related to cessation of spill on 1 September, or to the transition from A- to B-group steelhead (Table 4). As stated previously, radio-tagged fish passed via Bradford Island at higher than expected rates in August and September, and for all months combined. Fish with transmitters did not return to north-shore Bonneville pool tributaries, the Deschutes River, the John Day River or all lower Columbia River tributaries in aggregate at different than expected

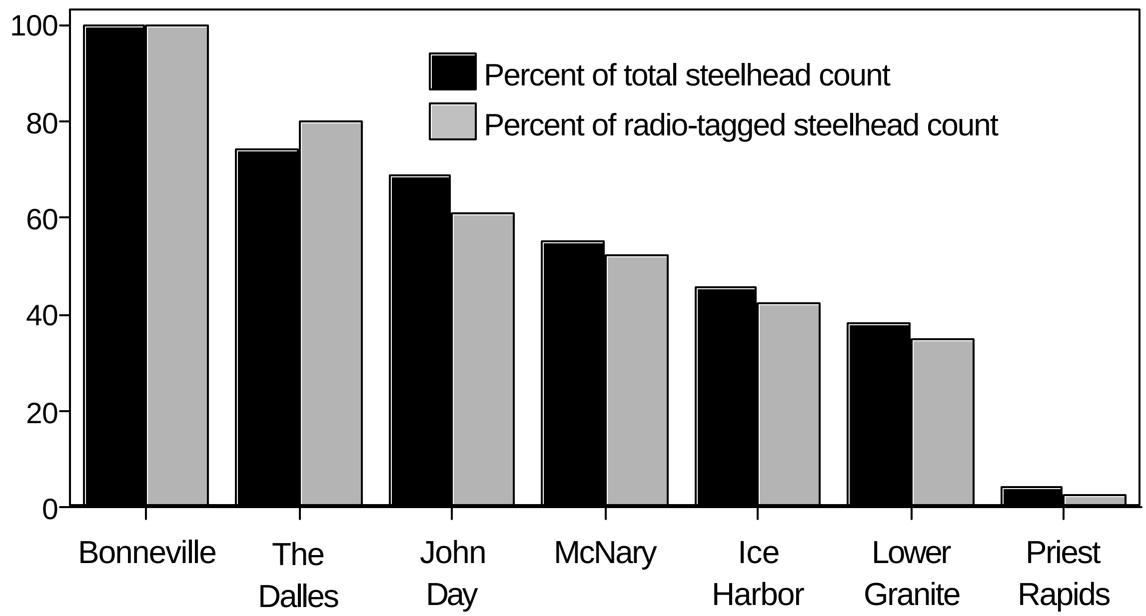


Figure 15. Percent of all steelhead counted at Bonneville Dam and radio-tagged steelhead recorded passing Bonneville Dam that were recorded at Columbia and Snake River dams in 1996. All counts adjusted for fallback and reascension behavior.

rates in any month ($P > 0.10$, X^2 goodness-of-fit tests) (Table 4). When all months were combined, the 12 radio-tagged fish that returned to the John Day River passed the Bradford Island ladder at slightly higher than expected rates ($P = 0.08$). Radio-tagged steelhead that passed Lower Granite Dam, and those last recorded in the Clearwater and Salmon rivers passed the Bradford Island ladder at higher than expected rates for all months combined ($P < 0.005$) (Table 4). Among individual months, all fish that passed Lower Granite Dam and those that returned to the Salmon River passed Bradford Island ladder at higher than expected rates ($P < 0.05$) in September, but not in any other months.

Passage, Migration History, and Final Distribution of Steelhead

Methods

In this report of the general migration of adult steelhead, we classified passage at a dam as successful for any radio-tagged fish recorded at top-of-ladder receivers or at sites upriver from a dam, regardless of whether they subsequently fell back over a dam or their final destination was downriver from a dam. Times to pass a dam in this report were calculated from tailrace receiver sites (0.5 to 3.2 km down river from each dam) to a fish's exit from the top of a ladder. Times were calculated from the first record on the first trip past the tailrace receiver to the last record at the top of a ladder for fish that were recorded at both sites. For steelhead tagged in 1996, more specific aspects of passage at individual dams, such as time to approach a dam and enter fishways, fishway entrances used, movements within fishways, and behavior in and passage time through transition pools were reported in Keefer et al. 2002a.

The percentage of adult steelhead with transmitters that passed each dam successfully was calculated from the number released and the number known to have passed each dam. The number known to have passed a dam was determined primarily from records of fish passing receivers at the tops of ladders, but also included fish recorded at sites upriver from a dam because receivers at the tops of ladders were efficient, but not 100% efficient, and some fish may have passed dams via navigation locks. Fish that were not recorded at the top of a ladder, but were recorded at another site further upriver, were treated as successfully passing the dam; they were not included in passage-time analyses for the missed dam.

Passage at Dams

We estimated that 66 of 770 steelhead (8.6%) outfitted with transmitters regurgitated their transmitters before reaching spawning areas or hatcheries. Five steelhead regurgitated transmitters in the transport tank prior to being released. Of the 765 released with transmitters, we believe 26 steelhead regurgitated transmitters at or near the release sites downriver from Bonneville Dam, and an additional 35 fish regurgitated transmitters after being recorded at one or more fixed receivers at dam or tributary sites (Table 5). Twenty-one of the 61 fish that regurgitated transmitters after release were recaptured later and identified as fish that had transmitters by the secondary tag, or their transmitters were recovered near the release sites, in reservoirs, or in tributaries. We located other presumably regurgitated transmitters by repeated mobile-track records in one location prior to spawning and usually downstream from spawning areas, or located them in 1997 following long periods with no evidence that fish entered tributaries. Some transmitters found in this manner may have been from fish that died. Overall, 21 (34%) were known to have regurgitated and 40 (66%) were presumed to have regurgitated transmitters based on circumstances associated with the transmitter.

We included steelhead that regurgitated transmitters in analyses where their telemetry records were valid, i.e. fish that regurgitated transmitters after passing Bonneville Dam were included in passage time calculations at Bonneville Dam. We also included fish that regurgitated transmitters in certain analyses and summaries that were later recovered upstream and identified by the secondary tag (i.e. fish was recaptured at the Lower Granite adult trap). Wherever appropriate we distinguished between fish recorded passing receivers, those known to have passed receivers but were not recorded while they retained transmitters, and those that we know passed after regurgitating transmitters.

To aid in transmitter retention by fish, we placed one rubber band on even-numbered transmitters and two rubber bands on odd-numbered transmitters. Twenty of the 66 (30%) regurgitated transmitters were from fish with odd-numbered tags, a significantly lower than expected rate ($P = 0.002$, X^2 goodness-of-fit test), indicating transmitters with two rubber bands were retained at higher rates.

Table 5. Summary of 66 steelhead outfitted with transmitters in 1996 that were believed to have regurgitated their transmitters, by category based on circumstances associated with the transmitter.

Number	Description
770 steelhead outfitted with transmitters	
5	regurgitated transmitters in transport tank
765 steelhead released with transmitters	
26	regurgitated transmitters at or near release site, no records at other sites
6	transmitters found near release site
6	fish not recorded anywhere after release
9	fish with mobile track records only at or near release site
3	recaptured at Lower Granite adult trap without transmitters
1	recaptured in Deschutes River without transmitter
1	recaptured at unreported location, probably near release site
35	regurgitated transmitter after passing one or more fixed receiver sites
6	recaptured at Lower Granite adult trap
3	had telemetry records only at Bonneville Dam
1	had last telemetry records at The Dalles Dam
1	had last telemetry records at McNary Dam
1	had last telemetry records at John Day Dam
3	transmitters found
1	downstream from Bonneville Dam
2	in Deschutes River
1	regurgitated in fishway at Bonneville Dam
25	repeatedly mobile-tracked/recorded at same location in 1996 or 1997[1]
7	in or near Bonneville tailrace
2	in Bonneville pool
1	in or near The Dalles tailrace
3	in or near John Day tailrace
3	in or near McNary tailrace
4	in or at mouth of Deschutes River
3	near mouth of Wind River
2	near mouth of White Salmon River

[1] transmitters located in 1997 were located prior to spawning season

Of the 739 steelhead we believed retained transmitters beyond the release site, 701 (94.9%) were recorded on their first passage of the Bonneville tailrace and 737 (99.7%) were known to pass the tailrace with transmitters in place (Table 6). Of the 739, 713 (96.5%) were recorded passing top-of-ladder or top-of-navigation lock receivers, and 720 (97.4%) were known to pass the dam with transmitters in place. At least 580 (78%) of the 739 steelhead that retained transmitters after release were known to have passed The Dalles Dam, 457 (62%) passed John Day, 394 (53%) passed McNary, 319 (43%) passed

Table 6. Number of adult steelhead released downriver from Bonneville Dam, number that regurgitated transmitters, number and percentage of 739 fish that retained transmitters that were recorded on tailrace and ladder receivers during first passage at each dam, and number and percentage of fish known to have passed tailrace and top-of-ladder receivers in 1996.

	Bonneville	The Dalles	John Day	McNary	Ice Harbor	Lower Granite	Priest Rapids
Steelhead released with transmitters							
Number	765	-----	-----	-----	-----	-----	-----
Number that regurgitated transmitters at or near the release site							
Number	26	-----	-----	-----	-----	-----	-----
Number and percentage of 739 recorded at first passage of tailrace receivers							
Number	701	386	441	251	244	160	19
Percent	94.9	52.2	59.7	34.0	33.0	21.7	2.6
Number and percentage of 739 known to have passed tailrace receivers							
Number	737	590	490	407	325	269	20
Percent	99.7	79.8	66.3	55.1	44.0	36.4	2.7
Percentage of those known to pass tailrace that were recorded at tailrace receivers							
Percent	95.1	65.4	90.0	61.7	75.0	59.5	95.0
Number and percentage of 739 recorded at tops of ladders[1]							
Number	713	558	440	327	307	257	18
Percent	96.5	75.5	59.5	44.2	41.5	34.8	2.4
Number and percentage of 739 known to have passed over dams							
Number	720	580	457	394	319	262	18
Percent	97.4	78.5	61.8	53.3	43.2	35.4	2.4
Percentage of those known to pass dams that were recorded at tops of ladders							
	99.0	96.2	96.3	83.0	96.2	98.1	100.0
Number and percent recorded at tailrace receivers but did not pass dams							
Number	17	10	33	13	6	7	2
Percent	2.3	1.7	6.7	3.2	1.8	2.6	10.0

[1] includes top of navigation lock at Bonneville and McNary dams

Ice Harbor, 262 (35%) passed Lower Granite, and 18 (2%) passed Priest Rapids dams (Table 6). Nine fish were recaptured without transmitters at the Lower Granite adult trap, of which three regurgitated transmitters near the release site and six were recorded at one or more dams, and then regurgitated transmitters at an unknown location.

At all dams, the percentage of steelhead known to have passed tailrace and top-of-ladder receivers was greater than the percentage recorded by receivers at those sites (Table 6). The proportion of steelhead recorded at tailrace receivers on their first passage ranged from 59.5% to 95.1% of those that were known to pass tailrace sites. Tailrace receivers were least efficient at Lower Granite (59.5%), McNary (61.7%), and The Dalles (65.4%) dams (Table 6). Lower efficiency at the Lower Granite Dam and McNary Dam tailrace sites was caused in part by a relatively high number of receiver outages during the 1996 migration (Table 4 in Bjornn et al. 2000a) and because we tried to cover the Lower Granite Dam tailrace with an antenna on only one side of the river. The proportions of 3- and 7-volt transmitters undetected at tailrace receivers were not significantly ($P < 0.05$, Z test) different at Bonneville, John Day, or Lower Granite dams. A significantly ($P < 0.05$) higher proportion of fish with 3-volt transmitters passed undetected at The Dalles Dam, and fish with 7-volt transmitters were undetected at significantly ($P < 0.05$) higher rates at John Day and McNary dams. Although we could not identify exactly when undetected fish passed tailrace sites, we did not include fish that we believe passed during known tailrace receiver outages in detection comparisons for 3- and 7-volt transmitters.

At top-of-ladder sites, the proportion of radio-tagged steelhead recorded on first passage of the dam was greater than 96% at all but McNary Dam (83%), where the receiver at the top-of-ladder site on the Oregon shore was defective for about 6 weeks in July and August. Inefficiency was inflated slightly at most sites because 6 steelhead were known to pass dams after regurgitating transmitters and were not recorded at one or more receiver sites along their migration route. All steelhead were included in the having-passed number if they were recaptured upstream of a dam, but were not recorded on an antenna at the dam; those that regurgitated transmitters near the release site were not included.

Most steelhead with transmitters known to have passed a dam's tailrace receiver eventually passed that dam. However, 10% of the fish known to have entered the Priest Rapids Dam tailrace, 6.7% that entered the John Day Dam tailrace, 3.2% that entered the McNary Dam tailrace, and 2.3% that entered the Bonneville Dam tailrace did not pass. More than 97% of the fish known to have entered tailraces at The Dalles, Ice Harbor, and Lower Granite dams passed those dams (Table 6). Failure of a significant number of steelhead to pass John Day Dam after being recorded in the tailrace may not be unusual because of the large number of steelhead produced in the Deschutes River.

Median, first and third quartile passage dates, taken from the last record at the top of a ladder at each dam, were progressively later as steelhead outfitted with transmitters moved upriver in 1996, with an exception being the small group of early-run steelhead that passed Priest Rapids Dam (Figure 16). Median first passage dates for all fish were 25 August at Bonneville, 12 September at The Dalles, 22 September at John Day, 26 September at McNary, 3 October at Ice Harbor, 11 October at Lower Granite and 10 September at Priest Rapids dams. Median first passage dates for A-group

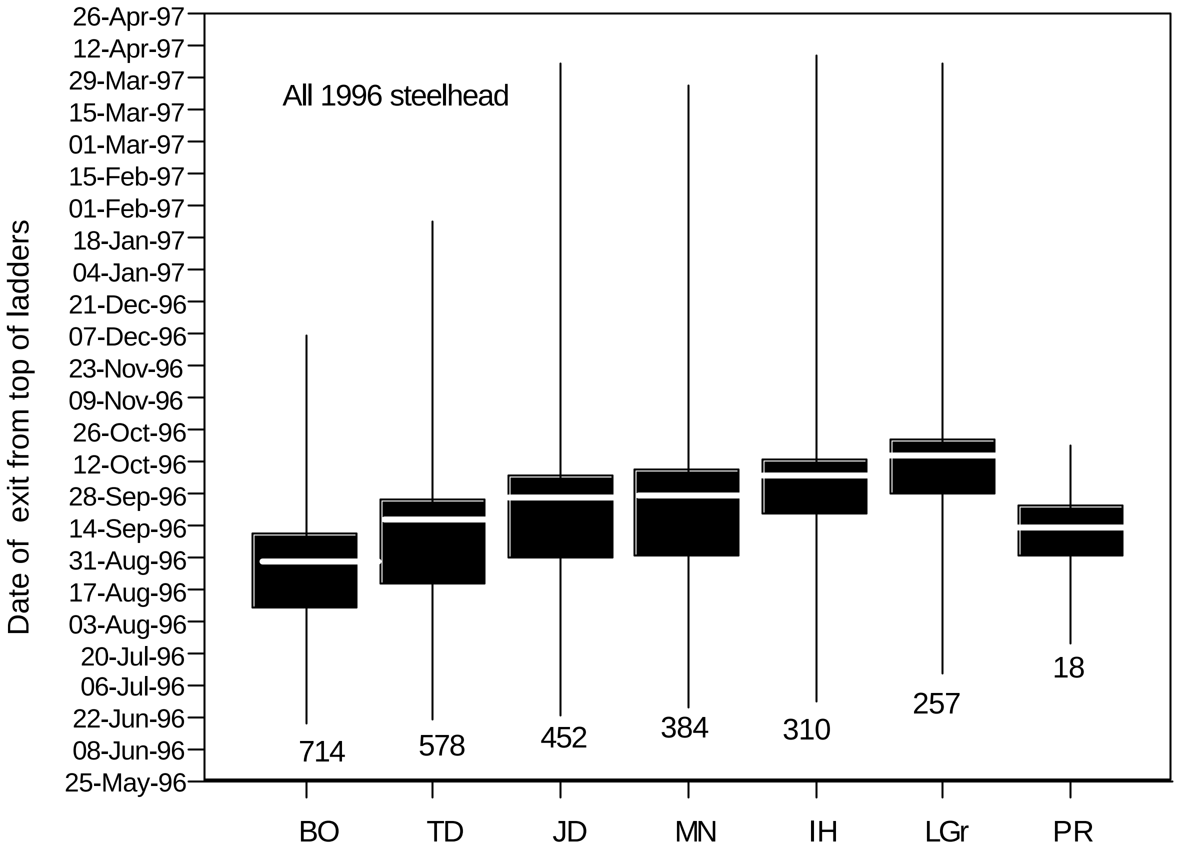


Figure 16. Median, first quartile, third quartile and range of passage dates for all steelhead with transmitters that passed Columbia and Snake River dams in 1996. Numbers of fish recorded at each dam are below each range line.

steelhead progressed upriver from 12 August at Bonneville Dam to 23 September at Ice Harbor and 4 October at Lower Granite dams, and for B-group steelhead progressed from 12 August at Bonneville Dam to 5 September at McNary Dam and 4 October at Lower Granite Dam (Figure 17). Due to overwintering by a small proportion of the radio-tagged steelhead, passage distributions at dams were spread over more than eight months at many sites, but most fish passed during the fall migration period. Less than 3% of steelhead tagged in 1996 first passed McNary and Ice Harbor dams in the spring of 1997, and 6.6% first passed Lower Granite Dam in 1997. Overall, 50% of A-group steelhead passed each dam within 31 days prior to and 26 days after the median date; 50% of B-group steelhead passed within +/- 12 days of the median date.

At Bonneville Dam, the passage date distribution was approximately the same as the distribution of tagging dates with a lag of less than one day (Figure 18). At The Dalles and John Day dams, passage was approximately normally distributed around median passage dates, while distributions at McNary, Ice Harbor, and Lower Granite dams were more bimodal. Distributions at the upriver dams also showed overwintering fish that passed in spring, 1997 (Figure 18).

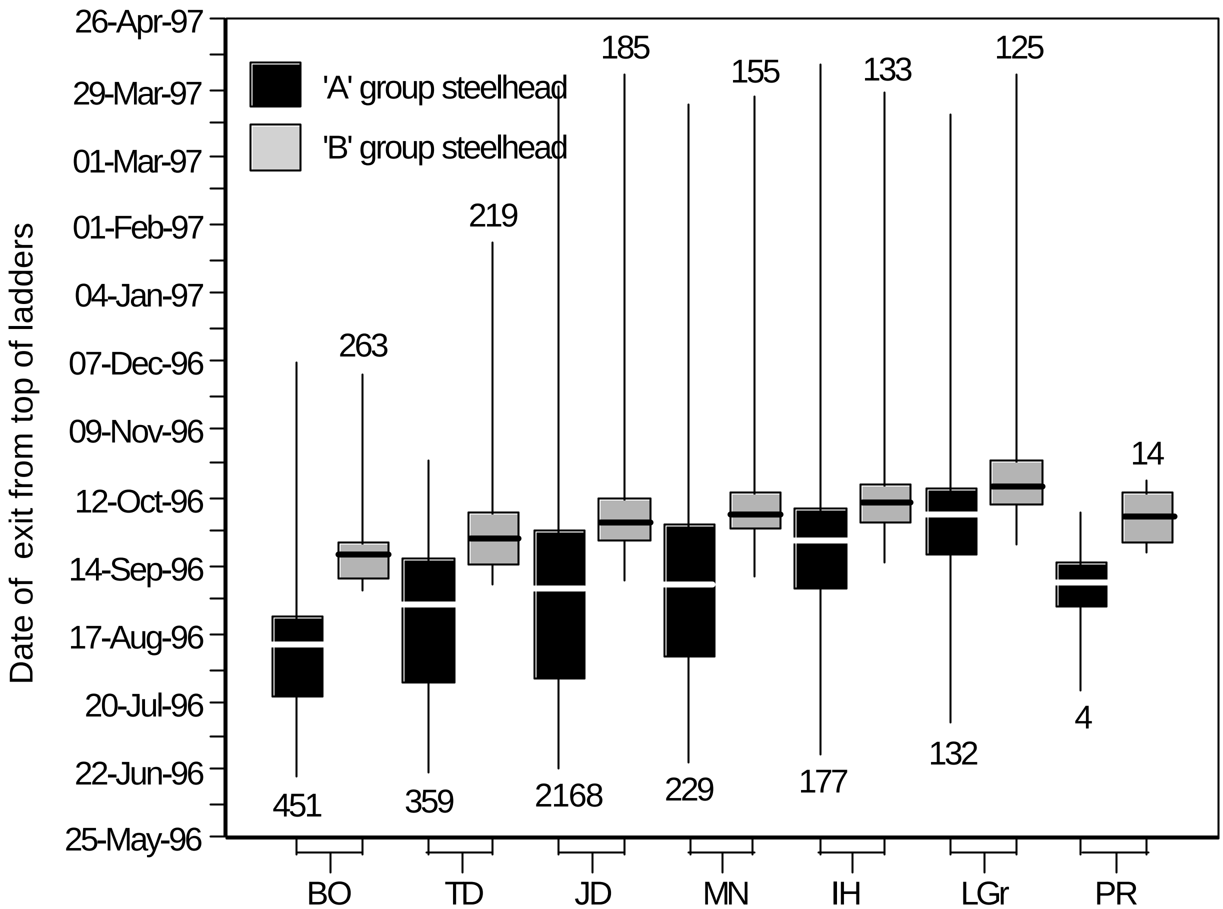


Figure 17. Median, first quartile, third quartile and range of passage dates for A-group and B-group steelhead with transmitters that passed Columbia and Snake River dams in 1996. Numbers of fish recorded at each dam adjacent to each range line.

Median times for steelhead to pass dams studied in 1996 were less than 1.1 d per dam and the majority passed most dams in less than 1.5 d (Figure 19). Median passage times from the tailrace receiver to exit from the top of a ladder were 0.71 d at Bonneville, 0.65 d at The Dalles, 0.85 d at John Day, 0.43 d at McNary, 0.61 d at Ice Harbor, 1.08 d at Lower Granite, and 0.57 d at Priest Rapids dams (Table 7).

Passage times at McNary Dam were slightly less precise than at other dams, because we approximated the time that some fish (14%) exited from the top of ladders when fish were recorded near top-of-ladder sites but missed the uppermost antennas due to receiver outages. We believe the error associated with including these fish in passage time calculations was minimal. Longer passage at Lower Granite Dam was probably caused by operation of the adult trap and some delay for all fish diverted into the trap. Mean passage times were longer than median times at all dams because a few fish took several days to pass dams and all distributions were right-skewed. We have presented both mean and median values, but believe medians more accurately portray the time most fish take to pass over a dam or through a reservoir.

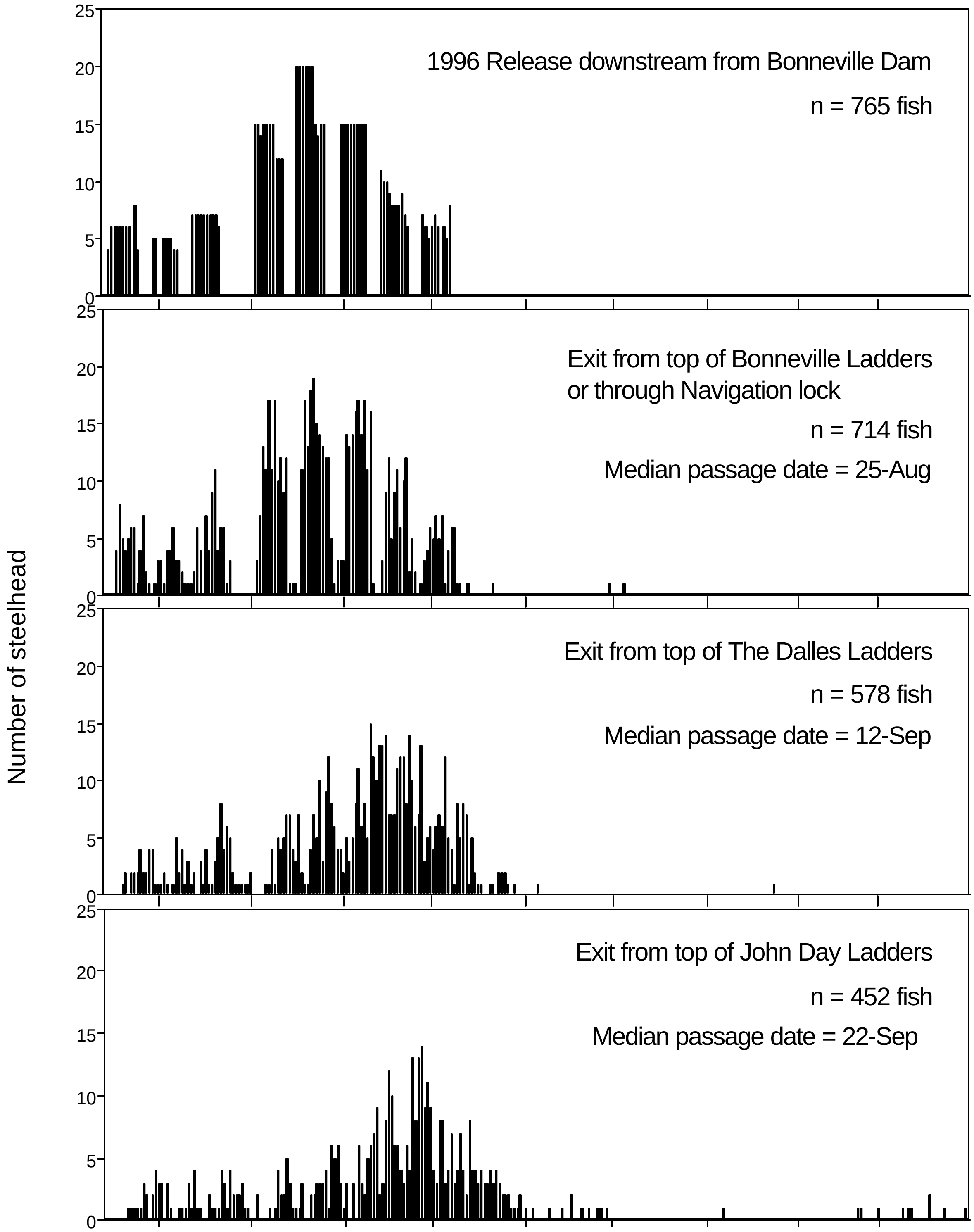
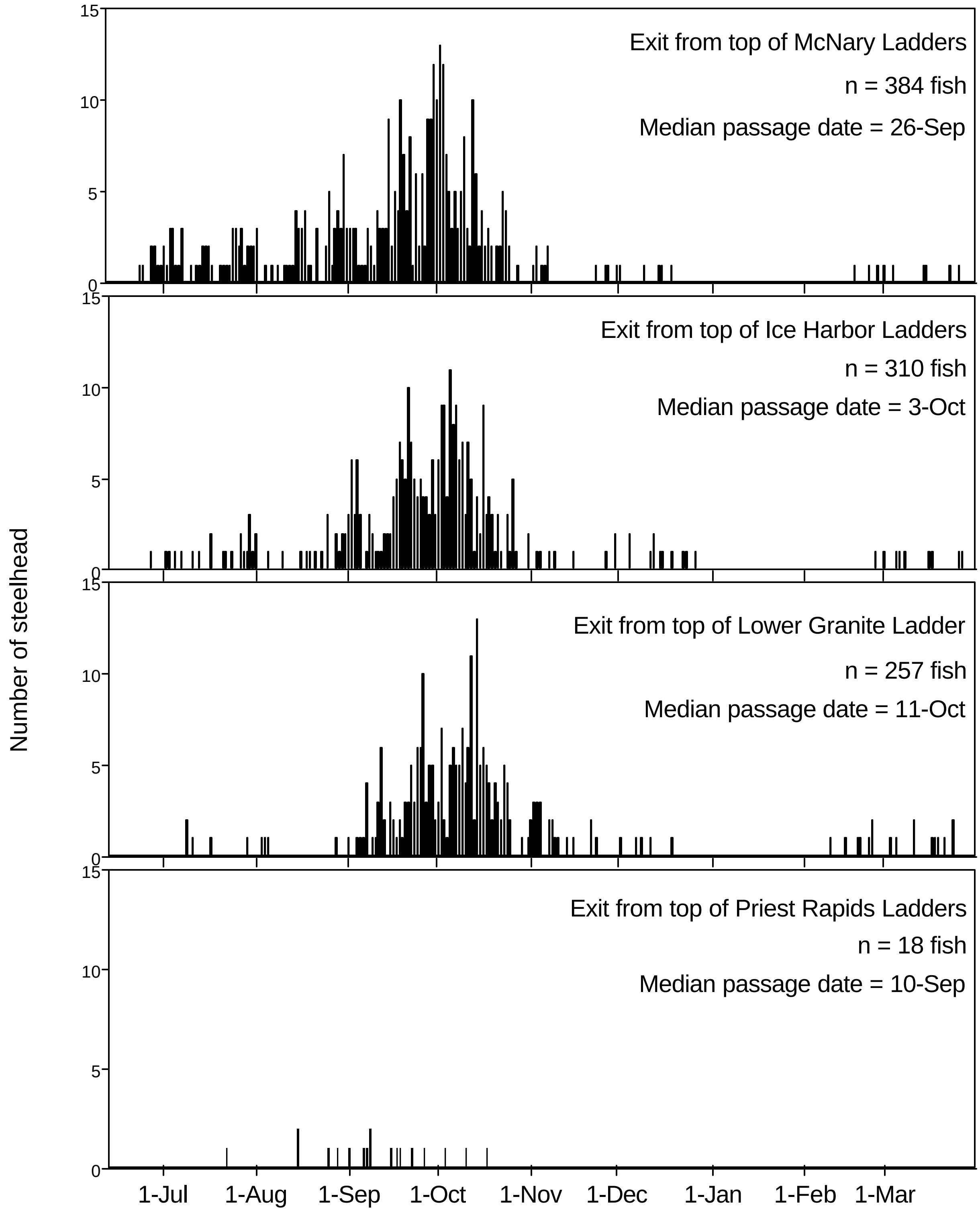


Figure 18. Frequency distributions for the date that steelhead were tagged at Bonneville Dam and the date they first were recorded at the tops of ladders or the navigation lock at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor,.



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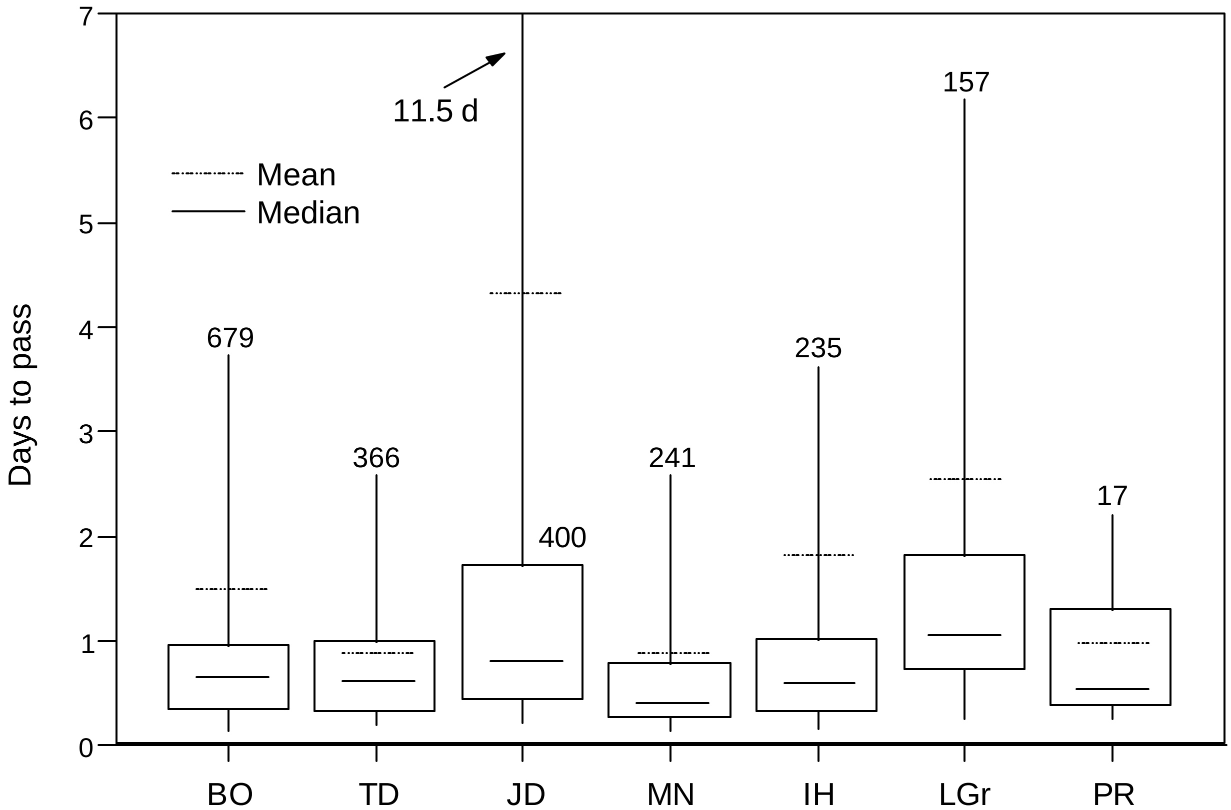

Figure 19. Mean, median, 5% and 95% percentiles, and quartile days steelhead with transmitters took to pass from tailrace receivers to top-of-ladder receivers at dams monitored in 1996-1997.

and Lower Granite dams in 1996

At Bonneville, The Dalles, McNary, and Ice Harbor dams, less than 5% of steelhead with transmitters took more than 5 days to pass the dams. About 10% percent at John Day Dam and 9% at Lower Granite Dam took more than five days to pass. Less than 4% took more than 10 days to pass at all dams except John Day Dam where 5.8% took more than 10 d. A few individual steelhead took more than one month to pass an individual dam, and some overwintering fish spent more than 100 d between their first record at tailrace sites and their first passage of a dam; we did not include those fish in mean passage time calculations (Table 7). Steelhead with transmitters passed tailrace receivers throughout the day and night in 1996, with a tendency for passing tailrace sites during daylight hours especially at Bonneville Dam where almost all fish passed during daylight hours (Figure 20).

Steelhead passed top-of-ladder receivers almost exclusively during daylight hours at all dams with only a small number of fish in ladders during late afternoon and evening passing dams after 2100 hours. Mean dam passage times were longer for A-group steelhead than

Table 7. Mean, median and quartile values for steelhead to pass each dam from tailrace receiver sites to tops of ladders, with standard deviations and percentages of steelhead that took more than 5 and 10 days to pass dams monitored in 1996[1].

	Bonneville	The Dalles	John Day	McNary	Ice Harbor	Lower Granite	Priest Rapids
Number of fish							
	679	366	400	241	235	157	17
Mean days to pass dam							
	1.49	0.93	2.51	0.90	1.83	2.59	1.00
Median days to pass dam							
	0.71	0.65	0.85	0.43	0.61	1.08	0.57
Quartile values							
First	0.33	0.32	0.42	0.26	0.32	0.72	0.37
Third	0.96	1.00	1.72	0.80	1.02	1.83	1.30
Standard deviations							
	4.64	1.17	7.08	2.73	7.04	6.44	0.78
Percentage of fish that took more than 5 days to pass dam							
	4.1	1.1	10.0	2.5	3.8	8.9	0.0
Percentage of fish that took more than 10 days to pass dam							
	2.2	0.3	5.8	0.8	2.6	3.2	0. 0

[1] Does not include fish (1 each at Bonneville and McNary dams, 6 at John Day Dam) that took > 100 d to pass in mean or standard deviation values

for B-group steelhead at all dams except Lower Granite Dam, but differences were only significant ($P < 0.05$, T-test) at Bonneville Dam. Median dam passage times were significantly ($P < 0.05$, K-W X^2 test) longer for A-group steelhead than for B-group steelhead at Bonneville and John Day dams (Table 8). Steelhead without fin clips had significantly longer ($P < 0.05$) mean passage times than fish with clips at John Day and Ice Harbor dams, but differences were not significant when we removed a small number of fish with passage times > 30 d. Median passage times were not significantly ($P < 0.05$) different for clipped and unclipped fish at any dams (Table 8).

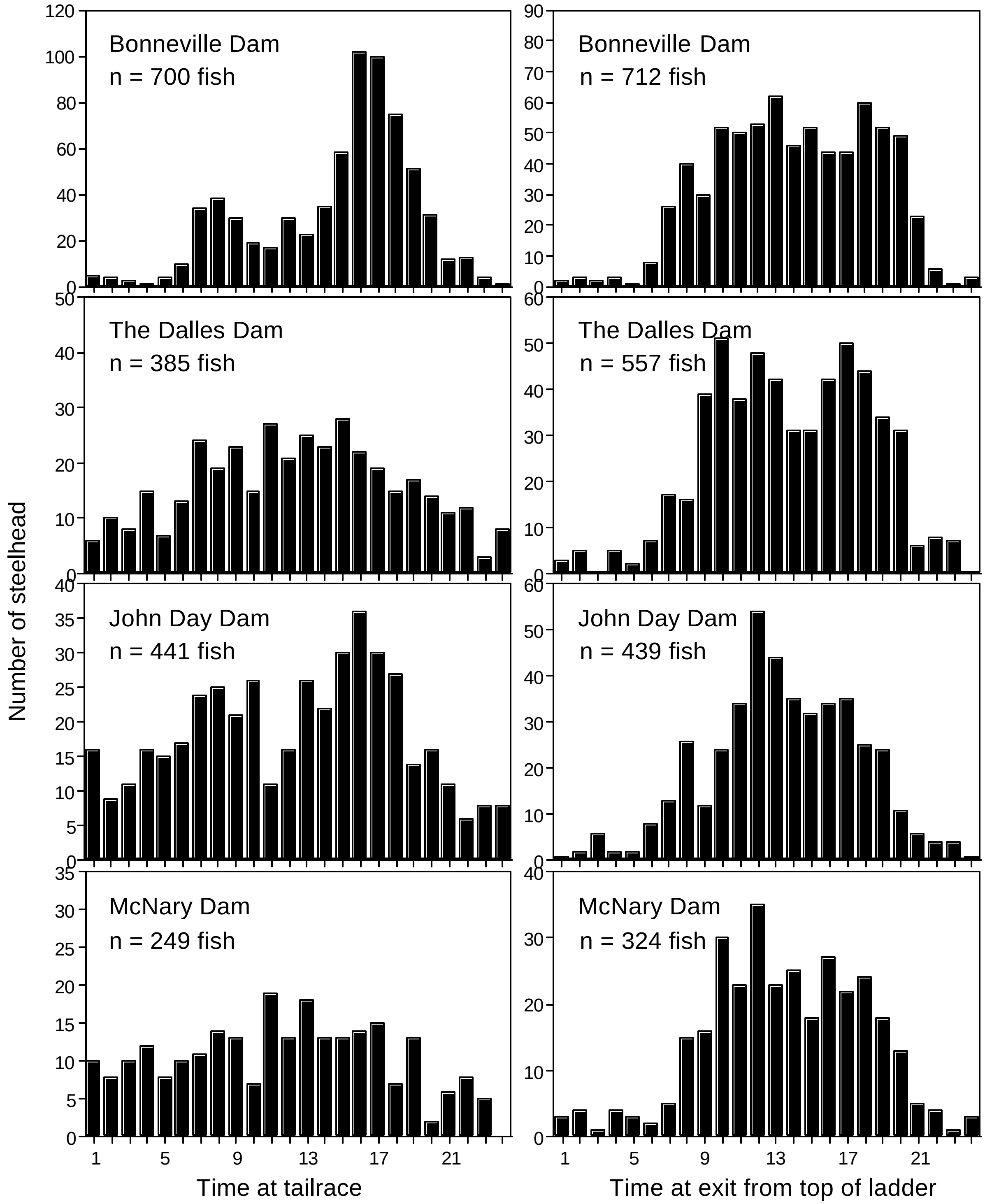

Figure 20. Frequency distribution of time of day that steelhead with transmitters were first recorded at tailrace receivers and last recorded at top-of-ladder receivers at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite, and Priest Rapids dams in 1996.

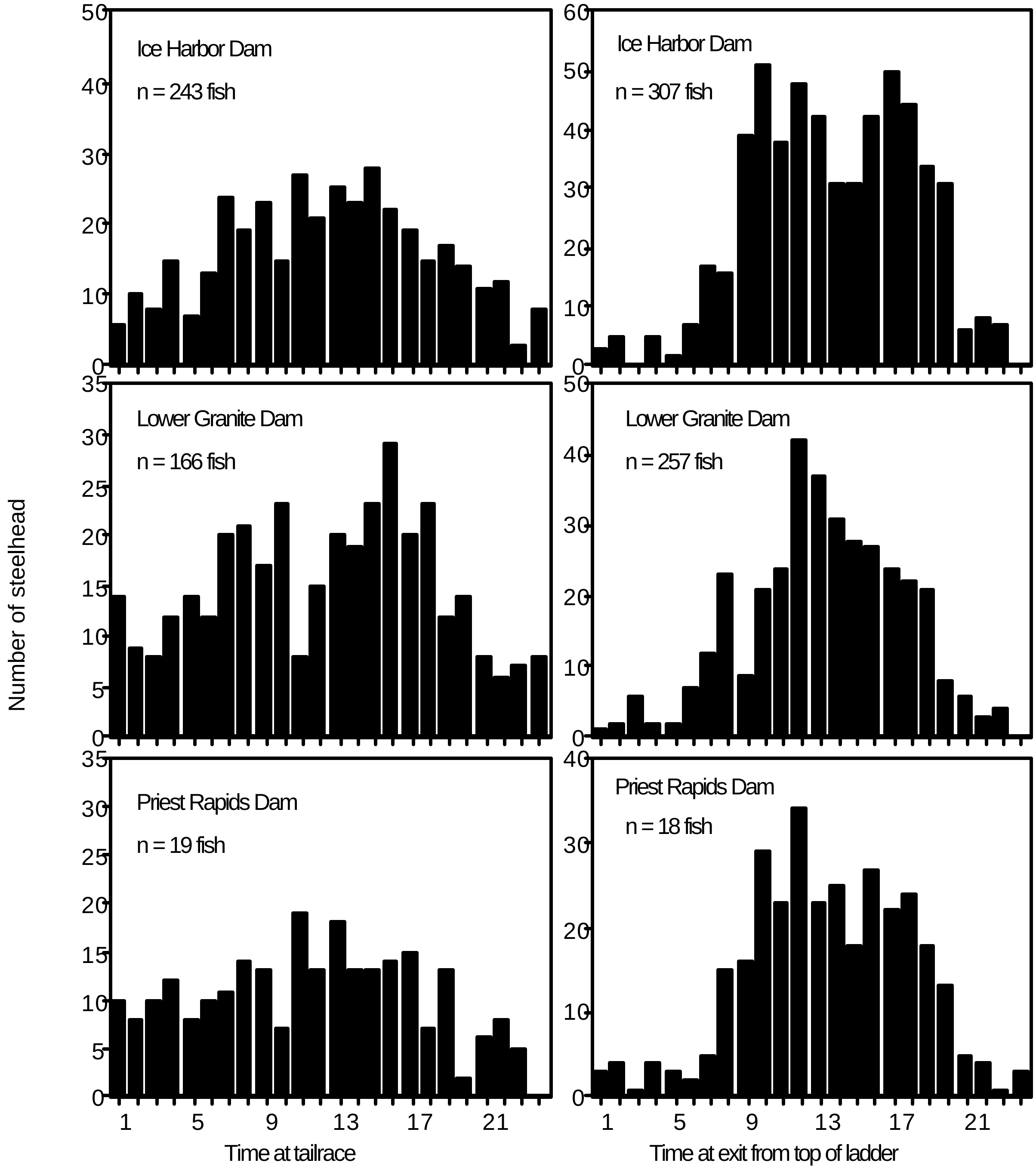

Figure 20. Continued.

Table 8. Mean and median times for A-group and B-group, and fin-clipped and unclipped steelhead to pass each dam from tailrace receiver sites to tops of ladders in 1996[1].

	Bonneville	The Dalles	John Day	McNary	Ice Harbor	Lower Granite	Priest Rapids
Number of fish							
A-group	432	225	247	156	99	51	13
B-group	247	142	153	85	87	71	4
Clipped	569	312	339	208	201	135	16
No clip	110	54	61	33	34	22	1
Mean days to pass dam							
A-group	1.83*	0.96	2.98	0.99	2.01	2.51	1.15
B-group	0.89*	0.87	1.75	0.72	1.52	2.68	0.51
Clipped	1.41	0.93	2.17*	0.91	1.44*	2.18	1.03
No clip	1.90	0.91	4.41*	0.85	4.15*	1.08	0.43
Median days to pass dam							
A-group	0.71*	0.62	0.94*	0.43	0.60	1.05	1.07
B-group	0.69*	0.69	0.79*	0.41	0.69	1.10	0.26
Clipped	0.70	0.64	0.84	0.44	0.61	1.08	0.82
No clip	0.72	0.74	0.91	0.34	0.60	1.08	0.43

* P < 0.05; ** P < 0.005, K-W X^2 test

[1] fish with passage times > 100 d not included

[2] no statistical tests for passage at Priest Rapids Dam

Effects of Environmental Conditions on Steelhead Passage at Dams

In general, daily spill volumes at Columbia and Snake River dams in 1996 fluctuated with total flow at each dam during spring and summer. Periods of no-spill began around 1 September at all dams (Figure 21). Dissolved gas levels were highly correlated with total flow and spill during spring and summer. Annual high spill and flow volumes at lower-Columbia River dams occurred between mid-May and late June, with peak flows at or near 475 kcfs on 11 June. Ice Harbor, Lower Granite and Priest Rapids dams also had annual peak flow and spill between mid-May and late June, and all dams had shorter, lower-volume peaks in mid-April. Flow and spill were decreasing during the early portion of the steelhead migration, and flow had leveled off at most dams by about mid-September. Secchi disk visibility increased steadily during the steelhead migration at all dams (see Figure 4). Water temperatures at dams increased from June through August, peaked in late August or early September at all dams, and decreased during peak steelhead counts at dams (see Figure 5).

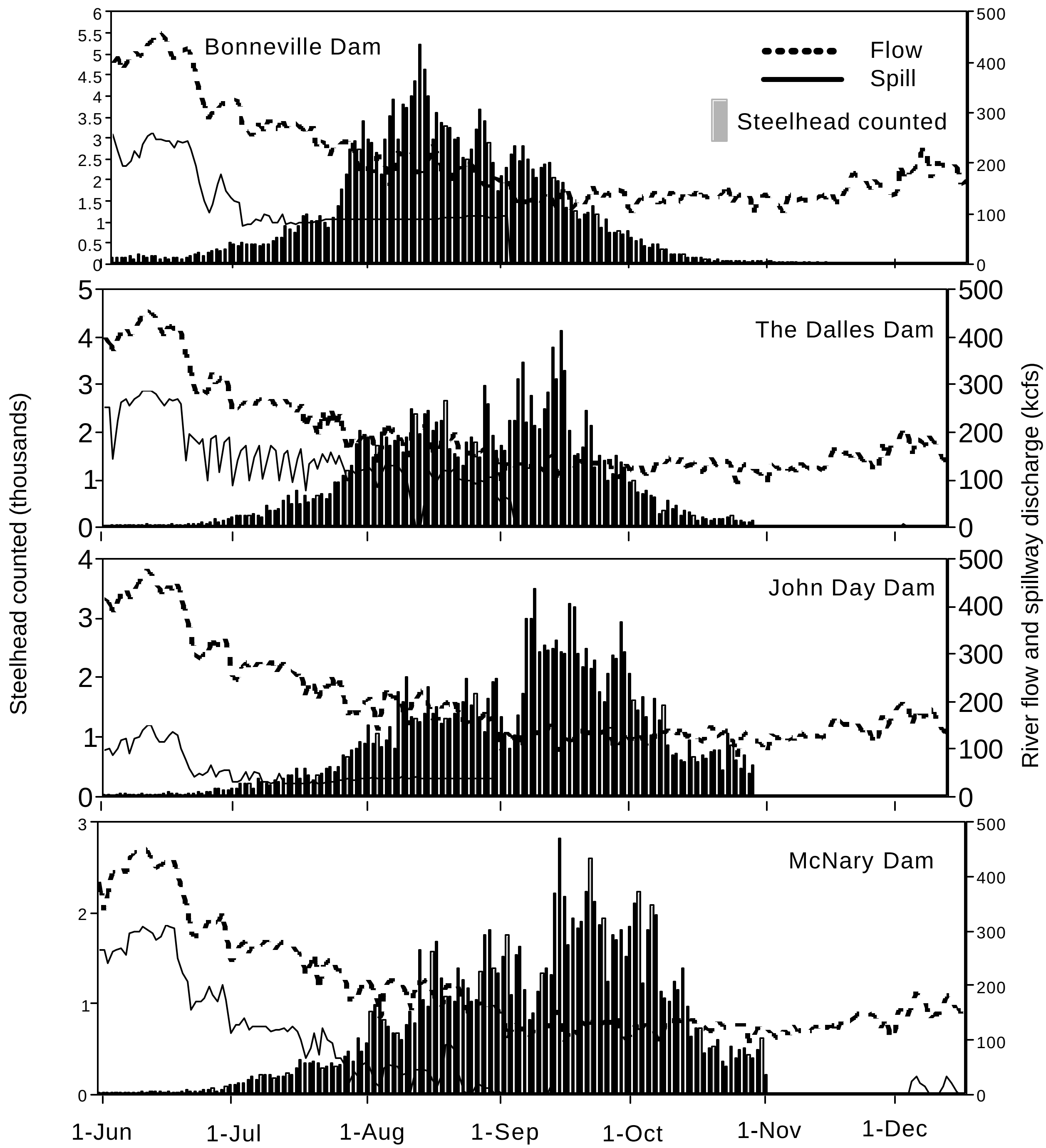

Figure 21. Daily mean total flow and spillway discharge (kcfs) at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite and Priest Rapids dams during the 1996 steelhead migration, and the number of steelhead counted passing each dam.

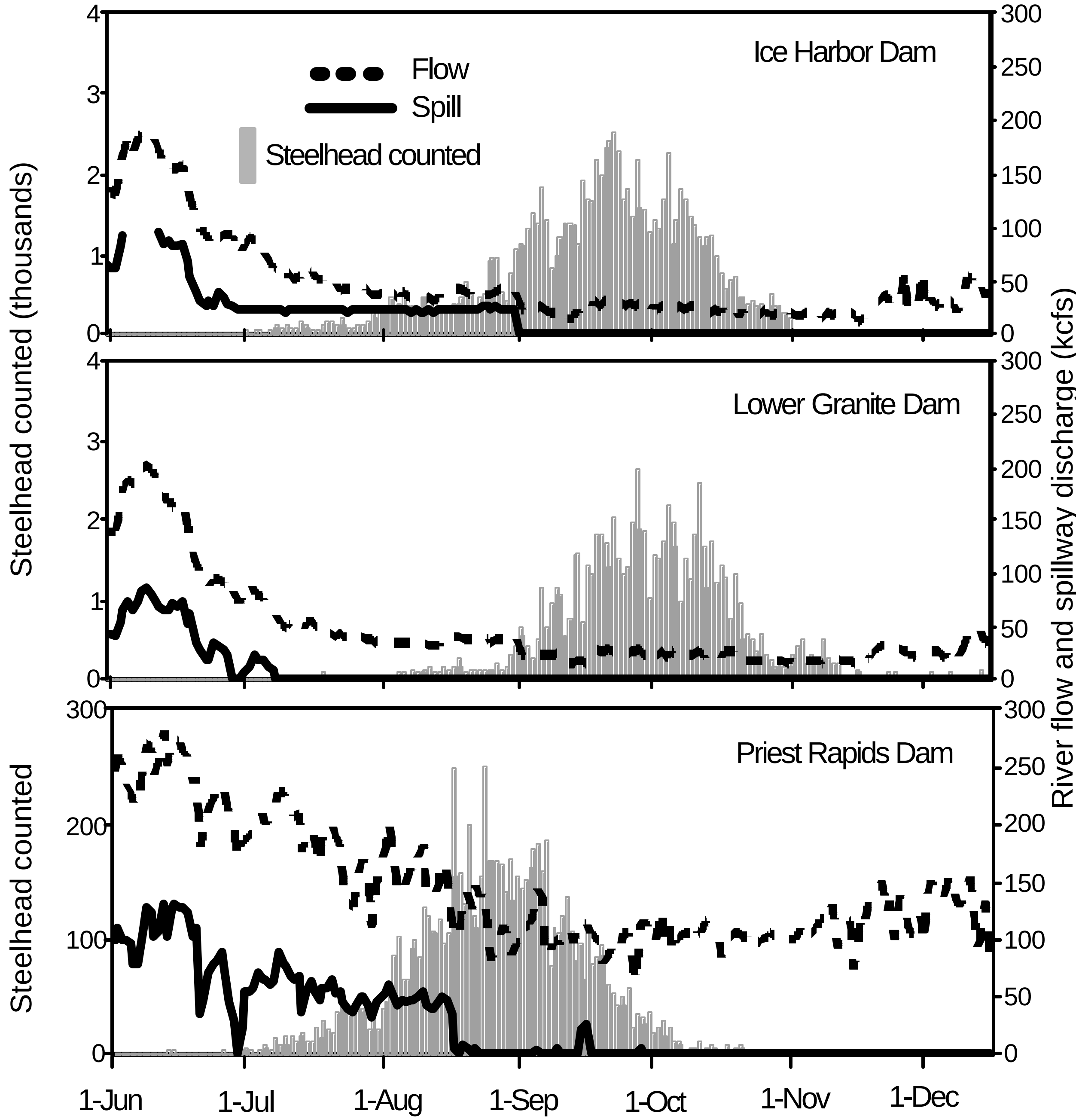

Figure 21. Continued.

During summer 1996, flow and spill were relatively high but neither appeared to affect passage of steelhead at the dams (Figure 22). Univariate correlations of time to pass a dam with flow were very low (r^2 less than 0.02) at all monitored dams, despite the range of flow conditions during the steelhead migration. Peak steelhead counts occurred after spill was terminated in the lower Columbia and most fish passed Snake River dams

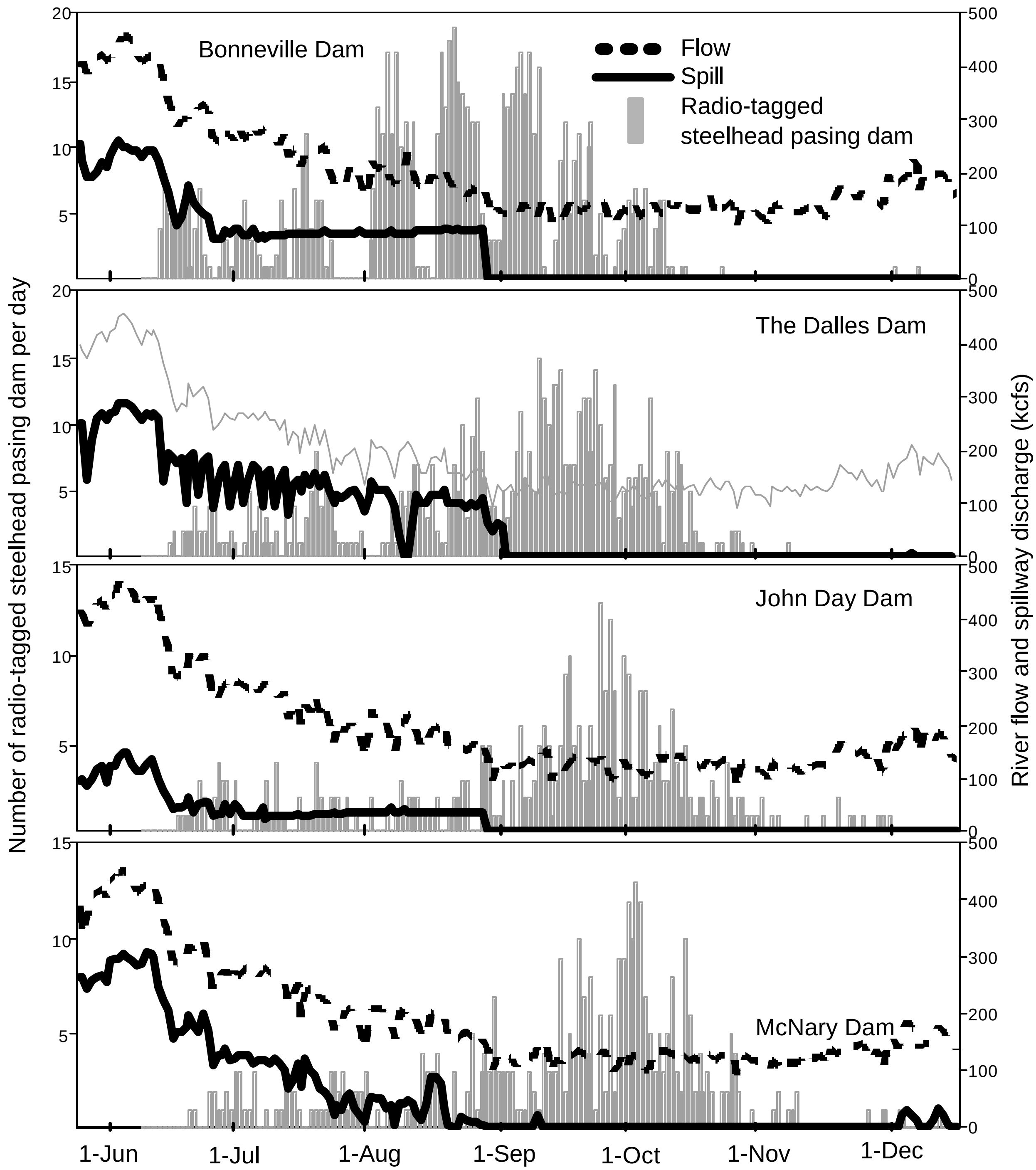

Figure 22. Mean total flow and spillway discharge (kcfs) at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite and Priest Rapids dams during the 1996 steelhead migration, and the number of steelhead with transmitters recorded passing each dam.

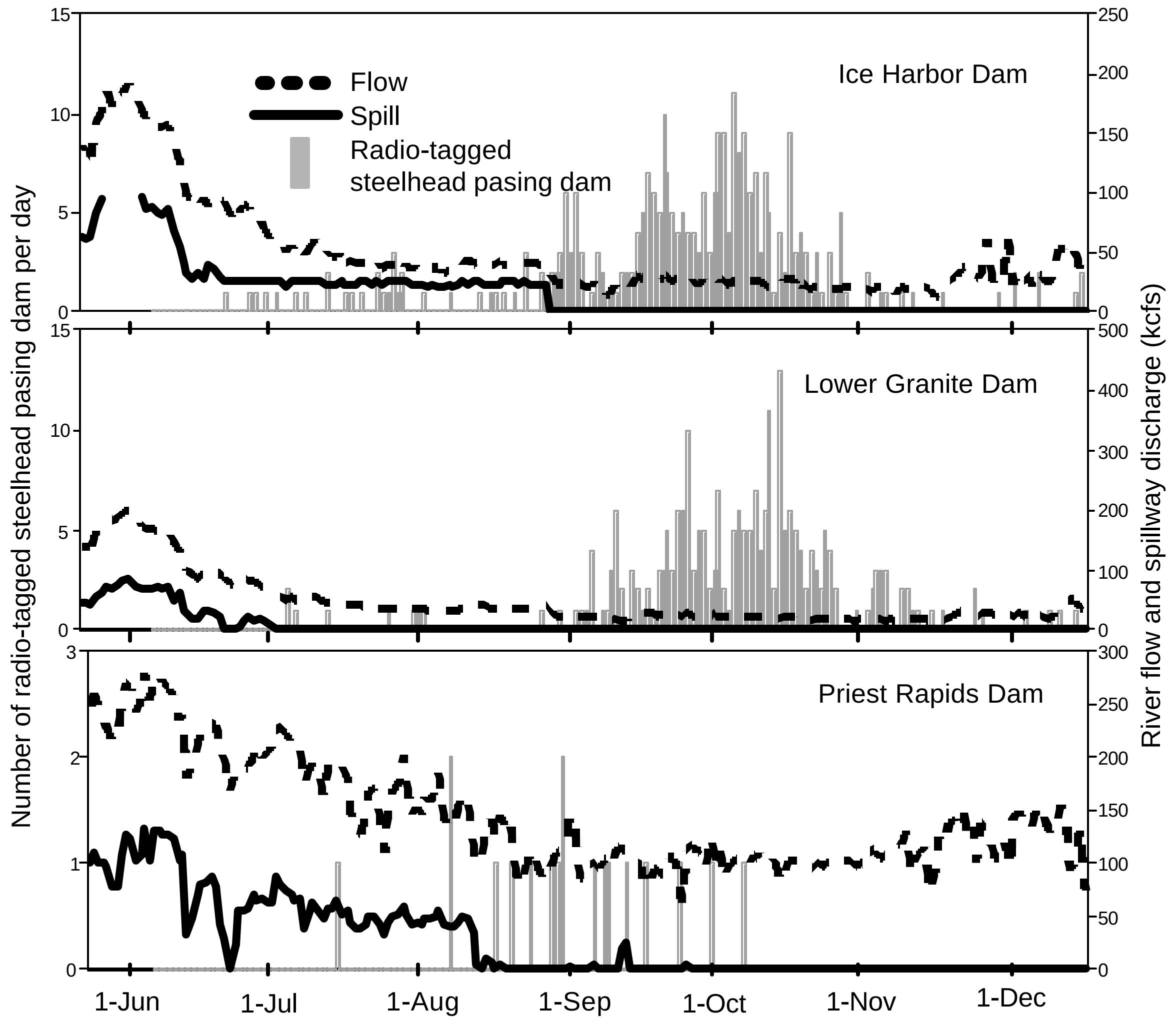

Figure 22 Continued.

during no-spill conditions, but there was no indication that spill significantly affected passage while it occurred. At Bonneville Dam, 39% of radio-tagged steelhead passed during zero flow, but we found almost no correlation between spill and passage time. Between 60% and 67% of radio-tagged fish passed The Dalles and John Day dams during zero or near-zero spill, and r^2 values for spill versus passage time there were less than 0.02. At McNary and Ice Harbor dams, more than 80% passed during zero spill, and correlations with passage time were similarly low. Almost all radio-tagged fish passed Lower Granite Dam during near-zero spill. In all models we excluded a small number of fish with passage times > 5 d, because they were likely subjected to a range of in-river conditions between their first tailrace and last top-of-ladder records.

We also tested the effects of Secchi depth visibility and water temperature on time to pass a dam, but univariate models produced very low correlations at all monitored dams. At all projects, r^2 values for Secchi depth and passage time were less than 0.03, and less than 0.02 for water temperature. Reported Secchi depth values at Lower Granite Dam were nearly uniform at 5.0 ft (USACE 1996), and tests using that data should be interpreted with caution.

We also used grouping methods to lower variability in univariate models. With flow and spill, fish were grouped by 10 kcfs increments (mean daily flow) and mean passage times were calculated for each group and weighted by the number of fish in the group. It was possible for fish from different portions of the run, but with similar river conditions, to be grouped together. We used weighted and unweighted linear regressions to test whether relationships with passage time were significant at $P < 0.05$. Passage times at dams tended to increase with flow, but no unweighted models were significant at $P < 0.05$. Among weighted flow models, only the one for John Day Dam was significant ($P = 0.04$) with an r^2 of 0.17. No weighted or unweighted models were significant ($P < 0.05$) with spill and passage at dams although weighted models approached significance for The Dalles Dam ($P = 0.09$) where passage times decreased as spill increased, and at Bonneville Dam ($P = 0.07$) where passage times increased as spill increased. Conducting regression analysis between passage times and spill may not be valid because high proportions of the steelhead runs passed during zero spill at upriver dams, and there was little variation in the spill that occurred at John Day, Ice Harbor, and Lower Granite dams.

With groups based on Secchi depth visibility, passage times tended to be faster with increasing visibility at Bonneville, John Day, and McNary dams, but no weighted or unweighted models were significant at $P < 0.05$. At Ice Harbor Dam, passage times increased with increasing visibility, but models were non-significant. Models for The Dalles Dam showed almost no relationship between passage time and Secchi depth visibility.

For temperatures, we found that passage times were faster with increasing water temperature at all dams except Ice Harbor, but weighted models were not significant at any dam. No unweighted models were significant, except at Lower Granite Dam ($P = 0.03$ and $r^2 = 0.25$), with passage times slower with increasing water temperature.

Forward stepwise multiple regression models of passage time from tailrace to top-of-ladder sites did not provide additional insight into passage time variability. Results of multiple regression models were similar to univariate models. At The Dalles, McNary, and Ice Harbor dams, no environmental variables or the date that steelhead passed tailrace sites met the $P = 0.15$ criteria for inclusion in models. At Bonneville Dam, flow was selected with $P = 0.043$ ($r^2 = 0.01$), but no additional variables were added to the model. At John Day Dam, Secchi depth was selected ($P = 0.01$; $r^2 = 0.02$), but no additional variables were added. When we removed Secchi depth from the John Day model, flow was selected at $P = 0.02$ ($r^2 = 0.02$). The stepwise model for Lower Granite Dam also selected Secchi depth ($P = 0.120$; $r^2 = 0.02$). A model for Lower Granite Dam without Secchi depth selected date fish passed the tailrace receiver ($P = 0.149$; $r^2 = 0.02$).

In summery, more of the variability in passage times from tailrace to top-of-ladder sites was explained by steelhead behavior in fishways, including fallout from transition pools into tailrace areas, than by environmental conditions at the dam (see Keefer et al. 2002a).

Passage through Lower Columbia River Reservoirs

Most steelhead with transmitters migrated through individual lower Columbia River reservoirs in less than 3 d. Median passage times for steelhead from top-of-ladder receivers to tailrace receivers at the next upriver dam were 2.91 d through the Bonneville pool, 1.22 d through The Dalles pool, 2.83 d through the John Day pool and 1.95 d through the McNary pool to the Ice Harbor tailrace (Table 9). Median reservoir passage times for steelhead were 1.4 to 1.8 times longer than those recorded for chinook salmon in 1996 (Bjornn et al. 2000a). Because some steelhead took several weeks to pass through a pool, mean values were higher than medians. Migration rates for individual steelhead ranged from less than 1 km/day to more than 80 km/day through reservoirs. Median rates were 24.0, 30.3, 42.5, and 34.5 km/day through the Bonneville, The Dalles, John Day and McNary pools (Figure 23). We included time that steelhead temporarily strayed into tributaries in total pool passage time. Fish with overwintering behavior at mainstem or tributary sites were not included in comparisons where the behavior likely inflated passage time through a pool (see section on steelhead overwintering behavior).

Median passage time through the Bonneville reservoir was significantly ($P < 0.005$, K-W X^2 test) shorter for B-group steelhead than for A-group steelhead (Table 9). By contrast, median passage times for A-group steelhead through the John Day and The Dalles reservoirs were significantly ($P < 0.005$) shorter than for B-group steelhead (Table 9). We found no significant differences in median migration times for A-group and B-group passage times through the McNary pool to the tailrace of Ice Harbor Dam (Table 9).

Table 9. Median number of days and median rates for steelhead to migrate through the Bonneville, The Dalles, John Day and McNary pools in 1996. Number of radio-tagged steelhead in parenthesis.

	Bonneville Pool	The Dalles Pool	John Day Pool	McNary Pool[1]
Median days to pass through pools				
All	2.91 (372)	1.22 (414)	2.83 (242)	1.95 (196)
A-group	**3.67 (228)	**1.11 (260)	**2.71 (159)	1.92 (112)
B-group	**2.58 (143)	**1.79 (154)	**3.09 (83)	1.98 (84)
Median migration rate (km/d) through pools				
All	24.0	30.3	42.5	34.5
A-group	**19.0	**33.3	**44.4	35.1
B-group	**27.1	**20.7	**39.0	34.0

[1] Passage through McNary Pool was to the tailrace at Ice Harbor Dam

** $P < 0.005$, K-W X^2 test

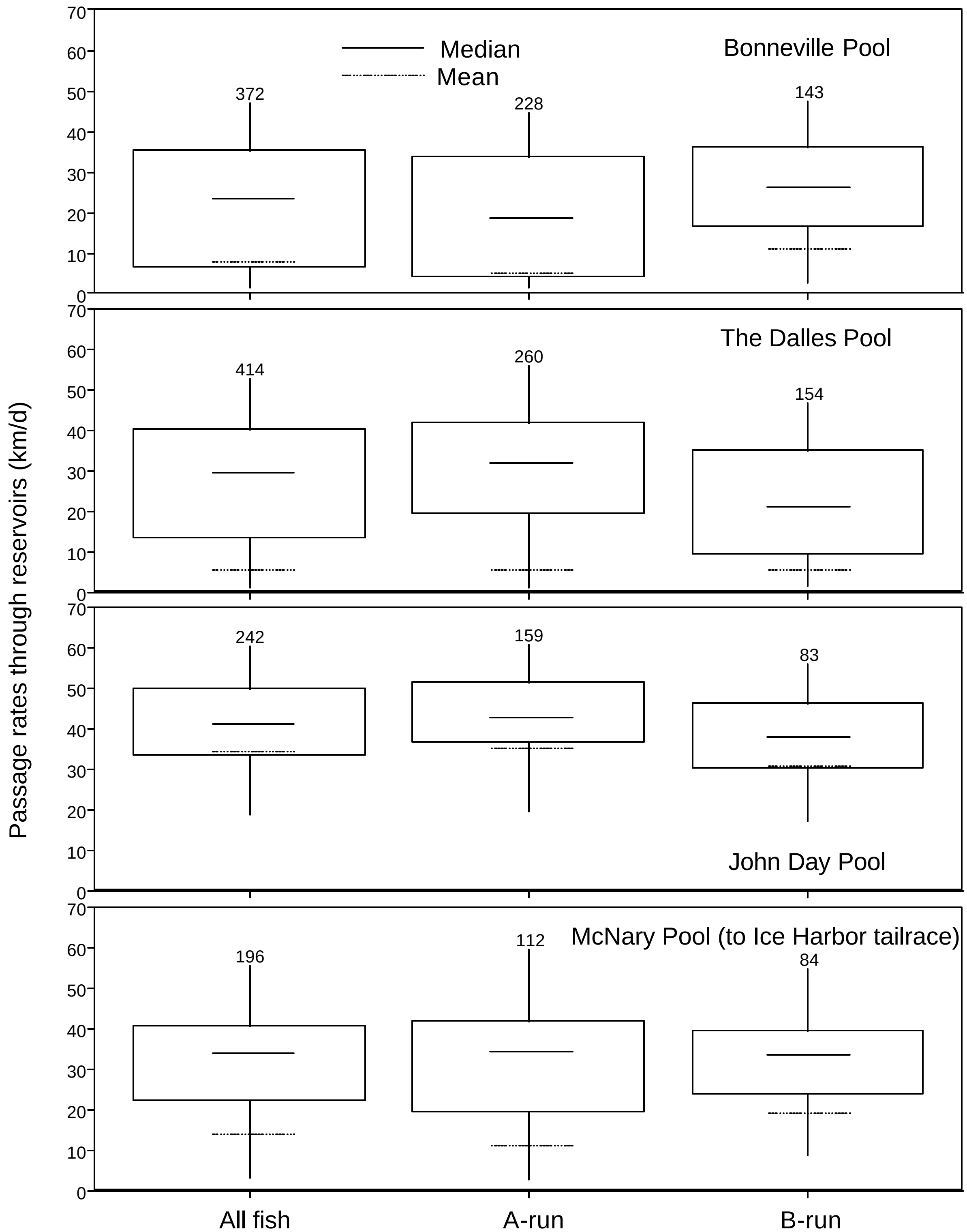

Figure 23. Median, mean, 5% and 95% percentiles, and quartile passage rates for steelhead through the Bonneville, The Dalles, John Day and McNary pools in the run-year 1996-1997. Times are from last record at the top a ladder to first record at upstream tailrace and do not include fallback time. Overwintering fish not included.

Passage Past Multiple Dams

Of the 739 steelhead that retained transmitters after release, 97.4% were known to have passed over Bonneville Dam, 78.5% passed The Dalles, 61.8% passed John Day, 53.3% passed McNary, 43.2% passed Ice Harbor, 35.4% passed Lower Granite, and 2.4% passed Priest Rapids dams. We calculated median passage times past multiple dams from the Bonneville tailrace site to the tops of ladders at McNary, Ice Harbor, Lower Granite and Priest Rapids dams for steelhead with transmitters that were recorded at top-of-ladder sites at those dams and at tailrace receivers downstream from Bonneville Dam. Fish with overwintering behavior at mainstem or tributary sites were not included in comparisons if doing so inflated passage time for a migration segment (see section on steelhead overwintering behavior). Passage time distributions were right-skewed for each migration segment, and median B-group steelhead passage times were significantly ($P < 0.005$, K-W X^2 tests) shorter than times for A-group steelhead for fish that passed McNary, Ice Harbor, and Lower Granite dams.

Passage times for 323 steelhead from the Bonneville Dam tailrace to the top of a ladder at McNary Dam ranged from 5.9 d to more than 100 d with median time of 16.1 d (Figure 24). Of these, 186 were A-group steelhead, with median passage time of 24.9 d and 137 were B-group steelhead with a median passage time of 12.9 d (Table 10).

Passage times for 283 steelhead from the Bonneville Dam tailrace to the top of a ladder at Ice Harbor Dam ranged from 7.3 d to more than 100 d with a median time of 26.2 d (Figure 24). Of the 283, 167 were A-group steelhead, with median passage time of 36.9 d, compared to 16.9 d for 116 B-group steelhead (Table 10). Passage times for 231 steelhead from the Bonneville Dam tailrace to the top of the ladder at Lower Granite Dam ranged from 11.9 d to more than 100 d with a median of 35.0 d (Figure 24). Of these, 123 A-group steelhead had median passage time of 47.2 d, compared to 25.4 d for 108 B-group steelhead (Table 10).

Seventeen steelhead migrated from the Bonneville Dam tailrace to the top of ladders at Priest Rapids Dam in a median passage time of 22.0 d (Figure 24). Passage times ranged from 11.3 d to 53.9 d; we limited statistical comparisons due to the small number of A-group and B-group fish that passed Priest Rapids Dam.

Although passage times were significantly different for A-group and B-group fish, passage times overall were weakly correlated with the date that fish were outfitted with transmitters, and data was highly variable. A linear regression of tagging date and passage time for individual fish from the Bonneville Dam tailrace to the top of McNary Dam had $r^2 \sim 0.01$ for all fish that passed in < 90 d. The r^2 values were 0.24 for fish that passed Ice Harbor Dam, and 0.39 for fish that passed Lower Granite Dam in < 90 d. Some early A-group steelhead and most B-group steelhead had lower than average upriver passage times; highest mean times were for fish that passed the Bonneville Dam tailrace in August. To examine the parabolic relationship between Bonneville tailrace date and upriver passage time, we calculated mean passage times for consecutive groups of 5 steelhead as well as a 5-group moving average. Results of the moving average analysis showed passage times pass multiple dams and reservoirs increased from June to July, peaked in August, and decreased in September and

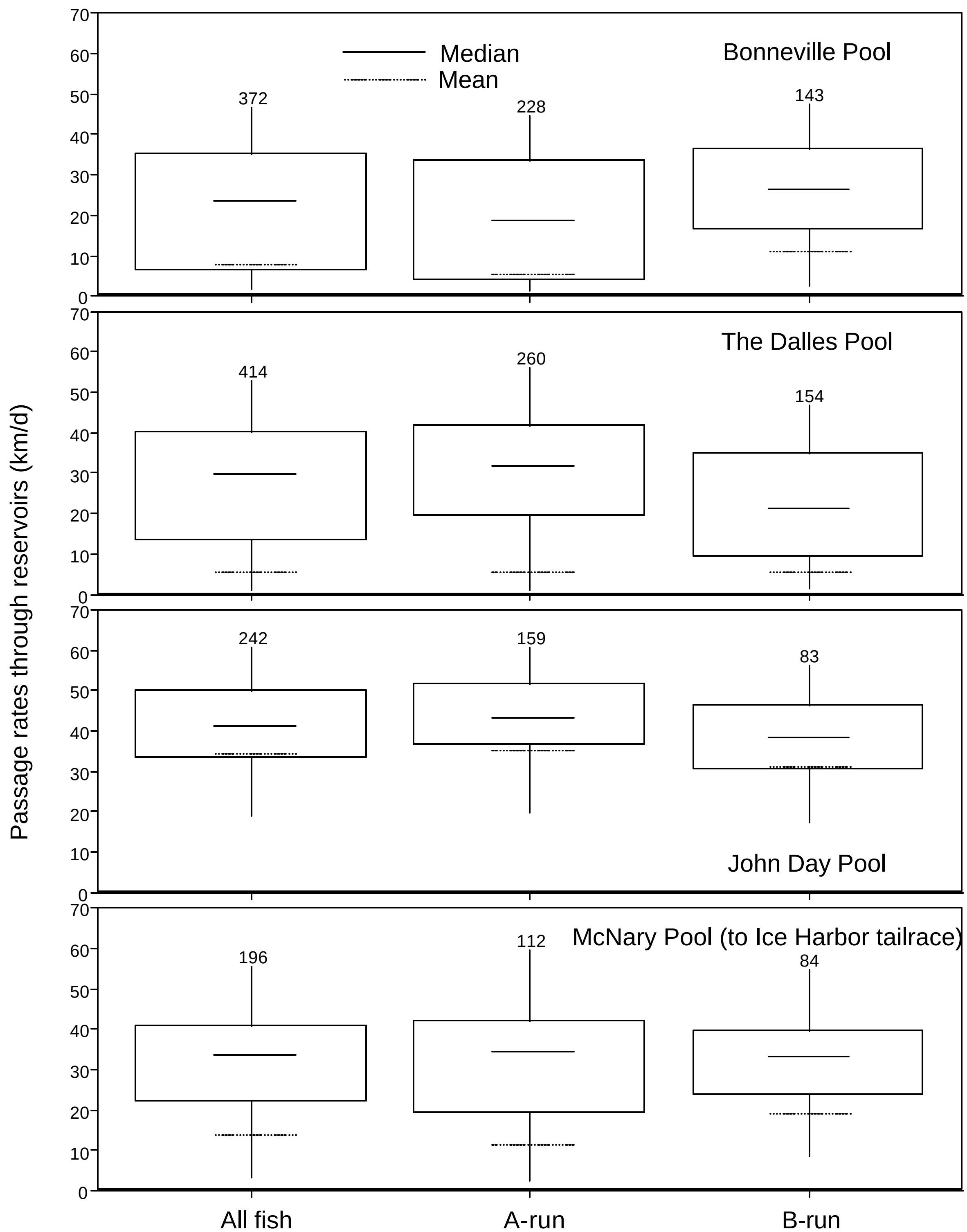

Figure 24. Distribution of passage times (d) for A-group and B-group steelhead with transmitters to pass from the Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, Lower Granite and Priest Rapids dams in the run-year 1996-1997. Fallback time included, overwintering fish not included.

Table 10. Median number of days and for radio-tagged A-group and B-group, fin-clipped, and unclipped steelhead to pass from a Bonneville Dam tailrace receiver site to exit from the top of McNary, Ice Harbor, Lower Granite and Priest Rapids ladders in 1996 (numbers of fish in parenthesis). Fish that overwintered at mainstem or tributary sites before migrating upriver not included.

	McNary	Ice Harbor	Lower Granite	Priest Rapids
Median days to pass from Bonneville Dam tailrace to top of ladder:				
All	16.05 (323)	26.22 (283)	35.01 (231)	22.04 (17)
A-group	**24.92 (186)	**36.93 (167)	**47.23 (123)	22.08 (13)
B-group	**12.85 (137)	**16.69 (116)	**25.41 (108)	17.42 (4)
Fin-clipped	15.11 (275)	26.22 (245)	35.10 (196)	20.85 (15)
Unclipped	21.18 (48)	25.94 (38)	31.80 (35)	28.49 (2)

* $P < 0.05$; ** $P < 0.005$, K-W X^2 test

October (Figure 25). The trend was most evident in passage times from the Bonneville Dam tailrace to the tops of ladders at McNary and Ice Harbor dams.

We also compared passage times based on fish released during each 10-d tagging period (Figure 26). The highest median passage times from the Bonneville dam tailrace to the top of McNary and Lower Granite dams were for fish released during August, with the lowest mean and median times for fish released early and late in the migration. Differences between releases were significant (ANOVA $P < 0.001$).

Median passage times for unclipped fish were significantly ($P = 0.08$, K-W X^2 test; $P = 0.03$, 1-way median test) longer than for fin-clipped fish from the Bonneville Dam tailrace to the top of McNary Dam (Table 10). Median passage times from the Bonneville Dam tailrace to the top of Ice Harbor or Lower Granite dams for fin-clipped versus unclipped steelhead were not significantly different ($P < 0.05$, K-W X^2 test).

Many steelhead that passed the Snake River or Priest Rapids dams entered lower-Columbia River tributaries; temporary straying that contributed to relatively low migration rates from the Bonneville Dam tailrace past upstream dams. By comparison, few steelhead temporarily strayed into monitored mid-Columbia River and lower-Snake River tributaries, and few were located in tributaries by mobile trackers. To examine steelhead passage rates past multiple dams with less influence by temporary straying, we calculated passage times from the first record in the McNary Dam tailrace to the first passage of top-of-ladder receivers at Ice Harbor, Lower Granite, and Priest Rapids dams. Fish with overwintering behavior were not included in comparisons if doing so inflated passage time for a migration segment.

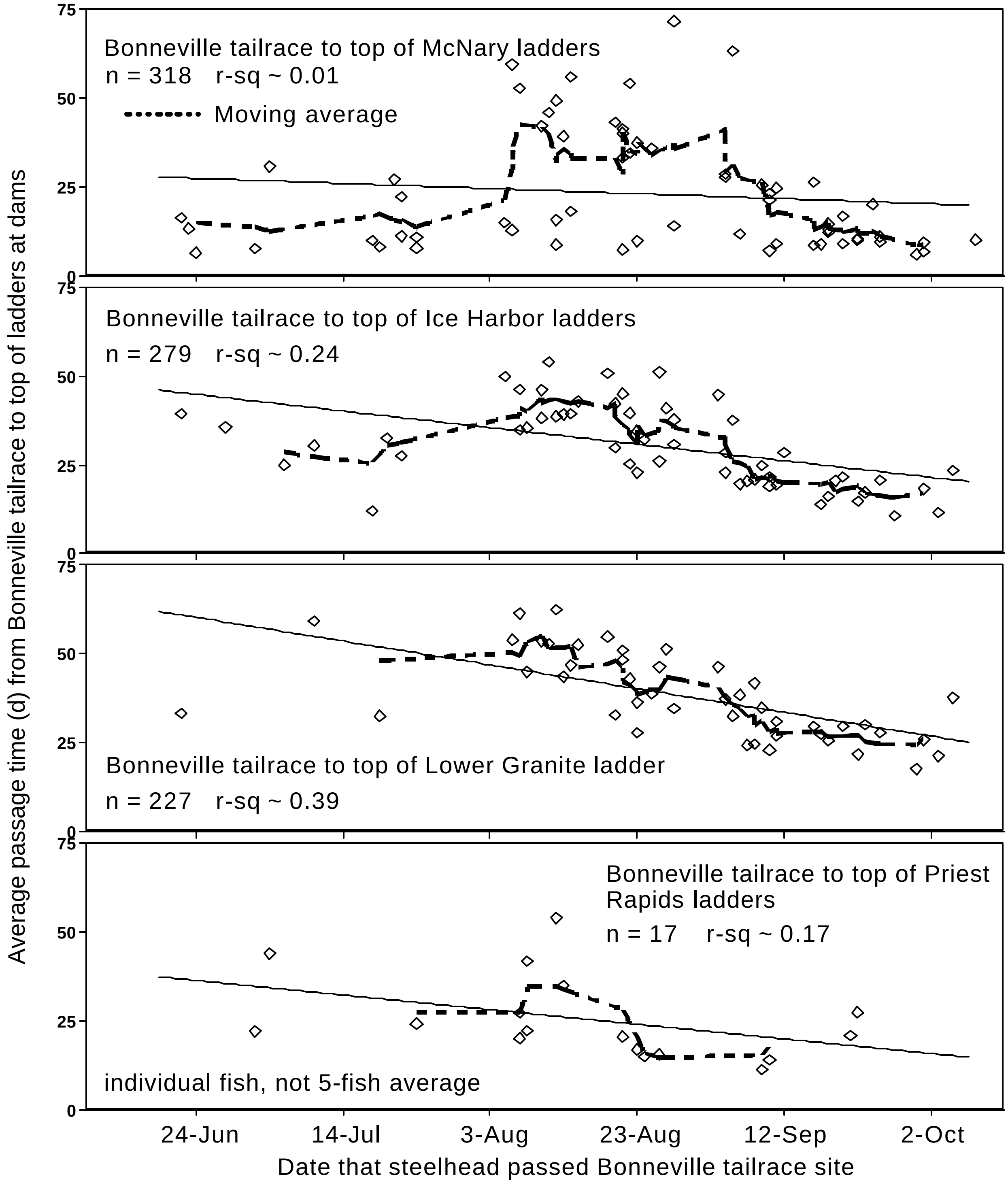

Figure 25. Mean days to pass from the Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, Lower Granite and Priest Rapids dams, based on date that groups of 5 steelhead passed the Bonneville Dam tailrace receivers. Overwintering fish and fish with passage times > 90 d not included.

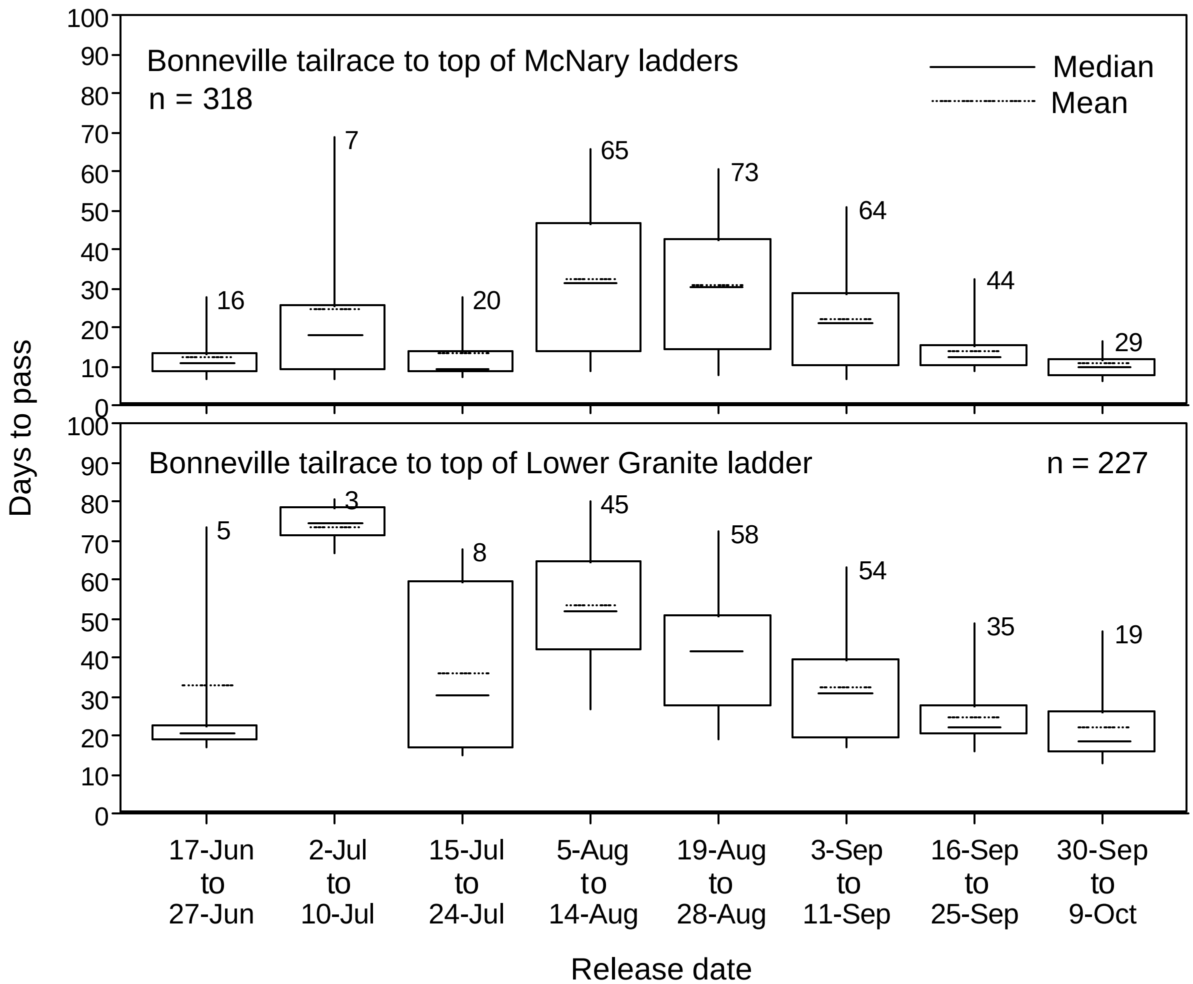

Figure 26. Mean, median, 5% and 95% percentiles, and quartile passage times for steelhead from the Bonneville Dam tailrace to the top of McNary and Lower Granite dams. Groups based on 10-d release schedule. Overwintering fish not included.

Passage times for 183 steelhead from the McNary Dam tailrace to the top of a ladder at Ice Harbor Dam ranged from 1.4 to 62 d with a median time of 3.38 d (Table 11). Of these, 116 were A-group steelhead, with a median passage time of 3.57 d and 67 were B-group steelhead with a median passage time of 3.16 d. Median time for 150 steelhead from the McNary Dam tailrace to the top of the Lower Granite Dam ladder was 11.02 d; times ranged from 5.5 d to more than 75 d. Median passage times were 11.51 d for A-group and 10.82 d for B-group steelhead (Table 11). Median passage times were significantly ($P < 0.05$, K-W X^2 test) longer for A-group versus B-group steelhead from the McNary Dam tailrace to pass Ice Harbor Dam. Differences in median passage times approached significance ($P = 0.09$, K-W X^2 test; $P = 0.25$, 1-way median test) for A-group versus B-group times past Lower Granite Dam. Median passage times for fin- clipped versus unclipped steelhead from the McNary Dam tailrace past either Ice Harbor or Lower Granite dams were not significantly different.

Table 11. Median number of days for radio-tagged A-group and B-group and fin-clipped and unclipped steelhead to pass from a McNary Dam tailrace receiver site to exit from the top of Ice Harbor, Lower Granite, and Priest Rapids ladders in 1996. Fish numbers are in parenthesis. Fish that overwintered at mainstem or tributary sites before migrating upriver not included.

	Ice Harbor	Lower Granite	Priest Rapids
Median days to pass from McNary Dam tailrace to top of ladder for all steelhead			
All	3.38 (183)	11.02 (150)	8.00 (10)
A-group	*3.57 (116)	11.51 (89)	10.51 (6)
B-group	*3.16 (67)	10.82 (61)	7.44 (4)
Fin-clipped	3.53 (160)	11.51 (129)	8.55 (9)
Unclipped	2.99 (23)	10.21 (21)	6.79 (1)

* $P < 0.05$; ** $P < 0.005$, K-W X^2 test

Median passage time was 8 d for 10 steelhead with records in the McNary Dam tailrace and top-of-ladder sites at Priest Rapids Dam (Table 11). We made no statistical comparisons for this group.

On average, steelhead with transmitters spent < 27% of the total time to migrate from the Bonneville Dam tailrace to the tops of McNary, Ice Harbor, and Lower Granite dams passing the 4 to 6 monitored dams (Figure 27). We only analyzed fish that were recorded at the tailrace and top-of-ladder receivers at each monitored dam. We summed first passage times over each dam and calculated the percentage of total passage time from the Bonneville Dam tailrace that was spent passing dams. We did not include time spent reascending a dam after fallback events. Median percentages were 22% from the Bonneville Dam tailrace to the top of McNary Dam, and about 18% to the top of Ice Harbor and Lower Granite dams. Mean and median percentages for fish that passed Lower Granite Dam were underestimates because passage times at Lower Monumental and Little Goose dams were not included in the sum of dam passage times. Cumulative dam passage time for steelhead was a relatively low proportion of overall passage times, in part because temporary straying by steelhead into tributaries significantly increased total passage times.

Steelhead with longer cumulative time to pass the dams tended to have longer total passage times to migrate from the Bonneville Dam tailrace to upriver dams. For each segment of the migration analyzed, total migration times increased with cumulative dam passage times; slopes of regression lines were positive, with r^2 values between 0.09 and 0.30 for fish that migrated past McNary, Ice Harbor and Lower Granite dams (Figure 28). Points that fell farthest from the regression lines (long total passage time and relatively short summed passage times at dams) were mostly fish that fell back over dams one or more times and subsequently reascended, or fish that strayed into tributaries for extended periods. Multiple passages at a single dam were not included in summed passage time. (See section on fallback at dams for additional information on the effects of fallbacks on passage times.)

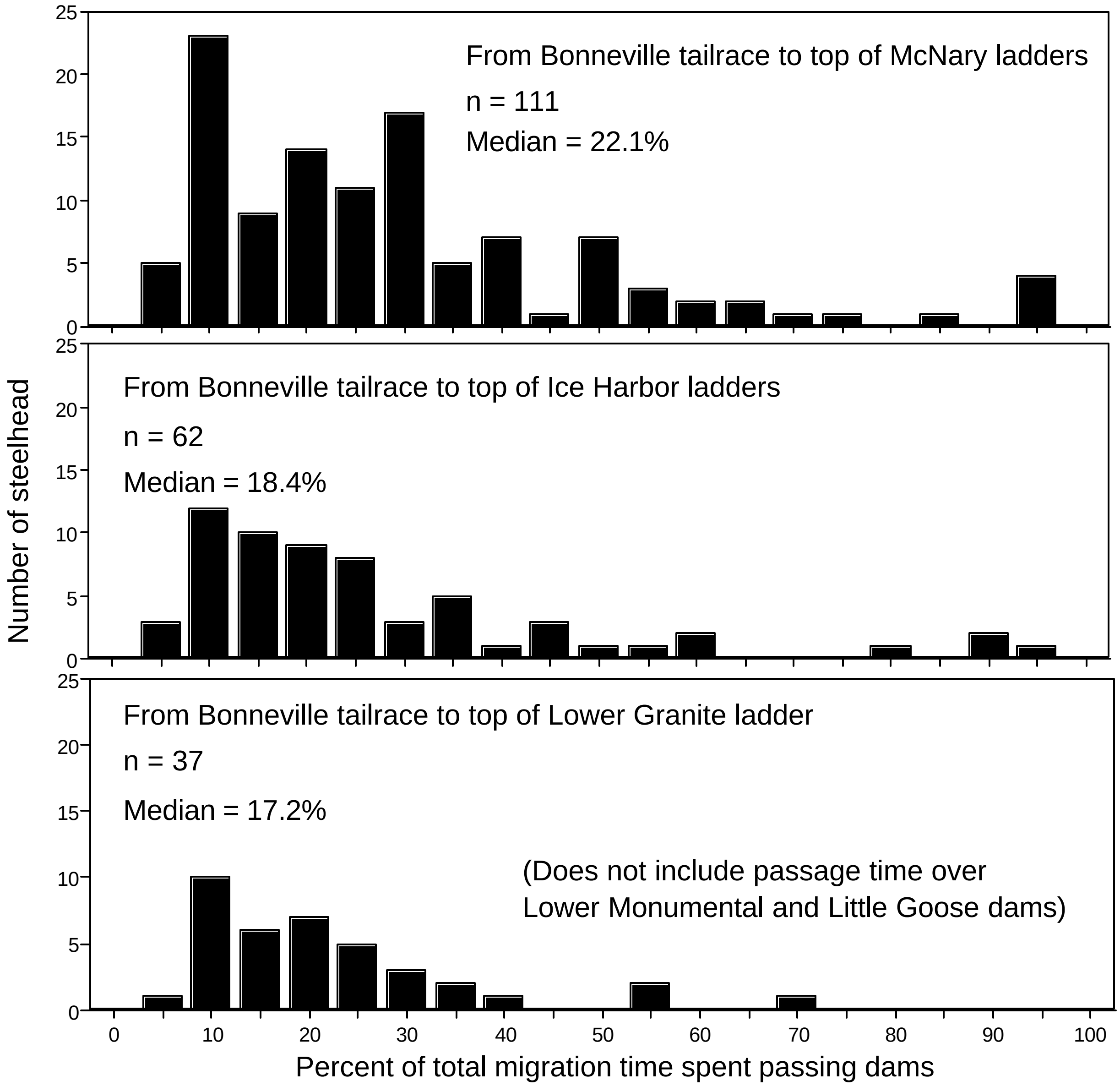

Figure 27. Number of steelhead and the percent of total passage time spent on first passage of dams (dam passage times after fallback not included) from Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, and Lower Granite for steelhead in the run-year 1996-1997. Overwintering fish and fish with passage times > 90 d not included. Percentages for fish that passed Lower Granite Dam are underestimates because passage was not monitored at Lower Monumental and Little Goose dams.

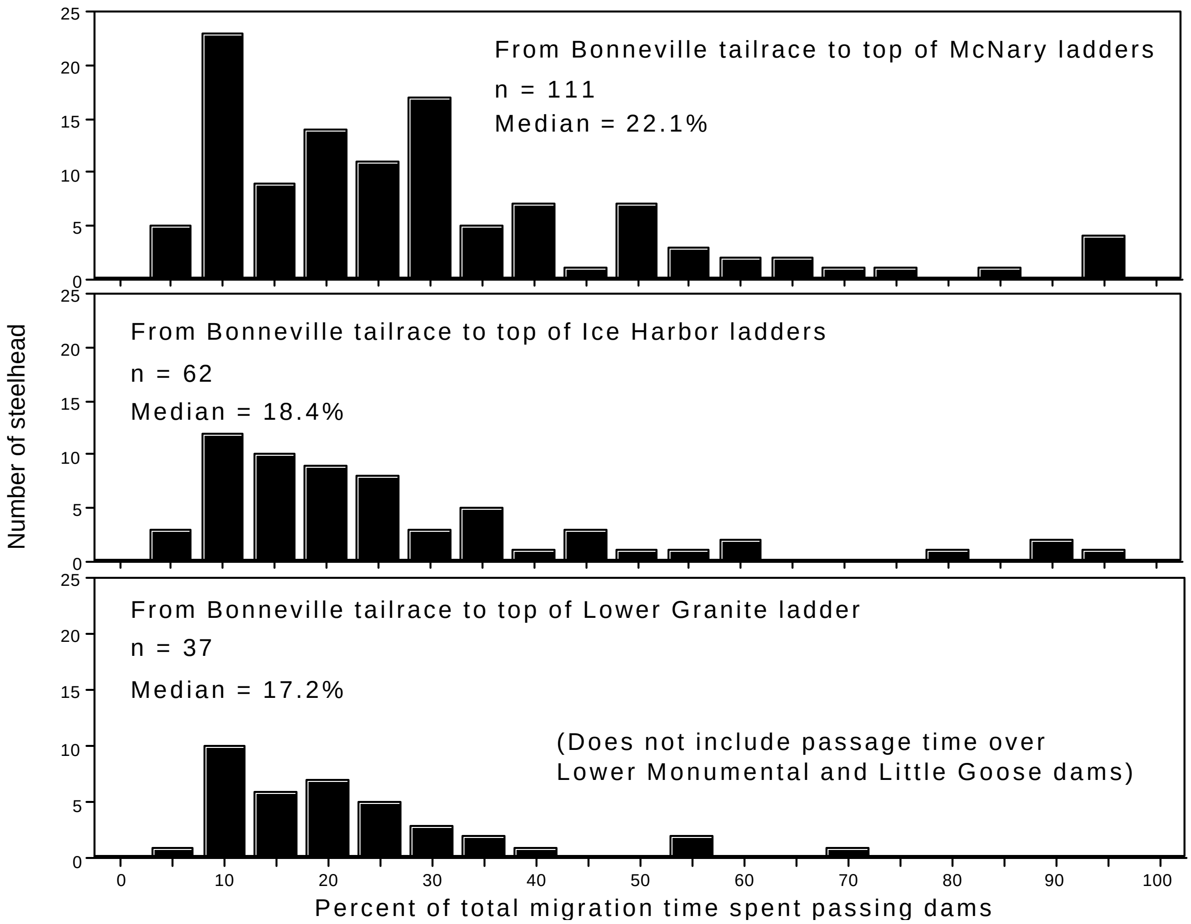

Figure 28. Sum of individual dam passage times and total time for steelhead to pass from the Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, and Lower Granite dams in the run-year 1996-1997. Time for fish to reascend dams following fallback events, overwintering fish and fish with passage times > 90 d not included.

Effects of Injury on Passage Times

We examined all steelhead outfitted with transmitters in 1996 for injuries at time of tagging, including fresh scrapes and bites from marine mammals, descaling, gill net marks, sores, cuts, and fungal infections. Of 770 steelhead outfitted with transmitters, 679 (88%) had marine mammal marks; 485 (63%) had fresh scrapes, and 194 (25%) had fresh marine mammal bites. About 47% of the 770 steelhead had no descaling, 48% less that 10%, 4% were 10-25% descaled, and < 1% were more than 25% descaled. Less then 1% of the steelhead we tagged had gill net marks. Approximately 91% had no head or mouth injuries, 3% had scrapes, cuts, or skinned areas, about 4% had sores or hook marks, < 1% had eye injuries, and about 3% had some head or jaw deformity. We used analysis of variance (ANOVA) and nonparametric tests, and X^2 tests to determine whether the most prevalent injuries, marine mammal marks and descaling, affected migration times past individual or multiple dams.

We first tested whether proportions of steelhead known to have passed McNary, Ice Harbor, or Lower Granite dams with and without fresh marine mammal marks and with or without descaling were different from the proportion in each category when fish were outfitted with transmitters. We found no significant differences in proportions ($P > 0.43$ for marine mammal marks, $P > 0.41$ for descaling) using X^2 tests of independence, but there was some evidence that marine mammal marks or descaling affected dam passage by steelhead. The proportion of fish passing dams with no fresh marine mammal marks increased at each dam from 11.8% at time of tagging to 14.6% at Ice Harbor Dam; at Lower Granite Dam the proportion with no marks was 12.9%. Of steelhead outfitted with transmitters, 46.8% had no descaling and the proportion passing dams with no descaling increased at each dam to 52.3% for those passing Lower Granite Dam. The proportion of fish passing dams with both descaling and fresh marine mammal marks was between 88.9% and 90.3%, compared to 90.5% at time of tagging. Although the trends suggested lower proportions of fish with marks were passing dams, we found no significant interaction between fresh mammal marks and descaling and the proportion of fish passing dams.

Fresh marine mammal marks had little impact on passage times past individual dams. In 3-category (no marks, fresh scrape, fresh bite) ANOVA and nonparametric tests, we found no significant differences at $P < 0.10$ in passage times from tailrace to top-of-ladder receivers among all fish that passed in < 10 d. Differences in mean passage times approached significance at Bonneville Dam, where mean passage for fish with no marks was 0.80 d versus 1.07 d for fish with fresh bites (ANOVA $P = 0.12$; $P = 0.60$, K-W X^2 test) (Table 12). At all other dams, P values for ANOVA and X^2 tests were > 0.24. Two-category tests (fish with no marks versus fish with either fresh scrape or bite) produced similar non-significant results.

Relatively few (4% to 6%) steelhead with transmitters that passed dams had > 10% descaling, but median passage times were longer for those fish than for steelhead with none or < 10% descaling at all but McNary Dam (Table 12). Mean passage times were longest for fish with >10% descaling at all but The Dalles and McNary dams. In 3-category (no descaling, <10% descaling, >10% descaling) ANOVAs, mean passage times were significantly different at Bonneville and John Day dams; fish with no descaling had the lowest mean times and fish with > 10% descaling had the longest mean times (ANOVA $P < 0.02$). At McNary Dam, fish with > 10% descaling had significantly shorter mean passage time (0.40 d) than fish with < 10% descaling (0.88 d) (ANOVA $P = 0.05$) (Table 12). We found no significant differences in mean passage times at The Dalles, Ice Harbor, and Lower Granite dams (ANOVA $P = 0.21$ to 0.25). Nonparametric tests of the effects of descaling produced mixed results. We found significant differences at The Dalles, John Day, and McNary dams ($P = 0.00$ to 0.02, K-W X^2 test). At the Dalles Dam, steelhead with > 10% descaling had the longest median passage time (0.77 d) and fish with < 10% descaling the shortest median time (0.55 d), at John Day Dam, fish with > 10% descaling had the longest median time (1.28 d) and fish with no descaling the shortest time (0.80 d), and at McNary Dam fish with < 10% descaling had the longest median time (0.62 d) and fish with no descaling had the shortest median time (0.34 d) (Table 12).

Table 12. Mean and median passage times past dams by steelhead with or without fresh marine mammal scrapes or bites, and with or without descaling at time of tagging at Bonneville Dam in 1996. Steelhead with passage times > 10 d not included.

	Marine mammal marks			Descaling		
	none	scrape	bite	none	<10%	>10%
Bonneville Dam						
Number	81	412	171	313	317	34
Mean time (d)	0.80	0.88	1.07	0.82	0.96	1.42
Median time (d)	0.65	0.71	0.68	0.69	0.69	0.82
The Dalles Dam						
Number	52	222	91	176	168	21
Mean time (d)	0.94	0.85	0.96	0.98	0.81	0.83
Median time (d)	0.68	0.63	0.68	0.73	0.55	0.77
John Day Dam						
Number	50	223	104	186	172	19
Mean time (d)	1.64	1.31	1.19	1.10	1.36	3.14
Median time (d)	1.02	0.83	0.80	0.80	0.83	1.28
McNary Dam						
Number	34	132	39	104	92	9
Mean time (d)	0.81	0.65	0.79	0.58	0.88	0.40
Median time (d)	0.35	0.43	0.49	0.34	0.62	0.39
Ice Harbor Dam						
Number	32	138	59	123	97	9
Mean time (d)	0.65	0.92	0.72	0.72	0.95	0.98
Median time (d)	0.61	0.61	0.60	0.60	0.61	0.65
Lower Granite Dam						
Number	19	87	46	76	66	10
Mean time (d)	1.13	1.60	1.44	1.48	1.39	2.22
Median time (d)	1.02	1.10	1.05	1.05	1.06	1.35

We found no significant difference in median passage times at Bonneville, Ice Harbor, or Lower Granite Dams (P = 0.20 to 0.40, K-W X^2 test).

Two-category tests (no descaling versus > 0% descaling) produced results generally similar to 3-category tests. At Bonneville Dam, fish with descaling had significantly longer mean passage time (1.00 d) than fish with no descaling (0.82 d) (ANOVA P = 0.04). At The Dalles Dam, fish with descaling had significantly shorter median passage time (0.60 d) than fish with no descaling (0.73 d) (P = 0.02, K-W X^2 test). At John Day Dam, fish with no descaling had significantly shorter mean passage time (1.10 d) than fish with descaling (1.54 d) (ANOVA P = 0.01), and at McNary Dam steelhead with no descaling had significantly shorter mean (0.58 d versus 0.83 d) and median (0.34 d versus 0.57 d) passage times than fish with descaling (ANOVA P = 0.05; P = 0.00, K-W X^2 test).

We found little evidence that fresh marine mammal scrapes or bites delayed steelhead migration past multiple dams. Fish recorded at the Bonneville Dam tailrace receiver and at the top of McNary Dam ladders had median passage times of 21.0 d for fish with no scrapes or bites, 14.8 d for fish with fresh scrapes, and 19.3 d for fish with fresh bites (Table 13). With all steelhead included that did not overwinter, passage time differences were not significant among the three categories (ANOVA P = 0.25; P = 0.37, K-W chi-squared test); P values were higher when we removed the 21 (7%) fish with passage times > 60 d. Median times from the Bonneville Dam tailrace to the top of Ice Harbor Dam were 28.1 d for fish with no marks, 24.9 d for fish with fresh scrapes, and 26.0 d for fish with fresh bites (Table 13). Mean and median passage times were not significantly different (P values ~ 0.44) with all fish included. Removal of the 28 (10%) fish with passage times > 60 d lowered P values, but differences were not significant at P < 0.10. Median times from the Bonneville Dam tailrace to the top of Lower Granite Dam were 38.3 d for fish without fresh no scrapes or bites, 35.0 d for fish with fresh scrapes, and 33.8 d for fish with fresh bites (Table 13). We found no significant differences in mean or median passage times past Lower Granite Dam (P values ~ 0.69 with all fish included; P > 0.40 after removal of 39 (17%) fish with passage times > 60 d). Median times from the McNary Dam tailrace to the top of Lower Granite Dam were 10.0 d for fish with no scrapes or bites, 11.1 d for fish with fresh scrapes, and 12.2 d for fish with fresh marine mammal bites (Table 13). Mean and median times were not significantly different (P values > 0.50 with all fish included, P > 0.70 after removal of 15 (10%) fish with passage time > 30 d).

When we compared passage times for fish without fresh marine mammal marks to those with either fresh scrapes or fresh bites, we found no significant (P < 0.10) differences in mean or median passage times from the Bonneville Dam tailrace to the top of McNary, Ice Harbor or Lower Granite Dam or from the McNary Dam tailrace to the top of Lower Granite Dam. Excluding the high passage-time fish described above had little impact on P values.

There was some evidence that > 10% descaling delayed passage past multiple dams, but results should be interpreted with caution due to the small number of fish in this category. Median times from the Bonneville Dam tailrace to the top of McNary Dam were about 16 d for fish with no or < 10% descaling, compared to 27.2 d for 14 fish with > 10% descaling (Table 13). Differences were significant (ANOVA P = 0.03; P = 0.13, K-W X^2 test). In 2-category tests (no descaling versus > 0% descaling) we found no significant differences in mean or median passage times (P values > 0.57). Steelhead with > 10% descaling had longer mean and median passage times from the Bonneville Dam tailrace to the top of Ice Harbor Dam (ANOVA P = 0.06; P = 0.28, K-W X^2 test), but we found no significant differences in 2-category tests in mean or median passage times (P values > 0.70). Median passage times from the Bonneville Dam tailrace to the top of Lower Granite Dam were 36.6 d for fish with no descaling, 33.9 d for fish with < 10% descaling, and 36.9 d for 8 fish with > 10% descaling (Table 13); differences in mean and median passage times were not significant (P values > 0.47). Excluding fish with passage times > 60 d had little impact on P values for passage time analyses from the Bonneville Dam tailrace.

Table 13. Mean and median passage times past multiple dams by steelhead with or without fresh marine mammal scrapes or bites, and with or without descaling at time of tagging at Bonneville Dam in 1996. Overwintering steelhead not included.

	Marine mammal marks			Descaling		
	none	scrape	bite	none	<10%	>10%
Bonneville Dam tailrace to top of McNary Dam						
Number	45	196	82	166	143	14
Mean time (d)	29.1	23.7	25.4	24.4	24.0	38.7
Median time (d)	21.0	14.8	19.3	16.0	16.1	27.2
Bonneville Dam tailrace to top of Ice Harbor Dam						
Number	39	170	73	148	121	13
Mean time (d)	34.8	30.2	30.6	30.5	30.0	44.1
Median time (d)	28.1	24.9	26.0	24.4	27.0	39.8
Bonneville Dam tailrace to top of Lower Granite Dam						
Number	26	140	65	124	99	8
Mean time (d)	41.7	39.4	37.8	40.5	37.4	42.6
Median time (d)	38.3	35.0	33.8	36.6	33.9	36.9
McNary Dam tailrace to top of Lower Granite Dam						
Number	22	92	36	81	61	8
Mean time (d)	13.8	16.1	16.2	16.4	15.7	10.6
Median time (d)	10.0	11.1	12.2	10.9	12.8	9.9

Median passage times from the McNary Dam tailrace to the top of Lower Granite Dam were 10.9 d for fish with no descaling, 12.8 d for fish with < 10% descaling, and 9.9 d for 8 fish with > 10% descaling (Table 13). With all fish included, mean and median passage times were not significantly different (P values > 0.27). When we only included steelhead with passage times < 30 d, passage times for steelhead with no descaling were lower than times for steelhead with descaling (ANOVA P = 0.09; P = 0.11, K-W X^2 test).

Effects of Transition Pool Fallout on Passage Time

Steelhead behavior in fishways including entrance use, transition pool behavior, and passage time through portions of fishways have been summarized in Keefer et al. (2002a). In that report, we described passage delays associated with transition pool behavior, and found that significant delays occurred when fish exited transition pools into tailrace areas. Between 41% and 48% of the fish that passed Bonneville, McNary, or Lower Granite dams moved downstream from transition pools at the bottom of fish ladders into tailraces at those dams (Figure 29). Median times to pass through transition pools were 1.0 h or less for all fish that did not fall out to the tailraces, but times were between 4.0 h and 10.4 h for fish that fell out to the tailrace at Bonneville, McNary, or Lower Granite dams (Figure 29). Delays associated with exiting transition

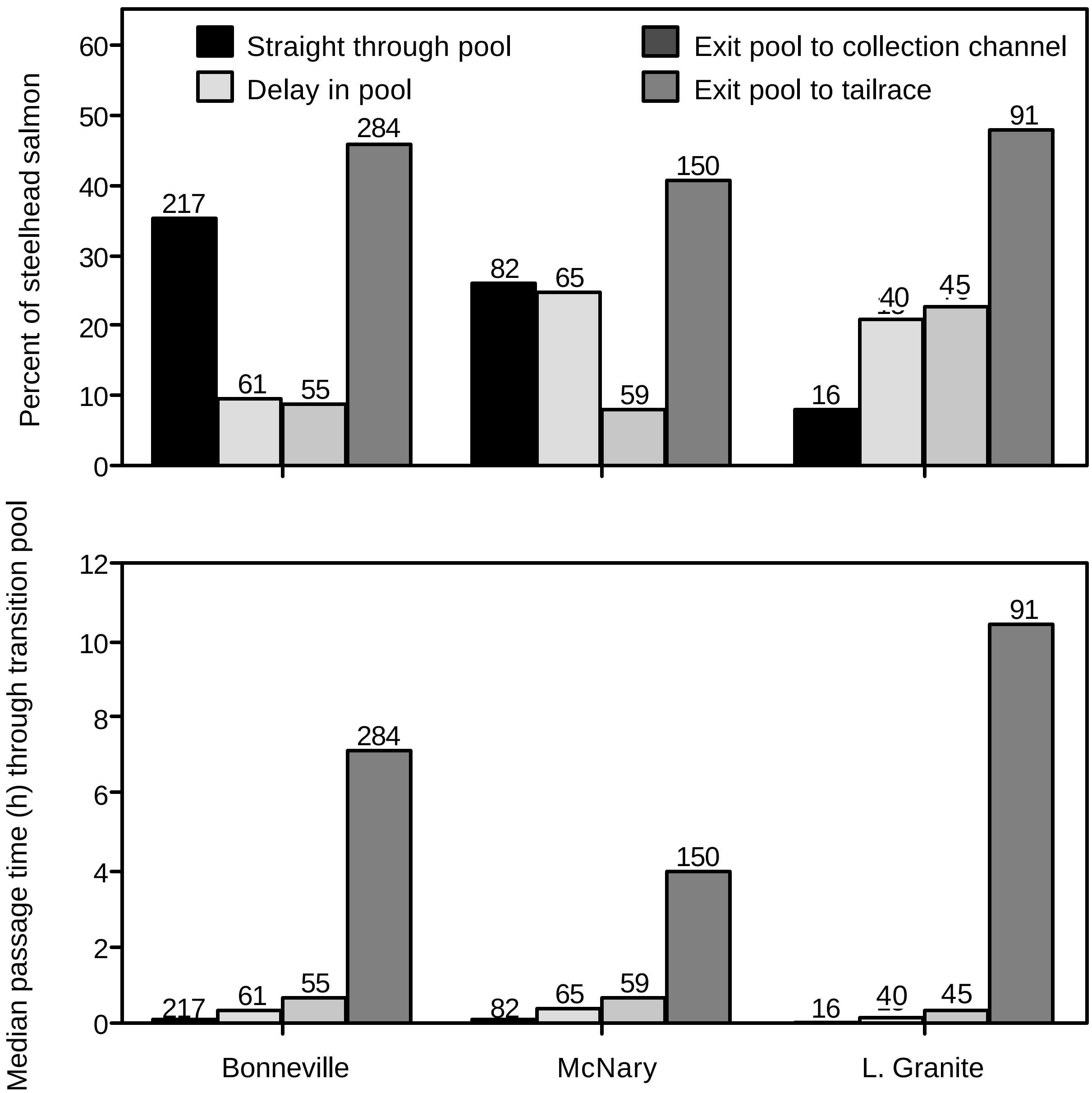

Figure 29. Percent of steelhead that moved straight through transition pools, were delayed temporarily, exited pools to collection channels, or exited pools into the tailrace (upper graph), and time to pass through transition pools at Bonneville, McNary, and Lower Granite Dam in 1996.

pools into tailraces increased steelhead passage times past individual dams. In the context of general migration, we tested whether delays due to transition pool fallout at dams affected the overall time to pass several dams.

We had complete transition pool records at both Bonneville and McNary dams for 243 steelhead with transmitters. Fish that fell out of transition pools at either Bonneville or McNary Dam or at both dams did not have significantly (P> 0.30, K-W X2 tests) longer median passage times from the Bonneville Dam tailrace to the top of McNary Dam than steelhead that did not fallout at either dam. The number of fallouts from transition pools at the two dams was not correlated with total passage time form the Bonneville Dam tailrace to the top of McNary Dam. Mean and median passage times were lower for fish with 1, 2, or 3 fallouts than for fish with no fallouts, and fish with 5 or more fallouts had similar mean and median times to fish with no fallouts; differences were not significant (Figure 30). Although telemetry coverage was less complete in fishways and transition pools at The Dalles and John Day dams, we believe records were sufficient to estimate transition pool behavior. Mean and median passage times from the Bonneville Dam tailrace to the top of McNary Dam increased with increased numbers of dams where fish fell out of transition pools (Figure 31). Medians times were 13.1 d for steelhead that did not fallout at any dam, 14.3 d for fish that fell out at 1 dam, 18.2 d for fish that fell out at 2 dams, 21.0 d for fish that fell out at 3 dams, and 16 d for all fish that fell out at one or more dams. Differences in medians were not significant (P = 0.11 for all categories, 0.18 for no fallouts versus 1 or more, K-W X^2 tests). Mean passage times were 12.8 d for fish that did not fallout, 21.6 d for fish that fell out at 1 dam, 30.1 d for fish that fell out at 2 dams, and 30.0 d for fish that fell out at 3 dams; differences were significant for fish that fell out at 2 or 3 dams (ANOVA P ~ 0.03) (Figure 31).

Multivariate Analysis of Steelhead Passage Times Past Multiple Dams

We used multiple regression techniques to analyze upriver passage by steelhead to determine which factors most influenced time to pass multiple projects. Based on first records of fish at tailrace receivers, we were able to identify in-river environmental conditions at discreet points during upstream migration, including total flow, spill, water temperature, and Secchi disk visibility. We also used the date fish were outfitted with transmitters, the number of downstream fallback events by each fish, and/or the time steelhead spent in lower Columbia River tributaries. (Also see sections on the effects of fallback and tributary use on passage time.) We did not include steelhead that overwintered prior to passing upstream dams in multiple regression models. Because tailrace receiver efficiency was < 100% (Table 6), some steelhead did not have tailrace records at every dam they passed. In addition, sample sizes varied because some environmental data was unavailable or of poor quality after 31 October.

We used forward stepwise multiple regression models to identify significant variables affecting passage from the Bonneville Dam tailrace to the top of Lower Granite Dam, and from the McNary Dam tailrace to the top of Lower Granite Dam. A significance level of P = 0.10 was the model retention cutoff. Prior to building multiple regression models, we used univariate graphical methods to identify the most influential

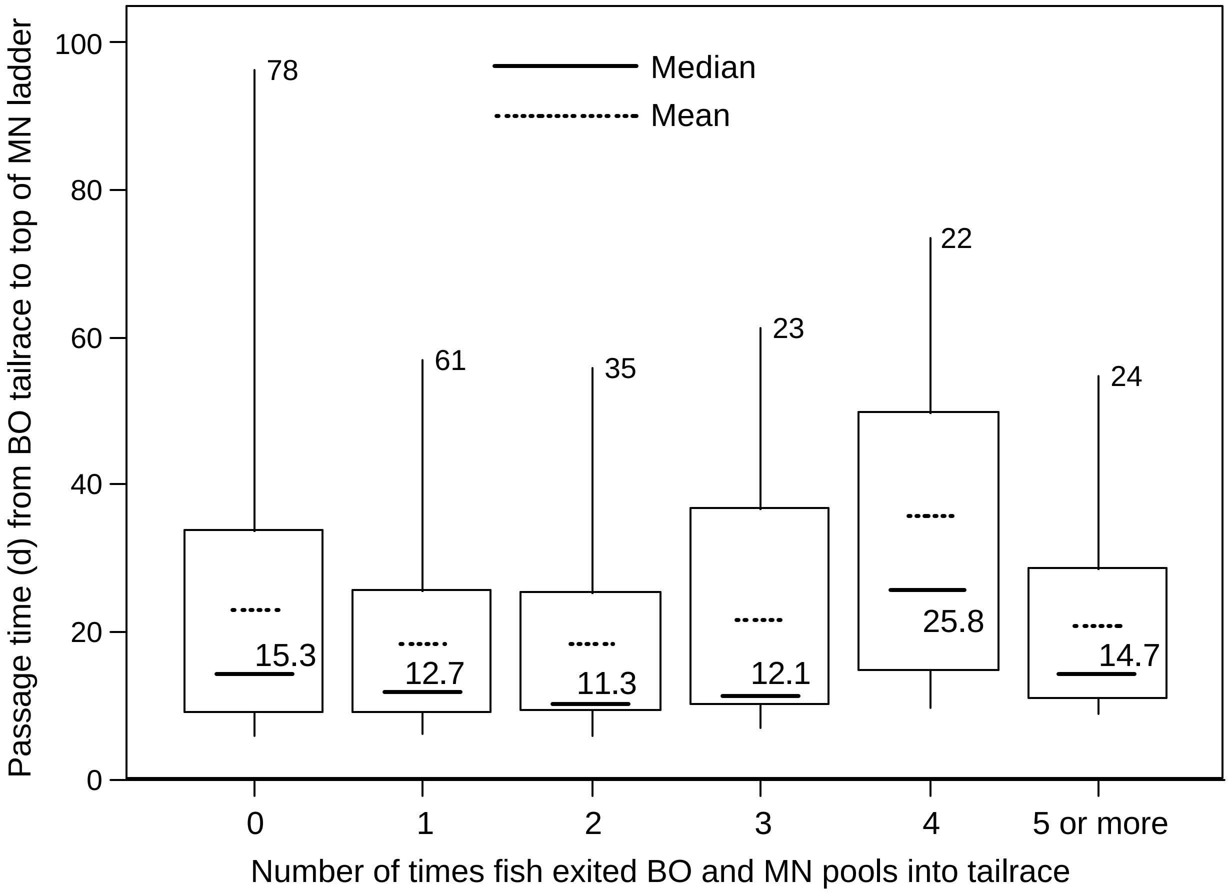

Figure 30. Mean, median, minimum, maximum and quartile times to pass from the Bonneville Dam tailrace to the top of McNary Dam by steelhead that did or did not fall out of transition pools into tailraces at Bonneville and/or McNary dams in 1996.

variables, to check data for linear and non-linear trends, and to identify outliers. We also compared subsets of multiple regression models using r^2 selection methods (Proc REG, SAS Institutes, Inc. 2001)

Many independent variables were non-normally distributed, or had little variability (i.e. spill, number of fallbacks, Secchi depth at Lower Granite Dam) (Figure 32). Sixteen of 33 independent variables had correlation coefficients > 0.20 with total passage time from release to the top of Lower Granite Dam (Figure 33). Time steelhead spent in lower Columbia River tributaries had the highest correlation (0.58) with total passage time (see section on temporary straying for calculations of time in tributaries). The dates that steelhead passed tailrace sites at dams and tagging date also had relatively high correlations with passage time, as did Columbia River water temperatures when fish passed tailrace sites (Figure 33). Spill, flow, and Secchi depth conditions when fish passed tailrace sites were only weakly correlated with upriver passage times (r^2 generally < 0.20), except for spill (r^2 = 0.42) at Bonneville Dam. The higher correlation between spill at Bonneville Dam and passage time was likely

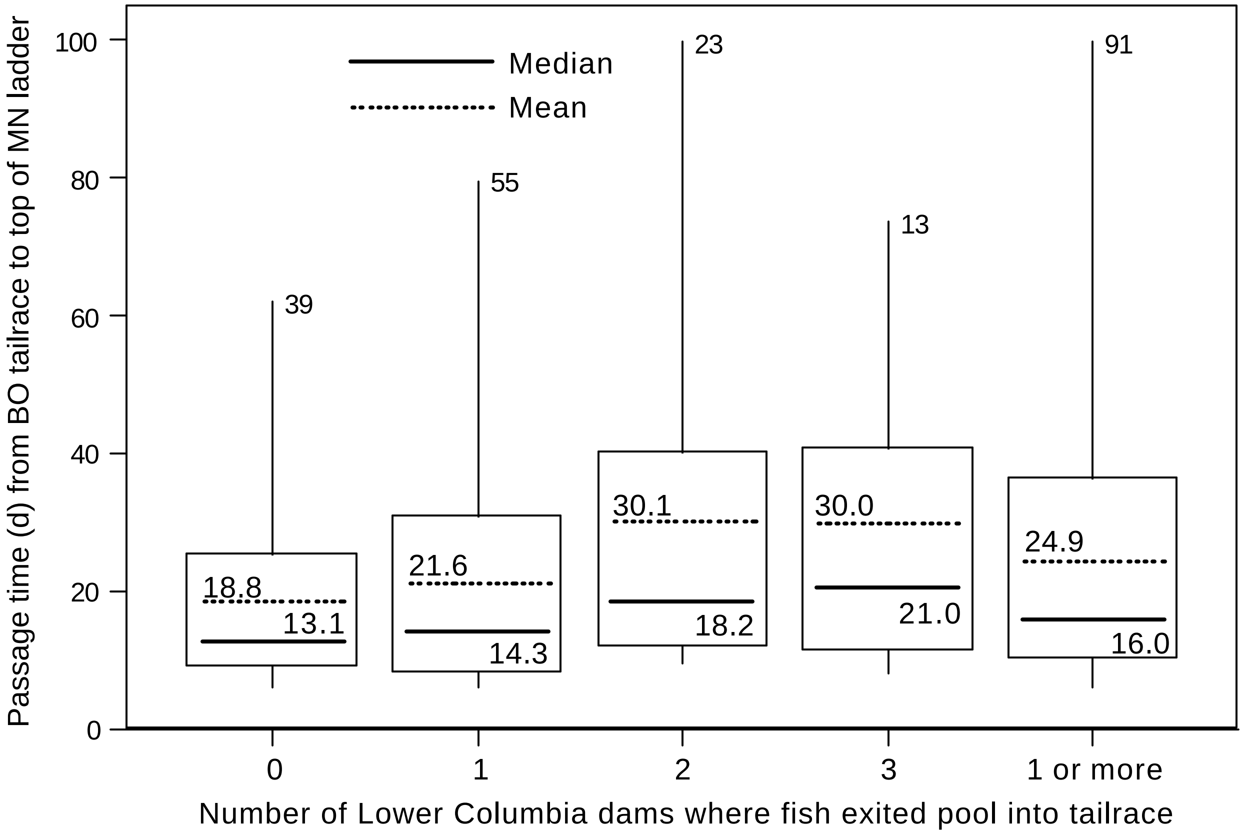

Figure 31. Mean, median, minimum, maximum and quartile times to pass from the Bonneville Dam tailrace to the top of McNary Dam by steelhead that did or did not fall out of transition pools into tailraces at Bonneville, The Dalles, John Day, and/or McNary dams in 1996.

because most B-group steelhead passed during near-zero spill, and B-group fish used tributaries less and migrated upstream at higher rates.

Because dates steelhead passed tailrace sites were highly correlated with tag date, dates at other dams, and water temperatures, we only included tag date in multiple regression models. In addition, it is important to note that environmental conditions at dams were correlated throughout the migration. This created analyses problems, as it was difficult at times to distinguish between effects of similar variables like flow, spill, and water temperature at different sites. (See statistical methods section for further discussion model building limitations and expectations.)

In a preliminary forward stepwise regression model, we included influential variables other than environmental conditions: time in lower Columbia River tributaries, tagging date, and number of downstream fallback events (Model 1; Table 14). Time in tributaries was the first variable selected for 235 non-overwintering fish, with an r^2 value of 0.42, followed by tag date and number of downstream fallback events for an overall model r^2 of 0.54. Tag date explained about 18% of the variability in passage times

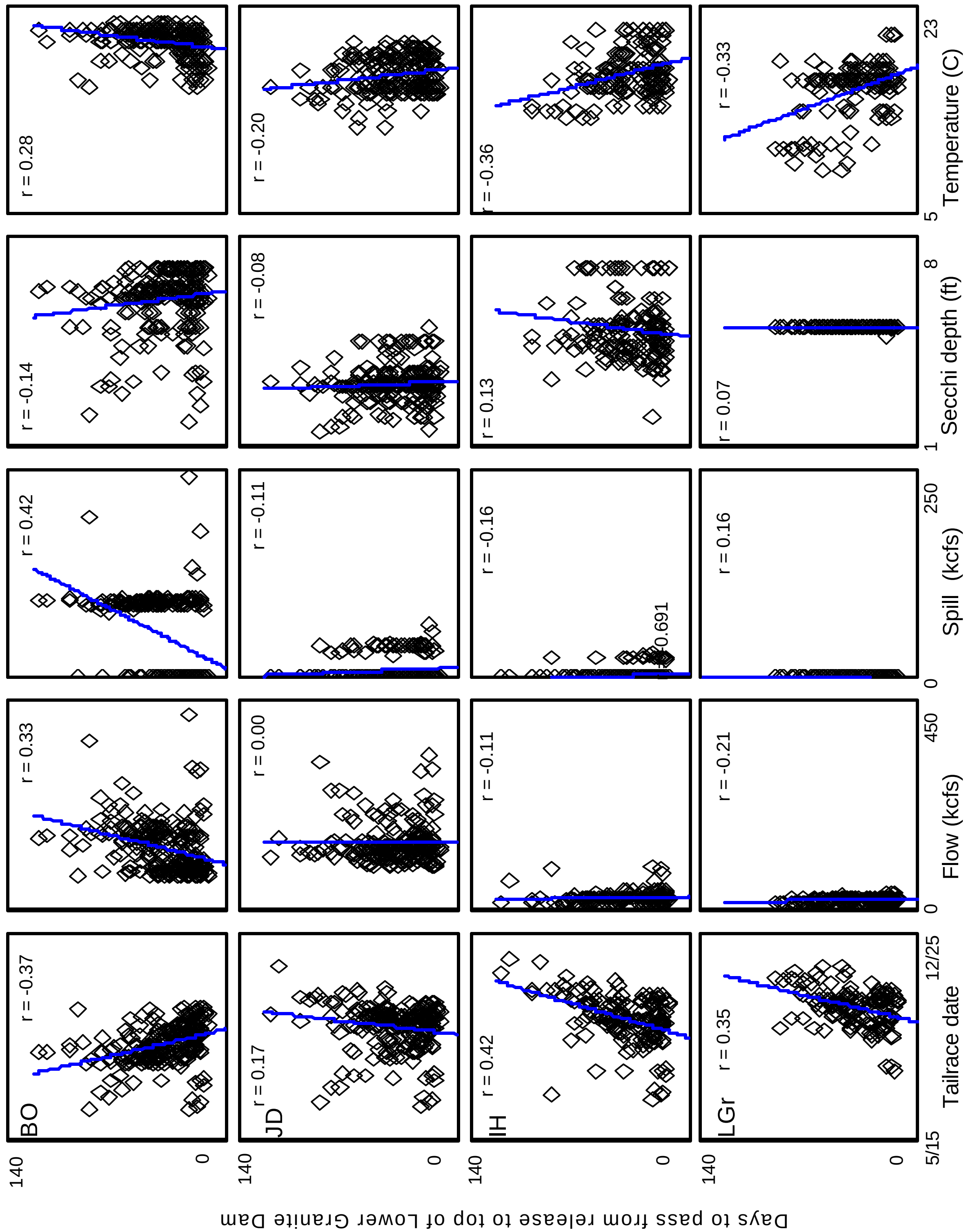

Figure 32. Selected scatter plots and correlation coefficients for environmental variables used in multiple regression models, based on daily mean values when steelhead first passed tailrace receivers at Bonneville Dam, John Day, Ice Harbor, and Lower Granite dams in 1996. Overwintering fish not included.

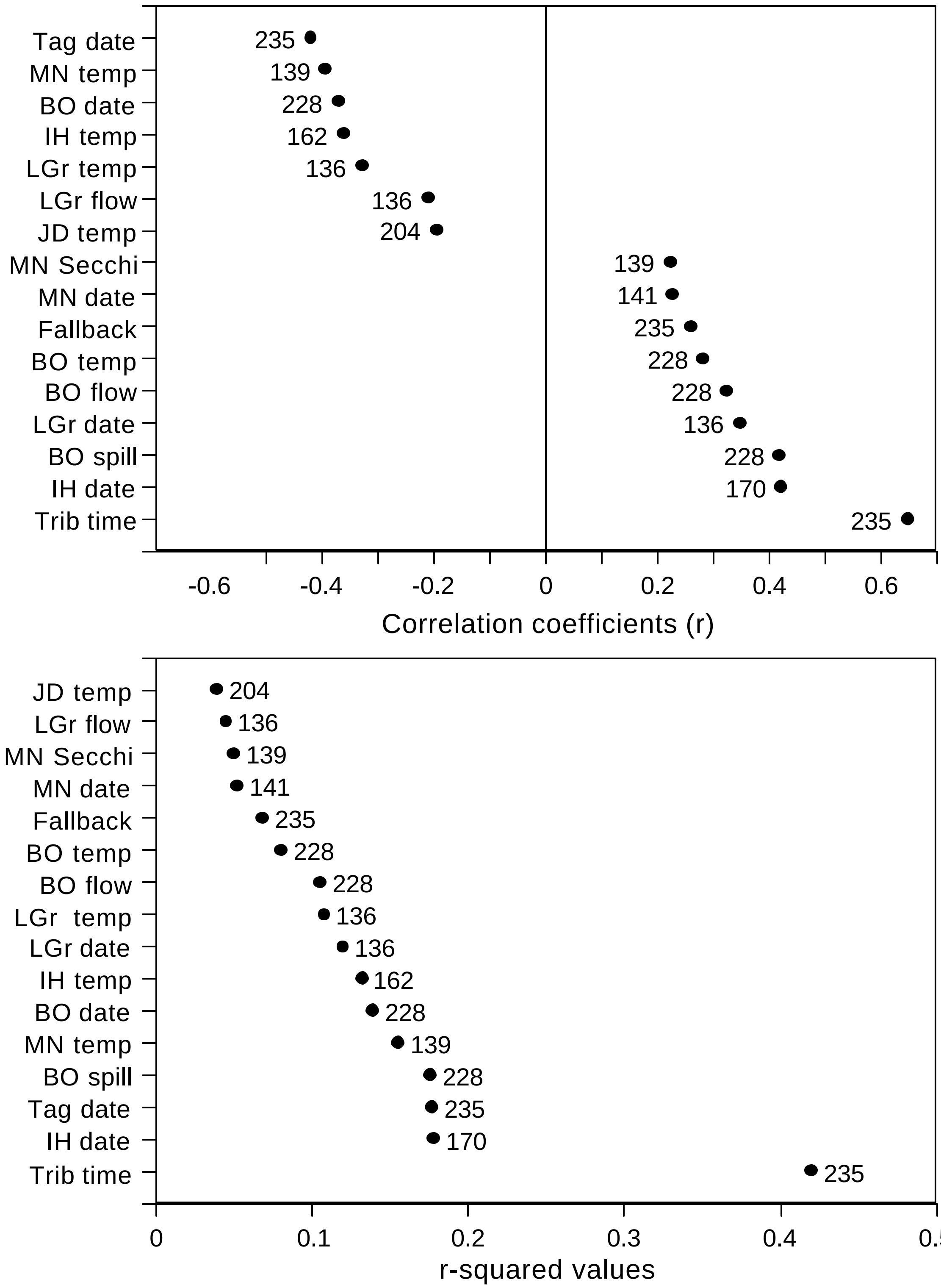

Figure 33. Comparisons of correlation coefficients and r^2 values for passage time from release to the top of Lower Granite Dam and independent variables used in multiple regressions. Only includes variables with r > 0.20. Overwintering fish not included.

Table 14. Stepwise multiple regression model outputs for the time to pass of steelhead from the Bonneville Dam tailrace to the top of Lower Granite Dam in 1996, including models run, variables retained, and standard procedure outputs. Independent variables were tag date, number of downstream fallback events, and time in lower Columbia River tributaries.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
	tag date	fallback events	tributary time			
Model 1, All variables; 235 fish						
	a. Tributary time		0.4199	0.4199	168.63	0.0001
	b. Tag date		0.4998	0.0799	37.07	0.0001
	c. Fallback events		0.5385	0.0388	19.40	0.0001
Model 2, All variables *except* tributary time; 235 fish						
	a. Tag date		0.1775	0.1775	50.28	0.0001
	b. Fallback events		0.2139	0.0364	10.75	0.0012
Model 3, All variables, fish that fell back not included; 203 fish						
	a. Tributary time		0.4957	0.4957	197.61	0.0001
	b. Tag date		0.5362	0.0405	17.46	0.0001

when time in tributaries was excluded from the model (Model 2; Table 14). When we removed all fish that fell back at dams downstream from Lower Granite Dam, tributary time was first selected, followed by tag date, for a model r^2 of 0.54 (Model 3; Table 14).

Building on models in Table 14, we added flow, spill, Secchi depth visibility, and water temperature at the time fish passed tailrace receivers, starting with data at Bonneville Dam for 228 fish. With all variables included, time in tributaries, tag date, and number of downstream fallback events were selected for an overall r^2 of 0.54; no environmental variables were selected (Model 1; Table 15). When we removed time in tributaries, spill at Bonneville Dam was first selected, followed by the number of fallback events, water temperature, tag date, and Secchi depth for an r^2 of 0.26 (Model 2; Table 15). Excluding fish that fell back produced similar results: time in tributaries explained the highest proportion of the variability in passage times, and spill and water temperature at Bonneville Dam were selected when tributary time was removed.

Stepwise models for 161 fish with records in the Ice Harbor Dam tailrace produced more significant results than those for fish recorded in the tailraces of Bonneville or John Day dams. Time in tributaries, tag date, and number of fallback events were again selected first (r^2 = 0.61), followed by temperature and flow on the date that fish passed the Ice Harbor tailrace for a model r^2 of 0.76. When we removed tributary time, tag date and temperature at Ice Harbor Dam were first selected (r^2 = 0.49), followed by flow and Secchi depth at Ice Harbor Dam for a model r^2 of 0.73. However, high correlation (r^2 = -0.71) between the date and water temperature when fish passed the Ice Harbor Dam tailrace indicated that tag date and Ice Harbor water temperature should not be included in the same model. When we removed tag date, the stepwise model selected temperature at Ice

Table 15. Stepwise multiple regression model outputs for the time to pass of steelhead from the Bonneville Dam tailrace to the top of Lower Granite Dam in 1996, including models run, variables retained, and standard procedure outputs. Independent variables were tag date, number of downstream fallback events, time in lower Columbia River tributaries, and environmental variables measured on the date that each fish passed the Bonneville Dam (BO) tailrace.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
	tag date	fallback events		tributary time		
	BO flow	BO spill		BO temperature	BO Secchi	
Model 1, All variables; 228 fish						
	a. Tributary time		0.4165	0.4165	161.33	0.0001
	b. Tag date		0.4943	0.0778	34.60	0.0001
	c. Fallback events		0.5393	0.0450	21.88	0.0001
Model 2, All variables *except* tributary time; 228 fish						
	a. BO spill		0.1756	0.1756	48.14	0.0001
	b. Fallback events		0.2136	0.0380	10.86	0.0011
	c. BO temperature		0.2354	0.0218	6.38	0.0122
	d. Tag date		0.2451	0.0097	2.88	0.0911
	e. BO Secchi		0.2631	0.0179	5.41	0.0210
	f.	BO temperature	0.2613	0.0017	0.51	0.4741

Harbor Dam and fallback events for a model r^2 of 0.22.

We had complete environmental data for 158 steelhead with records at tailrace receivers at both Bonneville and Ice Harbor dams. With all variables included, time in tributaries, downstream fallback events and tag date were selected first ($r^2 = 0.60$), followed by water temperature, flow, and Secchi depth at Ice Harbor Dam on the date fish entered the Ice Harbor tailrace for an overall r^2 of 0.78 (Model 1; Table 16). When we excluded time in tributaries, spill at Bonneville Dam was first selected, followed by water temperature and flow at Ice Harbor Dam, and tag date for an r^2 of 0.70 (Model 2; Table 16). When we removed both time in tributaries and tag date, spill at Bonneville Dam, temperature and flow at Ice Harbor Dam, and flow and temperature at Bonneville Dam were selected for a model r^2 of 0.63 (Model 3; Table 16). In both models 2 and 3, minimal improvements were made with the inclusion of fallback events and Secchi depth at Ice Harbor Dam.

We had complete data for 140 steelhead with records at the Bonneville, John Day, and Ice Harbor dam tailraces. With all variables included, time in tributaries, downstream fallback events, and tag date were again selected first ($r^2 = 0.60$), followed by temperature, flow, and Secchi depth at Ice Harbor Dam for an overall model r^2 of 0.77 (Model 1; Table 17). When we removed time in tributaries, temperature at Ice Harbor Dam was selected first ($r^2 = 0.14$), followed by tag date and flow at Ice Harbor

Table 16. Stepwise multiple regression model outputs for the time to pass for steelhead from the Bonneville Dam tailrace to the top of Lower Granite Dam in 1996, including models run, variables retained, and standard procedure outputs. Independent variables were tag date, number of downstream fallback events, time in lower Columbia River tributaries, and environmental variables measured on the date that each fish passed tailraces at Bonneville (BO) and Ice Harbor (IH) dams.

Models Run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
	Tag date	fallback events	tributary time			
	BO flow	BO spill	BO temperature	BO Secchi		
	IH flow	IH spill	IH temperature	IH Secchi		
Model 1, All variables; 158 fish						
	a. Tributary time		0.4350	0.4350	120.13	0.0001
	b. Fallback events		0.5535	0.1185	41.14	0.0001
	c. Tag date		0.6033	0.0498	19.32	0.0001
	d. IH temperature		0.6804	0.1044	36.92	0.0001
	e. IH flow		0.7652	0.0848	54.88	0.0001
	f. IH Secchi		0.7768	0.0116	7.88	0.0057
Model 2, All variables *except* tributary time; 158 fish						
	a. BO spill		0.1668	0.1668	31.23	0.0001
	b. IH temperature		0.4076	0.2408	63.00	0.0001
	c. IH flow		0.5102	0.1026	32.25	0.0001
	d. Tag date		0.7045	0.1943	100.60	0.0001
	e. BO spill$_{\text{(removed)}}$		0.7029	0.0016	0.84	0.3622
	f. IH Secchi		0.7335	0.0306	17.57	0.0001
	g. Fallback events		0.7419	0.0085	5.00	0.0269
Model 3, All variables *except* tributary time and tag date; 158 fish						
	a. BO spill		0.1668	0.1668	31.23	0.0001
	b. IH temperature		0.4076	0.2408	63.00	0.0001
	c. IH flow		0.5102	0.1026	32.25	0.0001
	d. BO flow		0.5575	0.0473	16.36	0.0001
	e. BO temperature		0.6306	0.0731	30.19	0.0001
	f.	BO spill$_{\text{(removed)}}$	0.6297	0.0009	0.36	0.5510
	g. IH Secchi		0.6600	0.0303	13.53	0.0003
	h. Fallback events		0.6749	0.0148	6.89	0.0095

Table 17. Stepwise multiple regression model outputs for the time to pass of steelhead from the Bonneville Dam tailrace to the top of Lower Granite Dam in 1996, including models run, variables retained, and standard procedure outputs. Independent variables were tag date, number of downstream fallback events, time in lower Columbia River tributaries, and environmental variables measured on the date that each fish passed tailraces at Bonneville (BO), John Day (JD), and Ice Harbor (IH) dams.

Models run	Variables retained	r^2	Partial r^2	F	Prob. > F
Variables:					
	tag date	fallback events	tributary time		
	BO flow	BO spill	BO temperature	BO Secchi	
	IH flow	IH spill	IH temperature	IH Secchi	
	JD flow	JD spill	JD temperature	JD Secchi	
Model 1, All variables; 140 fish					
	a. Tributary time	0.4300	0.4300	104.12	0.0001
	b. Fallback events	0.5578	0.1278	39.58	0.0001
	c. Tag date	0.6010	0.0432	14.73	0.0002
	d. IH temperature	0.6723	0.0713	29.35	0.0001
	e. IH flow	0.7609	0.0886	49.67	0.0001
	f. IH Secchi	0.7732	0.0123	7.21	0.0082
Model 2, All variables *except* tributary time; 159 fish					
	a. IH temperature	0.1351	0.1351	21.56	0.0001
	b. Tag date	0.4694	0.3343	86.32	0.0001
	c. IH flow	0.6997	0.2303	104.30	0.0001
	d. IH Secchi	0.7304	0.0307	15.36	0.0001
	e. Fallback events	0.7385	0.0081	4.16	0.0434
	f. BO temperature	0.7445	0.0081	3.13	0.0792

Dam (r^2 = 0.70) (Model 2; Table 17). Additional variables made minimal improvements. When both time in tributaries and tag date were removed, temperature at Ice Harbor was selected first, followed by spill at Bonneville Dam, and flow at Ice Harbor and Bonneville dams (r^2 = 0.63), and additional variables made minimal improvements.

Time steelhead with transmitters spent in lower Columbia River tributaries was the best predictor of passage time from release to the top of Lower Granite Dam in all multiple regression models where it was included. Time in tributaries was most highly correlated with Columbia River water temperatures and the dates that steelhead passed tailrace sites at dams (Figure 34). Time in tributaries decreased as the date fish passed Bonneville Dam increased, and increased with water temperatures at Bonneville Dam (Figure 35). The opposite was true at John Day, Ice Harbor, and Lower Granite dams, where time in tributaries decreased with temperature on the date fish passed tailrace sites. We believe many fish entered lower Columbia River tributaries when mainstem water temperatures were highest, then continued their upstream migrations when Columbia River temperatures decreased

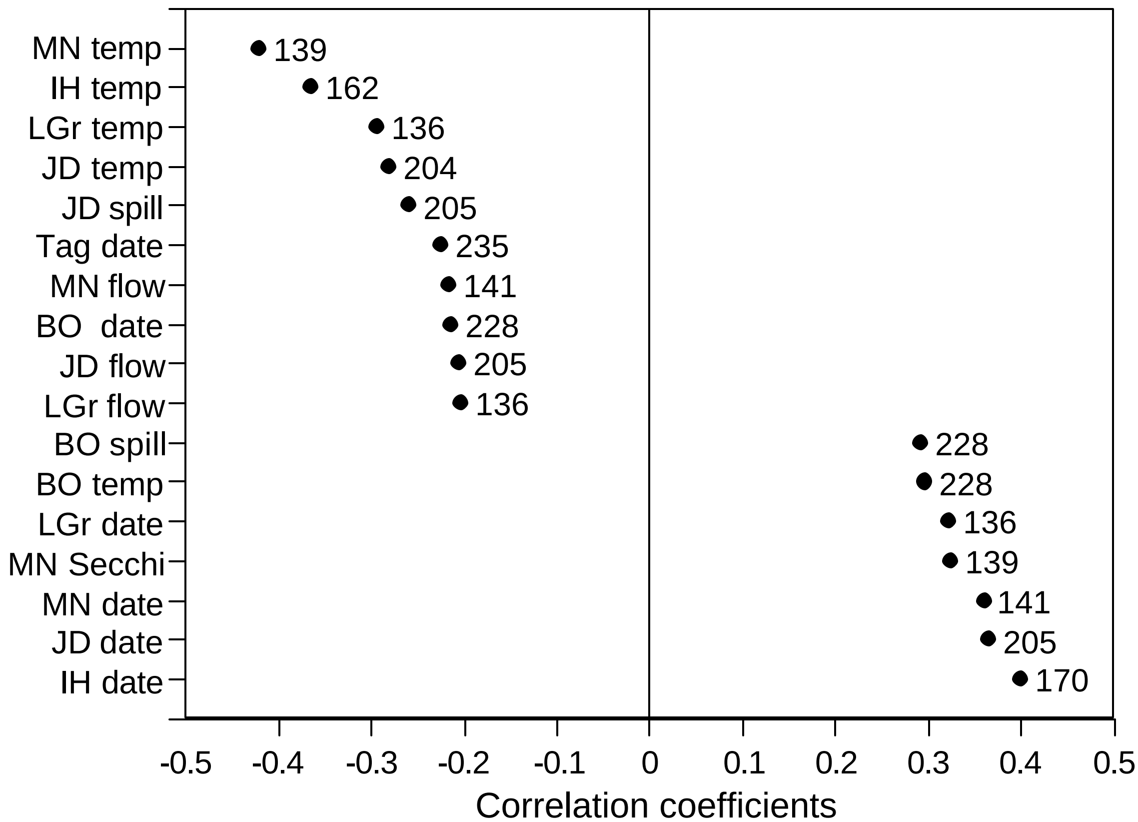

Figure 34. Comparisons of correlation coefficients for time steelhead spent in lower Columbia River tributaries en route to Lower Granite Dam and independent variables used in multiple regressions. Only includes variables with $r^2 > 0.20$. Overwintering fish not included.

By the time most (~80%) steelhead with transmitters reached McNary Dam, water temperatures in the mainstem Columbia River were decreasing. We examined passage times from the McNary Dam tailrace to the top of Lower Granite Dam because effects of environmental data during that portion of the migration were less obscured by time steelhead strayed into tributaries, due both to lower mainstem temperatures and fewer opportunities for straying. The first model we tested included passage times for 139 fish with transmitters, tag date, number of fallback events at McNary and Ice Harbor dams, and flow, spill, Secchi depth, and temperature at McNary Dam when fish passed the tailrace. Number of fallback events was the only variable selected ($r^2 = 0.17$). When we removed fallback events no variables met the $P < 0.10$ criteria for inclusion in the model.

We ran similar models for 104 steelhead with data at Ice Harbor Dam. Again, only the number of fallback events was selected ($r^2 = 0.16$). When we removed fallback events, no Ice Harbor Dam variables met the $P < 0.10$ criteria for inclusion in the model. Results were the same when we included all data from both McNary and Ice Harbor dams for the same 104 steelhead.

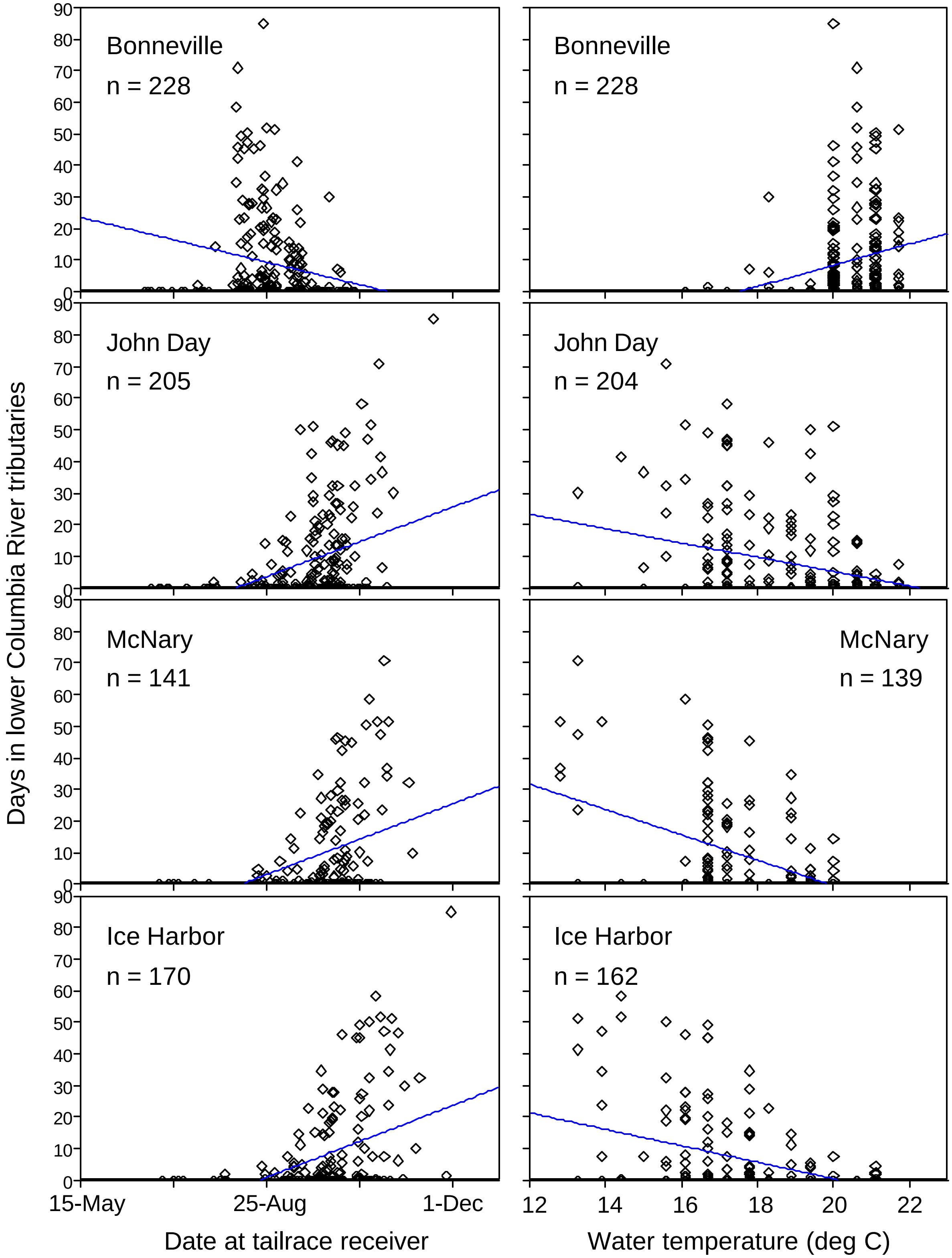

Figure 35. Time steelhead with transmitters spent in lower Columbia River tributaries and the dates and mainstem water temperatures when fish passed tailrace sites at Bonneville, John Day, Ice Harbor, and Lower Granite dams in 1996.

We found a slight correlation between water temperature at Lower Granite Dam and time to pass from the McNary Dam tailrace. The general tendency was for passage times to decrease as temperatures increased ($r^2 = 0.09$). Several A- and B-group steelhead with times > 30 d passed Lower Granite Dam when water temperatures were < 12º C; another group of A-group steelhead with passage times > 30 d passed Lower Granite when temperatures were > 18 º C.

Fallback at Dams

Higher-than-average flows in 1996 resulted in nearly continuous spill at all study dams on the Columbia and Snake rivers through approximately 1-September, when periods of no-spill or near-zero spill began. In previous studies, high levels of spill affected passage and increased fallback rates (see Bjornn and Peery 1992 for review), and we found similar trends in 1996. (Complete analyses of fallback behavior at Bonneville, The Dalles, and John Day dams were reported in Bjornn et al. 2000b, 2000c, and 2000d).

At least 143 steelhead with transmitters fell back during their upstream migration at least once at one or more of the seven monitored dams. We believe most fell back over spillways because fallback rates declined significantly when no spill occurred, but a few may have fallen back through powerhouses, navigation locks, juvenile channels, or ice and trash sluiceways. Of the 718 steelhead known to have passed Bonneville Dam with transmitters in place, 19.9% eventually fell back at one of the monitored dams. The 143 fish had 207 recorded fallback events, with 18% of all events at Bonneville, 19% at The Dalles, 25% at John Day, 16% at McNary, 9% at Ice Harbor, and 12% at Lower Granite dams. Among those that passed Bonneville Dam with transmitters, a significantly higher proportion of A-group steelhead (22.4%) fell back over dams than B-group steelhead (15.8%) ($P = 0.03$, Z-test). We did not include fallbacks that occurred after likely spawning (post-kelt) in any summaries.

Of 718 steelhead that retained transmitters after release and were known to have passed Bonneville Dam, 80.1% were not recorded falling back at any dam, 14.1% fell back once, 3.9% fell back twice, 1.1% fell back 3 times and 0.8% fell back 4 or more times during their upstream migration.

The percentage of unique fish with transmitters that fell back over a dam ranged from 4.9% at Bonneville Dam to 10.1%% at John Day Dam (Table 18). About 6.0% percent of the fish that passed The Dalles Dam fell back, 7.4% fell back at McNary Dam, 5.6% fell back at Ice Harbor Dam, and 8.4% fell back at Lower Granite Dam. No steelhead were recorded falling back at Priest Rapids Dam. Standard 95% confidence intervals for fallback percentages based on a normal approximation to the binomial distribution were +/- 1.6 to 2.5% for all dams except Lower Granite Dam, where the interval was +/- 3.4%. Fallback percentages did not reflect multiple fallbacks by individual fish or multiple passages past a dam and should not be used as adjustment factors for counts of fish passing ladders.

Recapture records indicated that several steelhead regurgitated transmitters after being recorded at one or more sites during their migration; we included these fish in the 'known to pass' category and assumed they did not fall back at dams. Excluding these

Table 18. Number of unique steelhead with transmitters that fell back (FB) at dams, number known to have passed dams, number recorded at the tops of ladders at each dam and the percentage of fish that fell back at each dam in 1996.

Dam	Total that fell back at dam	Number known to pass dam	Recorded at top of ladder	FB percent of fish known to pass	FB percent of fish recorded
Bonneville	35	720	713	4.9	4.9
The Dalles	35	580	558	6.0	6.3
John Day	46	457	440	10.1	10.5
McNary	29	394	327	7.4	8.9
Ice Harbor	18	319	307	5.6	5.9
Lower Granite	22	262	257	8.4	8.6
Priest Rapids	0	18	18	0.0	0.0

fish from passage summaries would have increased fallback percentages at each dam by < 0.1%. When we only included fish recorded at top-of-ladder receivers, fallback percentages were 0.0% to 0.4% higher at all dams except McNary Dam, where the percentage was 1.5% higher due to top-of-ladder receiver outages (Table 18).

Fallback rates, the total number of fallback events divided by the number of unique steelhead with transmitters known to have passed a dam ranged from 5.3% at Bonneville Dam to 11.2% at John Day Dam (Table 19). Fallback rates present a more complete picture of fallback behavior by steelhead, because multiple fallbacks by individual fish are represented. As with the percentage of unique fish that fall back, fallback rates should not be used to correct bias in counts of fish passing ladders caused by fallbacks. Rates do not account for fish that reascended ladders after each fallback at a dam. (See section on adjusting counts of fish at ladders.) Fallback rates were between 6.3% and 9.2% at The Dalles, McNary, Ice Harbor, and Lower Granite dams (Table 19). Standard 95% confidence intervals using the binomial approximation were +/- 1.6% to 2.7% for all dams except Lower Granite Dam, where the interval was +/- 3.5%.

We made a second fallback rate calculation based on the number of fallback events divided by the number of unique fish recorded at the tops of ladders at a dam (Table 19). This rate excluded fish that that were not recorded at the tops of ladders due to receiver outages or malfunctioning or regurgitated transmitters. These rates were from 0.0% to 0.4% higher than rates calculated using the number known to pass each dam at all but McNary Dam where the difference was 1.8%. We believe the most accurate fallback rate probably falls between the two rates presented.

A relatively small number of individual steelhead fell back multiple times at individual dams. At Bonneville Dam, 32 fish fell back once and 3 (9%) fish fell back twice. At The Dalles Dam, 30 fell back once and 5 (14%) fell back twice. At John Day Dam, 42 steelhead fell back once, 3 (7%) fish fell back twice, and 1 (2%) fish fell back three

Table 19. Number of fallback (FB) events by steelhead with transmitters at dams, the number known to have passed dams, the number recorded at the tops of ladders at each dam and the fallback rate of fish at each dam in 1996.

	Total FB events at dam	Number known to pass dam	Recorded at top of ladder	FB rate of fish known to pass	FB rate of fish recorded
Bonneville	38	720	713	5.3	5.3
The Dalles	40	580	558	6.9	7.2
John Day	51	457	440	11.2	11.6
McNary	34	394	327	8.6	10.4
Ice Harbor	20	319	307	6.3	6.5
Lower Granite	24	262	257	9.2	9.3
Priest Rapids	0	18	18	0.0	0.0

times. At McNary Dam, 25 fell back once, 3 (10%) fell back twice, and 1 (3%) fell back 3 times. At Ice Harbor Dam, 16 fish fell back once and 2 (11%) fish fell back twice, and at Lower Granite Dam 20 fish fell back once and 2 (9%) fish fell back twice.

Steelhead with transmitters that fell back over dams in 1996 did so after a variety of movements upstream from the dams. Although we could not monitor the exact time that fish fell back we could usually estimate fallback times to within a few hours of the event using forebay, tailrace and fishway telemetry records. About two-thirds of all fallback events at Bonneville Dam occurred within 24 h of the fish passing the dam (Table 20). Between 20% and 25% fell back within 24 h at The Dalles, John Day, and Ice Harbor dams, and < 15% fell back within 24 h at McNary and Lower Granite dams. Many steelhead migrated upriver and were recorded at fixed receivers at tributary sites or at upriver dams before they moved back downstream and fell back. Seventy-three percent of the events at The Dalles Dam, 47% of the events at John Day Dam and between 20% and 26% of the fallback events at McNary, Ice Harbor, and Lower Granite dams occurred after fish were recorded upriver (Table 20). The remaining fallback events occurred more than 24 h after passing dams, but fish were not recorded at receivers upriver from dams. This occurred most frequently at McNary, Ice Harbor, and Lower Granite dams, where fish could migrate relatively large distances upriver before passing receivers.

At most dams monitored in 1996-1997, more fish passed via south-shore ladders than via north-shore ladders. The exceptions were Lower Granite Dam, which only has a ladder at the south shore, and Priest Rapids Dam, where ladders were on the East and West shores (Table 21). At Bonneville Dam, a significantly higher ($P < 0.005$, Z test) proportion of the fish that were recorded at the top of the Bradford Island ladder near the south shore fell back (7.9%), than fell back after passing via the north-shore ladder (0.9%). Differences in fallback percentages between ladders were not significant ($P < 0.10$) at The Dalles, John Day, or McNary dams. (Table 21). Three of 14 (21.4%) steelhead that passed the north-shore ladder at Ice Harbor dam fell back, a significantly

Table 20. Number of fallback (FB) events by steelhead with transmitters at dams in 1996, the number and percent that fell back within 24 h of passing dams, the percent recorded upriver before they fell back and the percent that fell back more than 24 h after passing but were not recorded upstream.

	Total FB events at dam	Number that FB in <24 h	Percent that FB in <24 h	Percent FB's >24 h	
				Recorded upriver	Not recorded upriver
Bonneville	38	26	68	16	16
The Dalles	40	8	20	73	8
John Day	51	12	24	47	29
McNary	34	1	3	26	71
Ice Harbor	20	5	25	20	55
Lower Granite	24	3	13	25	63
Priest Rapids	0	0	0	0	0

Table 21. Number of unique steelhead with transmitters recorded at the tops of south-shore and north-shore ladders at each dam, the number of unique fish that fell back (FB), and the percentage of fish that passed each ladder and fell back at each dam in 1996.

	South-shore ladder			North-shore ladder		
	Unique fish at top of ladder[1]	Unique fish that fell back	% past ladder that FB	Unique fish at top of ladder[2]	Unique fish that fell back	% past ladder that FB
Bonneville	367	29	7.9	333	6	0.9
The Dalles	482	26	5.4	100	9	9.0
John Day	377	41	10.9	73	6	8.2
McNary	320	26	8.1	62	2	3.2
Ice Harbor	296	15	5.1	14	3	21.4
Lower Granite	262	22	8.4	---	---	---
Priest Rapids[a]	13	0	0	5	0	0

[1] 'South' ladder at Priest Rapids Dam is on east side of Columbia River
[2] 'North' ladder at Priest Rapids Dam is on west side of Columbia River

higher (P = 0.01) proportion than the 5.4% that fell back after passing the south-shore ladder.

We also calculated the percentage of fallback events by steelhead with transmitters based solely on ladder passed, disregarding the disproportionate numbers of fish that passed via south-shore ladders. Seventy-three to 91% of the steelhead that fell back initially passed via south-shore ladders at the lower Columbia River dams and at Ice Harbor Dam (Table 22). When we only considered fallbacks that occurred within 24 h of passing these dams, 83% to 100% of steelhead passed south-shore ladders prior to falling back (Table 22).

Among dams, the highest number and largest proportion of fish that fell back within 24 h was at Bonneville Dam, where 96% of fallback events that occurred within 24 h were by fish that passed via the Bradford Island ladder (south-shore), compared to 84% of all fallback events at the dam. The Bradford ladder is unique in that the top of the ladder is on an island. Based on mobile-tracking of chinook and sockeye salmon and steelhead with transmitters in 1997 and 1998, many fish that exited the Bradford Island ladder followed the Bradford Island shoreline into the forebay of the spillway and fell back over the dam during periods of spill (Bjornn et al. 1999).

Escapements Past Dams Based on Adjusted Counts of Salmon at Dams

Counts of salmon and steelhead that pass up the ladders at the dams are used as indices of abundance of the runs at that point in their migration. Counts are indices of upriver escapement, rather than complete counts, because some fish pass the dams via navigation locks, and because fish that fall back over the dams and do or do not reascend over the dam add a positive bias to counts. Adjustment of counts for fish that pass through navigation locks and for fallbacks at Columbia and Snake river dams has been calculated only when adult tagging studies have been conducted. In previous studies, fallback rates varied among species and years, with river flow and spill at dams, as well as with the configuration of top-of-ladder exits at specific dams (Bjornn and Peery 1992; Liscom et al. 1979). In 1996, we used fallback and reascension rates for adult steelhead with transmitters to calculate adjustment factors for all monitored dams. Adjustments were then applied to run-year ladder counts of steelhead reported in the Annual Fish Passage Report (USACE 1996).

We believe the most accurate estimate of escapement past dams includes counts of steelhead passing ladders at dams, the number of fish that fall back, the number that reascend through ladders, and the number that pass upstream through navigation locks. Fallback of steelhead at dams and reascension through ladders creates a positive bias in the number of fish counted as they pass up the ladders, while passage through navigation locks is unaccounted for in counts of fish passing via ladders. Fish that pass through locks compensate for the positive bias in fish counts due to fallback and reascension, but the amount of compensation depends on the number of fallbacks and the number of fish passing through the lock.

We estimated escapement of fish past dams by calculating adjustment factors based on passage of fish with transmitters and then applied adjustments to the total number of fish counted at the dam. The first adjustment factor (AF) was calculated by the formula:

$$AF_1 = (LP_K + NLP_K - FB_{UF} + R_{UF}) / TLP_K$$

where:

Table 22. Number of total fallback (FB) events and fallback events within 24 h of passing each dam by steelhead with transmitters, and the percentage of fallback events by fish using the south-shore or north-shore ladders at each dam in 1996.

	All fallback events			Fallback events within 24 h		
	Number of events	Percent south ladder[1]	Percent north ladder[2]	Number of events	Percent south ladder	Percent north ladder
Bonneville	38	84	16	26	96	4
The Dalles	40	73	25	8	100	0
John Day	51	86	14	12	83	17
McNary	34	91	6	1	100	0
Ice Harbor	20	85	15	5	80	20
Lower Granite	24	100	n/a	3	100	n/a
Priest Rapids[a]	0	0	0	0	0	0

[1] 'South' ladder at Priest Rapids Dam is on east side of Columbia River
[2] 'North' ladder at Priest Rapids Dam is on west side of Columbia River

LP_K was the number of unique fish with transmitters known to have passed the dam via ladders (assumes that unrecorded fish passed dam via ladder),

NLP_K was the number of unique fish with transmitters known to have passed the dam via the navigation lock,

FB_{UF} was the number of unique fish that fell back at the dam one or more times,

R_{UF} was the number of unique fish that reascended the dam and stayed upstream from the dam regardless of the number of times it fell back, and

TLP_K was the total number of times unique fish with transmitters were known to have passed the dam via ladders (includes initial and all reascensions).

The TLP_K term was the count of radio-tagged steelhead equivalent to the total USACE count of steelhead that passed through ladders. When adjustment factor AF was applied to counts of steelhead that passed through ladders, the adjusted number approximated total escapement past dams. If the NLP term, passage through the navigation lock, was not available, the adjusted number was an underestimate of escapement by the number of fish that passed through the navigation lock. About 4% of steelhead with transmitters passed Bonneville Dam via the navigation lock, and one fish (< 1%) was recorded passing through the navigation lock at McNary Dam in 1996. Locks were not monitored at The Dalles, John Day, Ice Harbor, Lower Granite, or Priest Rapids dams.

Estimates of escapement derived from the adjustment factors were based on the assumption that fish with transmitters were good surrogates for the remainder of the fish in the run passing the dam. We calculated adjustments using pooled data for the entire range of passage by steelhead with transmitters. Temporal variability in fallback and reascension rates and variability in proportions of the run that were tagged likely biased pooled adjustment factors at some dams (see weighted estimates for comparison), but they were useful for comparisons among dams and for weighted adjustments. Pooled adjustment factors ranged from 0.992 at Bonneville Dam to 0.895 at John Day Dam (Table 23). No fish with transmitters fell back at Priest Rapids Dam.

We did not monitor navigation lock passage at dams other than Bonneville and McNary, but we estimated lock passage based on fish recorded at tailrace receivers at dams that were not recorded in ladders, but were recorded at sites upstream from The Dalles, John Day, and Ice Harbor dams. Five to 7 steelhead (0.8% to 1.5%) with transmitters likely passed via locks at The Dalles and John Day dams, and 1 fish likely passed via the Ice Harbor Dam lock. Using these estimates, pooled AF values would have increased to 0.946 at The Dalles, 0.908 at John Day, and 0.942 at Ice Harbor dams.

We also calculated adjustment factors using a stratified sampling method using consecutive 5 d blocks during the time that radio-tagged steelhead were passing dams. Each block was weighted by the total number of steelhead counted passing ladders during that block; 95% confidence intervals were calculated using the normal approximation to the binomial distribution. However, several factors complicated calculation of weighted AF values. First, USACE did not collect ladder passage data for steelhead at most dams from November to March. Second, although our sampling was generally representative of the 1996-1997 run-year, steelhead with transmitters passed and fell back at dams from June, 1996 to April, 1997, and the small number of radio-tagged fish passing dams early and late in the migration tended to distort passage, fallback and reascension calculations for those periods; sample sizes for some periods were too small for meaningful statistical analyses. Third, interruption of tagging due to high water temperatures in August created a 5-d block when > 14,000 steelhead passed Bonneville Dam, but no radio-tagged fish passed. Given these limitations, we tried to maximize sample sizes while limiting variance and error terms in weighted AF calculations by eliminating blocks with few or no radio-tagged fish. The first weighted AF maximized sample size by including all data except for 5-d blocks with no radio-tagged fish. The second weighted AF excluded all 5-d blocks with < 5 radio-tagged fish, an arbitrary cutoff that we believe removed blocks with the highest variance and error terms. Both methods did not include ladder-count data before tagging began in mid-June, and both did not include radio-tag data collected when ladder counts were not reported. By comparison, pooled AF values included 100% of radio-tag data.

At Bonneville Dam, the weighted AF was 1.006 (+/- 0.011) with 99.4% of all radio-tagged and 88.8% of all ladder count data included, indicating that escapement through the navigation lock more than compensated for positive ladder count bias caused by fallback and reascension (Table 24). The AF did not include one 5-d block in August when > 14,000 steelhead were counted passing ladders but no radio-tagged fish passed. Blocks immediately before and after the excluded block had AF values of 1.00 and 1.046, suggesting that an AF for the excluded block was likely near 1.00. When we excluded 5 blocks with < 5 radio-tagged fish, the weighted AF was 1.007 (+/-0.011). The latter AF included 98.6% of radio-tagged and 88.2% of ladder count data (Table 24).

Table 23. Unique fish with transmitters known to have passed the dams via ladders (LP_K) and navigation lock (NLP_K), unique fish that fell back one or more times (FB_{UF}), unique fish that reascended (R_{UF}), total number of times fish with transmitters were known to have passed through ladders (TLP_K), and pooled fish count adjustment factors (AF) for steelhead with transmitters at monitored Columbia and Snake river dams in the run-year 1996-1997.

Dam	LP_K[1]	NLP_K	FB_{UF}	R_{UF}	TLP_K	pooled AF
Bonneville	693	31	35	30	725	0.992
The Dalles	584	n/a	35	27	614	0.938
John Day	460	n/a	46	21	486	0.895
McNary	398	1	29	12	413	0.925
Ice Harbor	322	n/a	18	7	331	0.940
Lower Granite	262	n/a	22	8	272	0.912

[1] Includes fish that passed dam unrecorded

Table 24. Pooled and weighted adjustment factors for counts of adult steelhead passing through ladders during the 1996-1997 run-year. Weighted adjustments calculated using stratified sampling method over consecutive 5 d blocks.

	Pooled	Weighted adjustment factor[1]			Weighted adjustment factor[2]		
	AF	AF	%Tag	%Count	AF	%Tag	%Count
Bonneville	**0.992**	**1.006**	99.4	88.8	**1.007**	98.6	88.2
The Dalles	**0.938**	**0.963**	96.8	98.8	**0.962**	95.6	92.2
John Day	**0.895**	**0.919**	93.5	97.6	**0.926**	90.2	92.2
McNary	**0.925**	**0.912**	92.9	94.9	**0.938**	88.2	87.8
Ice Harbor	**0.940**	**0.920**	89.4	93.2	**0.921**	83.5	84.2
Lower Granite	**0.912**	**0.910**	96.3	93.7	**0.905**	81.9	79.9

[1] includes all data during time radio-tagged fish passed dams and ladder counts were available; 5-d blocks with no radio-tagged fish not included
[2] includes only 5-d blocks with > 4 radio-tagged fish

At The Dalles Dam, no 5-d blocks had zero radio-tagged fish and three had < 5 tagged fish. Both weighted adjustments were about 0.963 (+/- 0.016) and included between 95.6% and 96.8% of radio-tag and 98.8% and 92.2% of ladder-count data (Table 24). At John Day Dam, no 5 d blocks had zero radio-tagged fish and 5 had < 5 tagged fish. Weighted AF values were 0.919 with 93.5% of radio-tag and 97.6% of ladder-count data included, and 0.926 with 90.2% of radio-tag and 92.2% of ladder- count data. Weighted AF values at McNary Dam were 0.912 and 0.938. The latter AF did not include seven 5-d blocks with < 5 radio-tagged fish, and included 88.2% of radio tag and 87.8% or ladder count data. Weighted AF values at Ice Harbor Dam were 0.920 and 0.921, and included < 90% of radio-tag and between 84% and 93% of ladder-count data (Table 24). One 5-d block at Ice Harbor Dam had zero radio-tagged fish and 10 had < 5 tagged fish. At John Day and McNary dams, 5-d blocks with < 5 radio-tagged fish tended to be early or late in the fall migration or during the spring of 1997, and several had AF values of < 1.00. Excluding those blocks resulted in higher weighted AF values.

At Lower Granite Dam, the pooled AF was 0.912 and weighted AF values were 0.910 (+/- 0.041) excluding nine blocks with zero tagged fish, and 0.905 (+/- 0.048) excluding 27 blocks with < 5 tagged fish (Table 24). The first weighted AF included 96.3% of radio-tag and 93.7% of ladder-count data, while the second included 81.9% of radio-tag and 79.9% of ladder-count data (Table 24).

Stratified weighting using ladder counts had variable impacts on adjustment factors. Weighted AF values were 0.014 to 0.031 higher than pooled AF values at Bonneville, The Dalles, and John Day dams. At Ice Harbor and Lower Granite dams, weighted AF values were 0.002 to 0.020 lower than pooled values; differences were mixed at McNary Dam.

We calculated adjusted escapements of steelhead past dams by multiplying fish counts reported by USACE by pooled and weighted AF values (Table 25). For example, the Bonneville Dam adult count in 1996 was 205,213 fish, and the adjusted escapement counts were 203,571 (+/- 1,355) using the pooled AF and about 206,500 (+/- 2,260) using weighted AF values (Table 25). The pooled adjustment had a positive bias of 1,642 fish, and weighted adjustments had negative biases of 1,231 and 1,436 fish. The USACE adult count at The Dalles Dam for the 1996-1997 run-year was 162,447. Adjusted escapements were 152,375 (+/- 3103) using the pooled AF and about 156,350 (+/- 2,500) using weighted AF values.

Biases as a proportion of adjusted counts were 0.8% at Bonneville Dam using the pooled AF, and -0.6% to -0.7% using weighted AF values (Figure 36). At the Dalles Dam, biases were 6.6% using the pooled AF and 3.8% to 4.0% using weighted AF values. Biases were 11.7% at John Day Dam using the pooled AF, and 8.0% to 8.8% using weighted AF values. Biases were 8.1% using the pooled AF at McNary Dam, and 6.6% to 9.6% using weighted AF values. At Ice Harbor Dam, biases were 6.4% using the pooled AF and about 8.65% using weighted AF values. Biases at Lower Granite Dam were 9.6% using the pooled AF and 9.9% to 10.5% using weighted AF values (Figure 36).

Passage through locks would increase adjusted escapement values and decrease positive biases described above for The Dalles, John Day, Ice Harbor, and Lower Granite dams, where navigational locks were not monitored. We estimated that adjusted escapements may have increased by approximately 2,000 fish at John Day Dam, 1,300 fish at The Dalles Dam, and 200 fish at Ice Harbor Dam based on presumed passage through navigation locks.

Table 25. Reported USACE counts of adult steelhead passing through ladders at monitored dams, estimated escapements using pooled and weighted adjustment factors, 95% confidence intervals, and bias in the counts in the 1996-1997 run-year as escapement indices.

	USACE ladder escapement	Adjusted escapement	95% confidence interval (+/-)	Bias
Bonneville	205,213			
pooled		203,571	1,355	1,642
weighted[1]		206,444	2,258	-1,231
weighted[2]		206,649	2,258	-1,436
The Dalles	162,447			
pooled		152,375	3,103	10,072
weighted[1]		156,436	2,437	6,011
weighted[2]		156,274	2,599	6,173
John Day	156,924			
pooled		140,447	4,268	16,477
weighted[1]		144,213	4,394	12,711
weighted[2]		145,312	4,237	11,612
McNary	124,820			
pooled		115,459	3,170	9,362
weighted[1]		113,836	4,119	10,984
weighted[2]		117,081	2,746	7,739
Ice Harbor	101,384			
pooled		95,301	2,606	6,083
weighted[1]		93,273	3,549	8,111
weighted[2]		93,375	3,852	8,009
Lower Granite	86,898			
pooled		79,251	2,928	7,647
weighted[1]		79,077	3,563	7,821
weighted[2]		78,643	4,171	8,255
Priest Rapids	8,375	na	na	na

[1] includes all data during time radio-tagged fish passed dams and ladder counts were available; 5-d blocks with no radio-tagged fish not included

[2] includes only 5-d blocks with > 4 radio-tagged fish

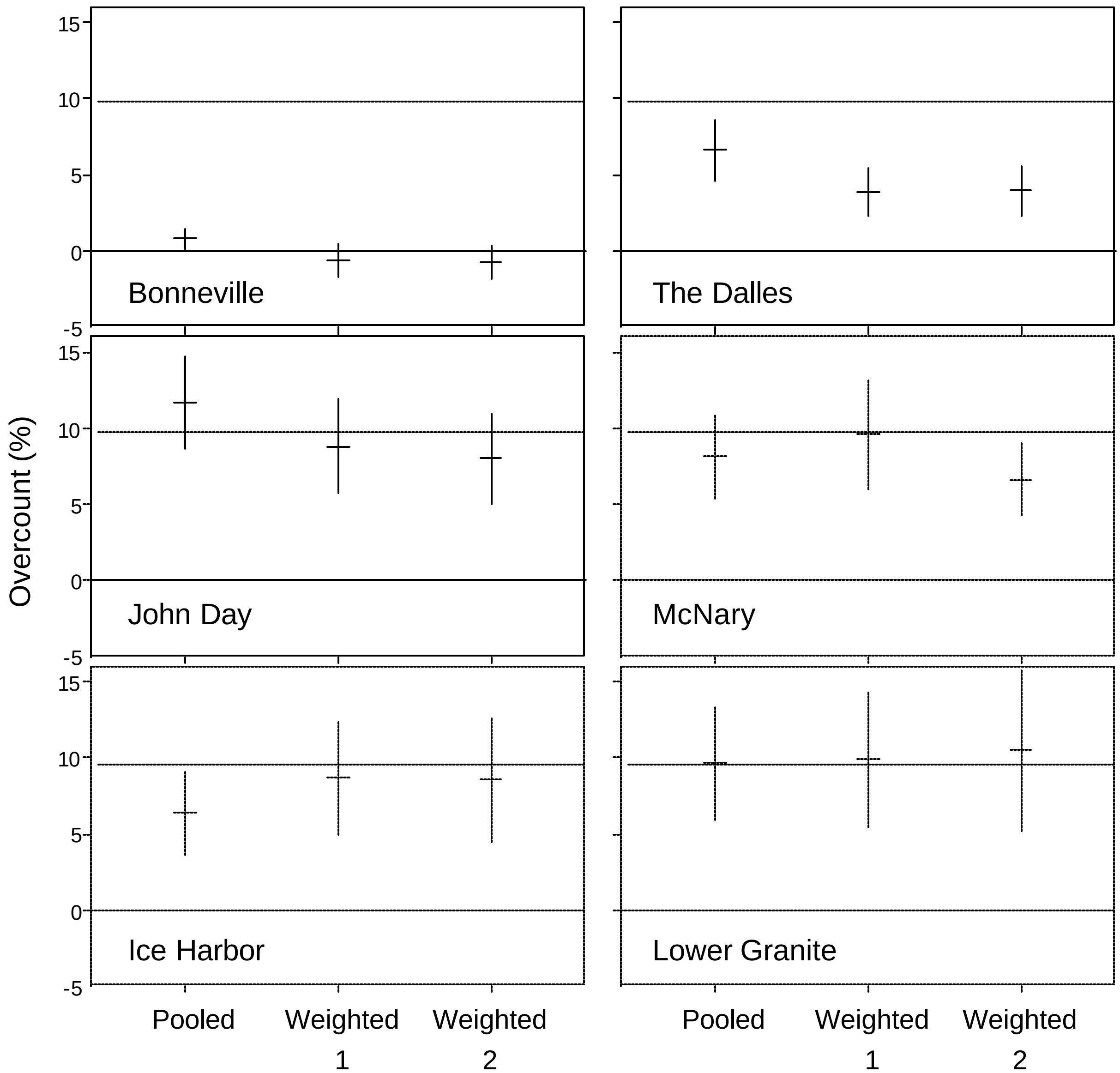

Figure 36. Percent of bias in USACE ladder counts of steelhead as an index of escapement in the 1996-1997 run-year. Biases calculated using pooled and weighted adjustment factors. (See text for explanation of differences between weighted adjustments.)

Effect of Flow, Spill, Turbidity, Temperature, and Dissolved Gas on Fallbacks

We limited fallback analyses related to environmental conditions for steelhead tagged in 1996 because fallback rates were relatively low (Table 19), because most fish fell back at dams more than 24 h after passage (except at Bonneville Dam) and many were recorded at upstream sites prior to falling back, and because some fallbacks were likely related to wandering behavior rather than environmental conditions. In addition, 41% of the 1996-1997 run passed Bonneville Dam during the period of no spill that began on 1

September, 62% to 74% passed The Dalles, John Day, and McNary dams during no-spill conditions, 89% passed Ice Harbor Dam during zero spill, and almost all steelhead with transmitters passed Lower Granite Dam during near zero spill. And, although the numbers of steelhead with transmitters recorded daily at each dam were generally proportional to daily counts of steelhead at the count windows in the ladders (Figure 37; also see Figure 8), low numbers of radio-tagged fish passed on some days and ratios of tagged fish to counted fish were highly variable. Additional variability was created because we stopped radio-tagging steelhead in late July/early August when river temperatures exceeded 21º C.

For the reasons listed above, our analyses of relationships between fallback rates for steelhead outfitted with transmitters in 1996 and flow, spill, temperature, and turbidity were mostly qualitative. Additional quantitative fallback analyses were reported in Bjornn et al. 2000b, 2000c, and 2000d for Bonneville, The Dalles, and John Day dams for chinook (1996, 1997, 1998) and sockeye salmon (1997), and steelhead outfitted with transmitters in 1997.

Peak discharge and total flow volumes during the steelhead migration in 1996 were similar at the four lower Columbia River dams, but spill rates differed between dams in June, July, and August. Spill averaged 45% of total flow at Bonneville and McNary dams, 60% of total flow at The Dalles Dam, and about 20% of total flow at John Day Dam. Spill dropped to near zero at all lower Columbia River dams on approximately 1 September. Spill at Ice Harbor Dam averaged about 50% of total flow during the summer months, then dropped to near zero on 1 September. At Lower Granite Dam, spill averaged 30% of total flow from 1 June to early July, then dropped to near zero. Spill resumed at all monitored dams in January, 1997. At all dams, Secchi depth visibility increased through summer and fall. Temperatures peaked in late August or early September and steadily decreased after mid-September (see Figures 4 and 5).

Steelhead were recorded falling back at dams throughout the migration, with 63% of all fallback events before 1 November (Figure 38). The proportion that fell back before 1 November ranged from 84% at Bonneville Dam to 42% at Lower Granite Dam. Although we were not able to determine the exact time of all fallback events, we estimated that 58% of all fallbacks occurred during spill. At Bonneville Dam, 87% of all fallback events and 100% of 26 events within 24 h of passage occurred during spill. At The Dalles Dam, 45% of all events and 50% of 8 events within 24 h occurred during spill. At John Day Dam, 76% of all events and 100% of 12 events within 24 h occurred during spill. From 29% to 50% of all fallback events at McNary, Ice Harbor, and Lower Granite Dam occurred during spill; less than 5 steelhead fell back within 24 h at those dams (Figure 38).

Mean daily spill on the date fish exited from tops of ladders at Bonneville Dam was significantly higher for fish that fell back within 24 h than for those that did not fall back within 24 h ($P < 0.001$, T-test) (Figure 39). Mean daily spill was also higher for fish that fell back within 24 h at John Day and Ice Harbor dams, but sample sizes were too small for statistical comparisons. For comparative purposes only, we calculated mean daily spill rates on the dates all steelhead fell back at individual dams. Mean spill on days when fish fell back was higher than mean spill on days when fish that did not fall back passed Bonneville, John Day, Ice Harbor dams, and was not comparable at Lower Granite Dam (Figure 39).

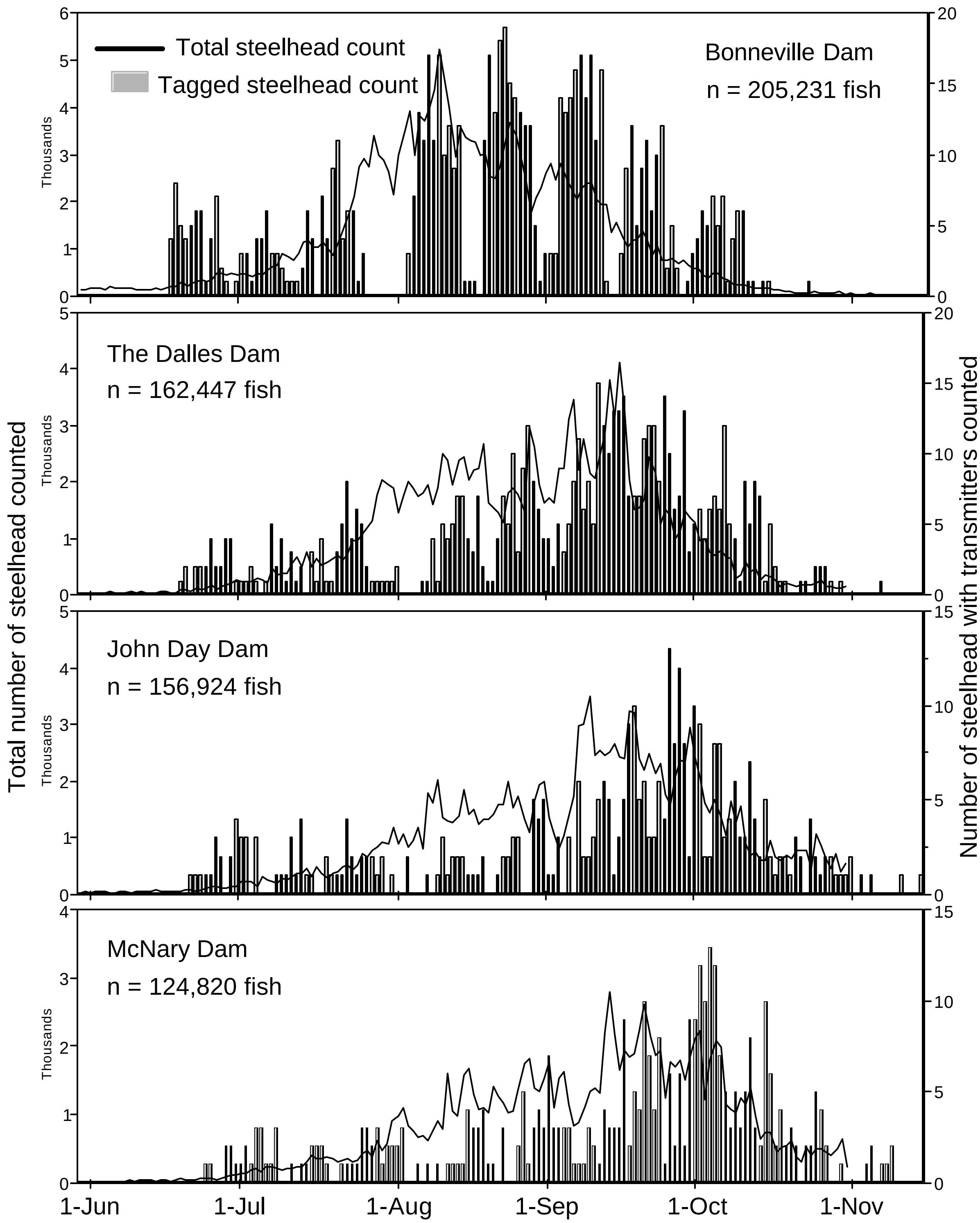

Figure 37. Daily steelhead counts and the number of steelhead with transmitters that passed Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996.

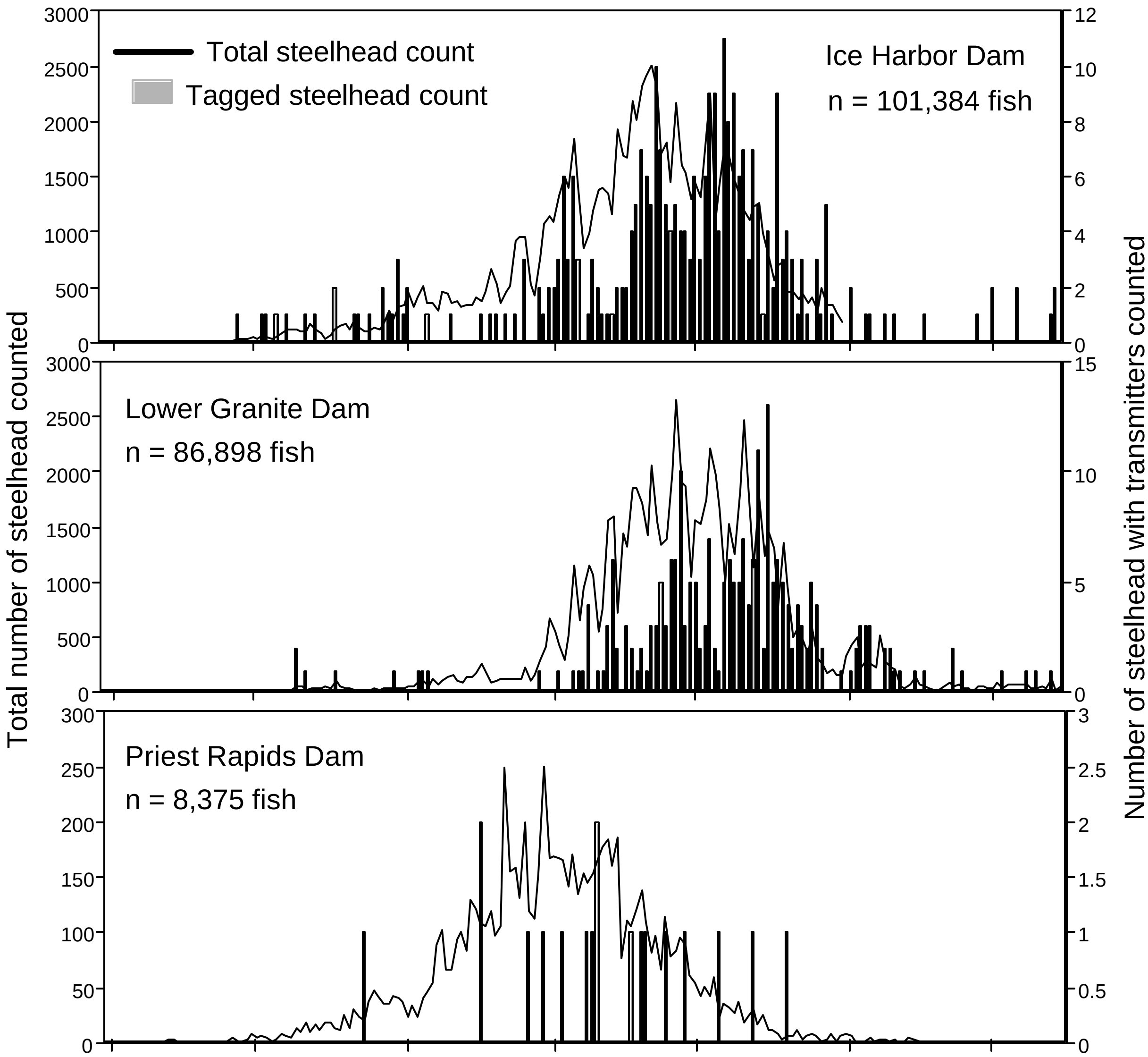

Figure 37 Continued.

We made similar comparisons using mean daily flow on the date fish exited from the tops of ladders and either did or did not fall back within 24 h; sample size limitations were the same as for comparisons with spill. Mean daily flow on the date fish passed Bonneville Dam was significantly higher for fish that fell back within 24 h than for those that did not fall back and fell back after 24 h ($P < 0.001$, T-test) (Figure 40). Mean daily flow was also higher for fish that fell back within 24 h at John Day and Ice Harbor dams. Mean flow on the date all fish fell back was higher at all dams than mean flow on days when fish that did not fall back passed dams (Figure 40).

We found no indications that water temperature or Secchi depth visibility contributed to fallback by steelhead at any dams except Bonneville Dam. At Bonneville Dam, mean

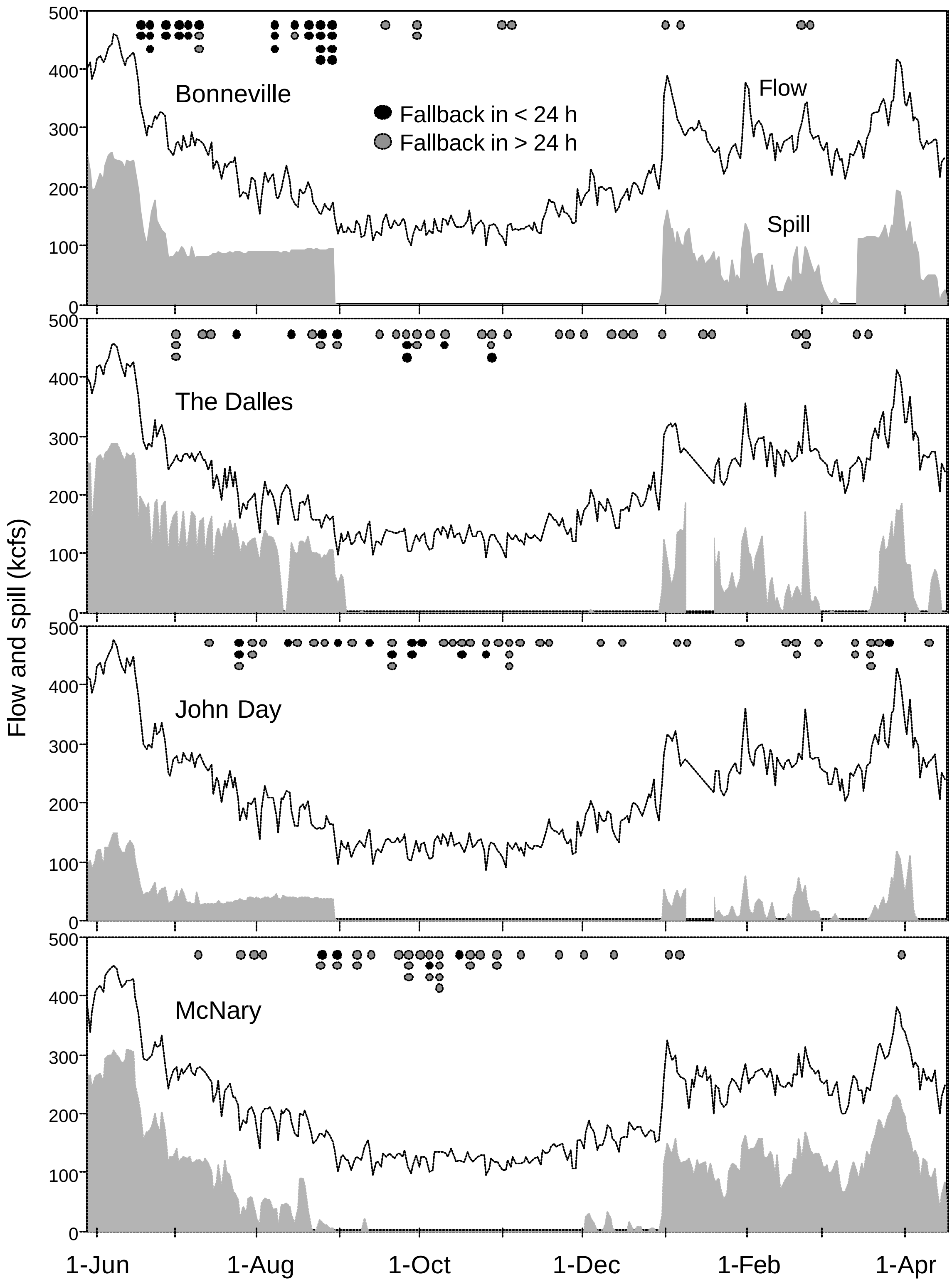

Figure 38. Flow, spill, and distribution of fallback events by steelhead with transmitters at all monitored dams in the run-year 1996-1997.

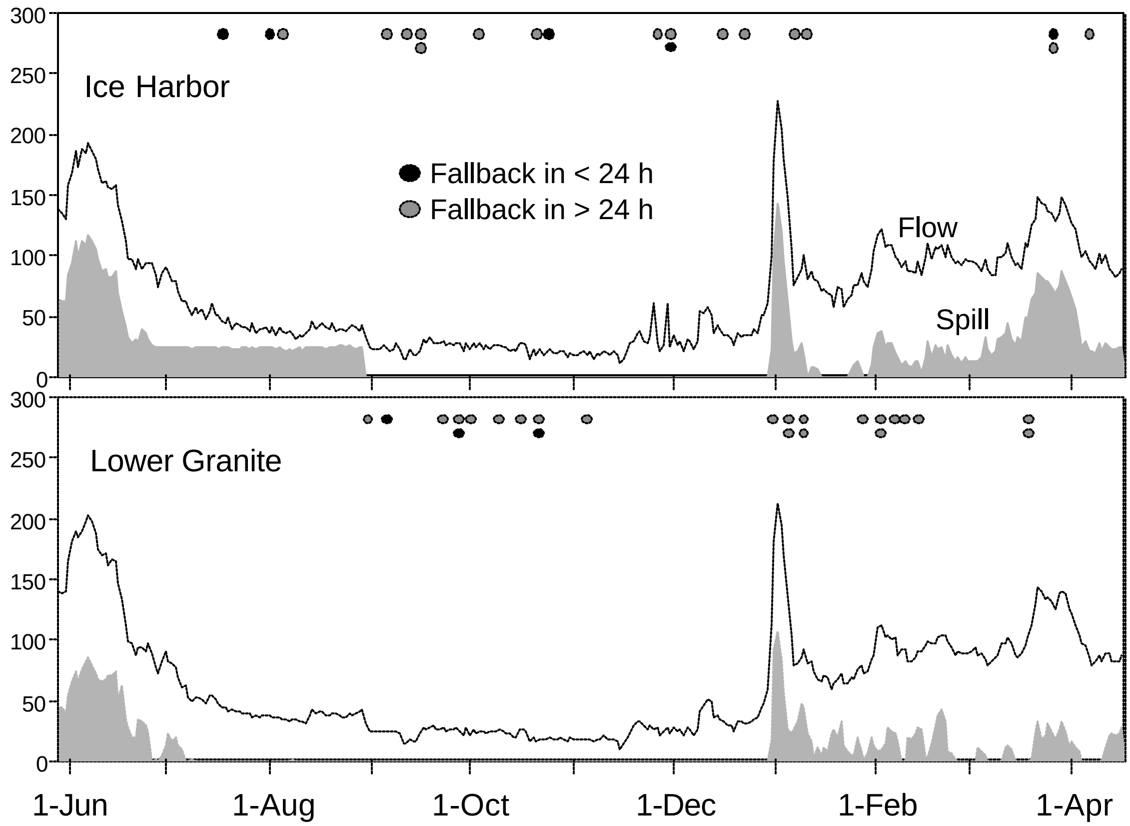

Figure 38 Continued.

water temperatures at the time of passage were significantly lower (P = 0.007, T-test) for fish that fell back within 24 h (19.2º C) than for those that did not fall back within 24 h (19.9º C). Mean Secchi visibility was 4.6 ft at time of passage for fish that fell back within 24 h, significantly lower than 5.5 ft for fish that did not fall back within 24 h (P = 0.004). Both water temperature and Secchi depth visibility at Bonneville Dam were correlated with spill, and the significant relationships described above may partially be a function of higher spill early in the migration before temperatures peaked and Secchi depth increased.

We believe fallbacks within 24 h of passage at a dam were those most likely to be influenced by environmental conditions. Sixty-eight percent of fallback events at Bonneville Dam, and from 20% to 25% at The Dalles, John Day, and Ice Harbor dams were within 24 h of passage. For these four dams, we calculated daily fallback/daily passage ratios for radio-tagged fish. Daily fallback ratio variability was high (values up to 100%) particularly on days when few radio-tagged fish passed dams but one or more fell back. To moderate the influence of individual fallback events, we calculated daily fallback ratios using the 5-d moving average number of fallback events and the moving average number of steelhead with transmitters recorded at the tops of fishways over the same 5 days. Fallback events that occurred more than 24 h after a fish exited from the top of a fishway were excluded from the analysis. We present this information to give a

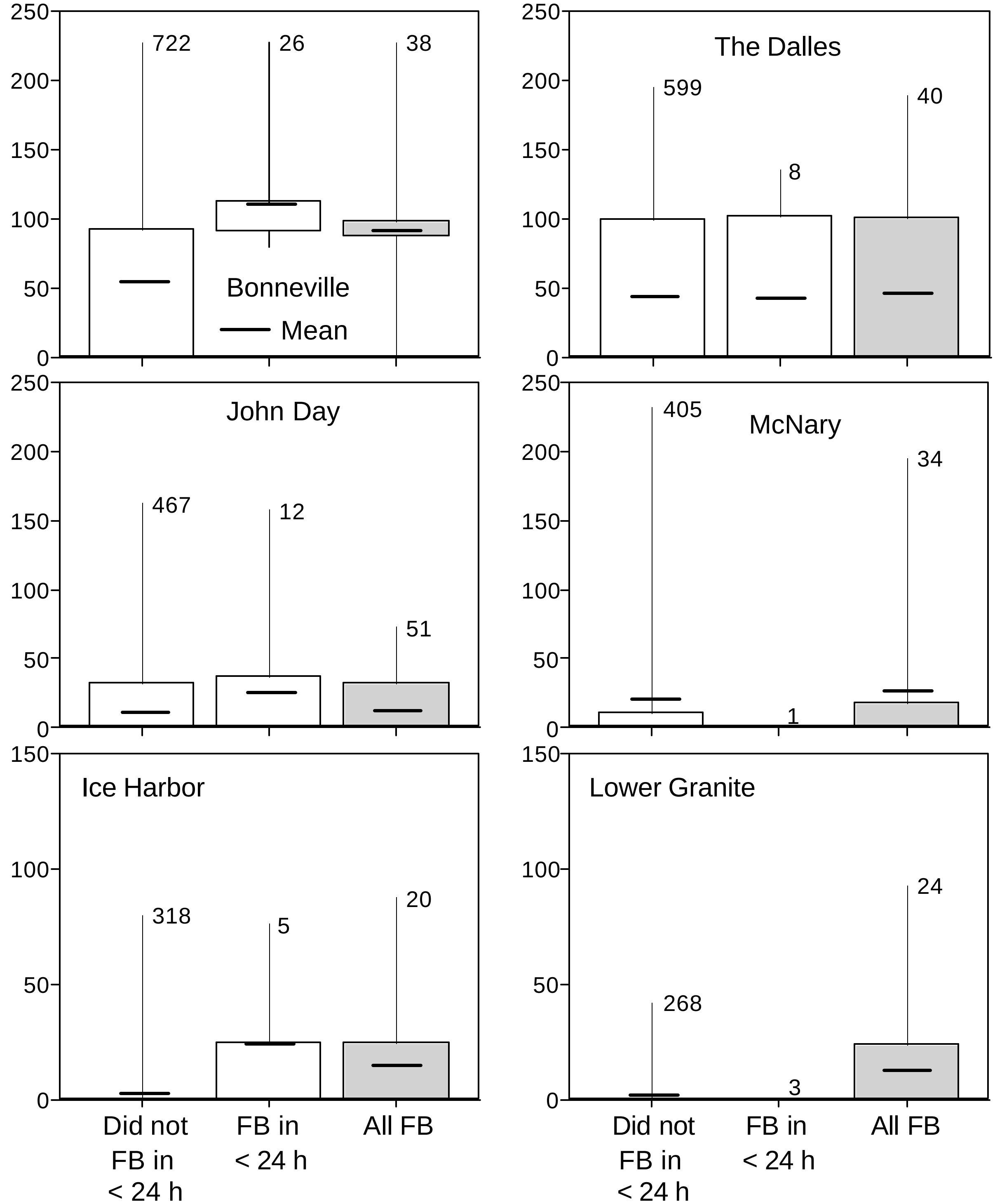

Figure 39. Minimum, maximum, quartile, and mean total daily spill on the date steelhead with transmitters passed dams and either did or did not fall back within 24 h in the run-year 1996-1997. The latter group includes fish that did not fall back and those fish that fell back > 24 h. Gray bar is mean daily spill on the date that all fallback events occurred.

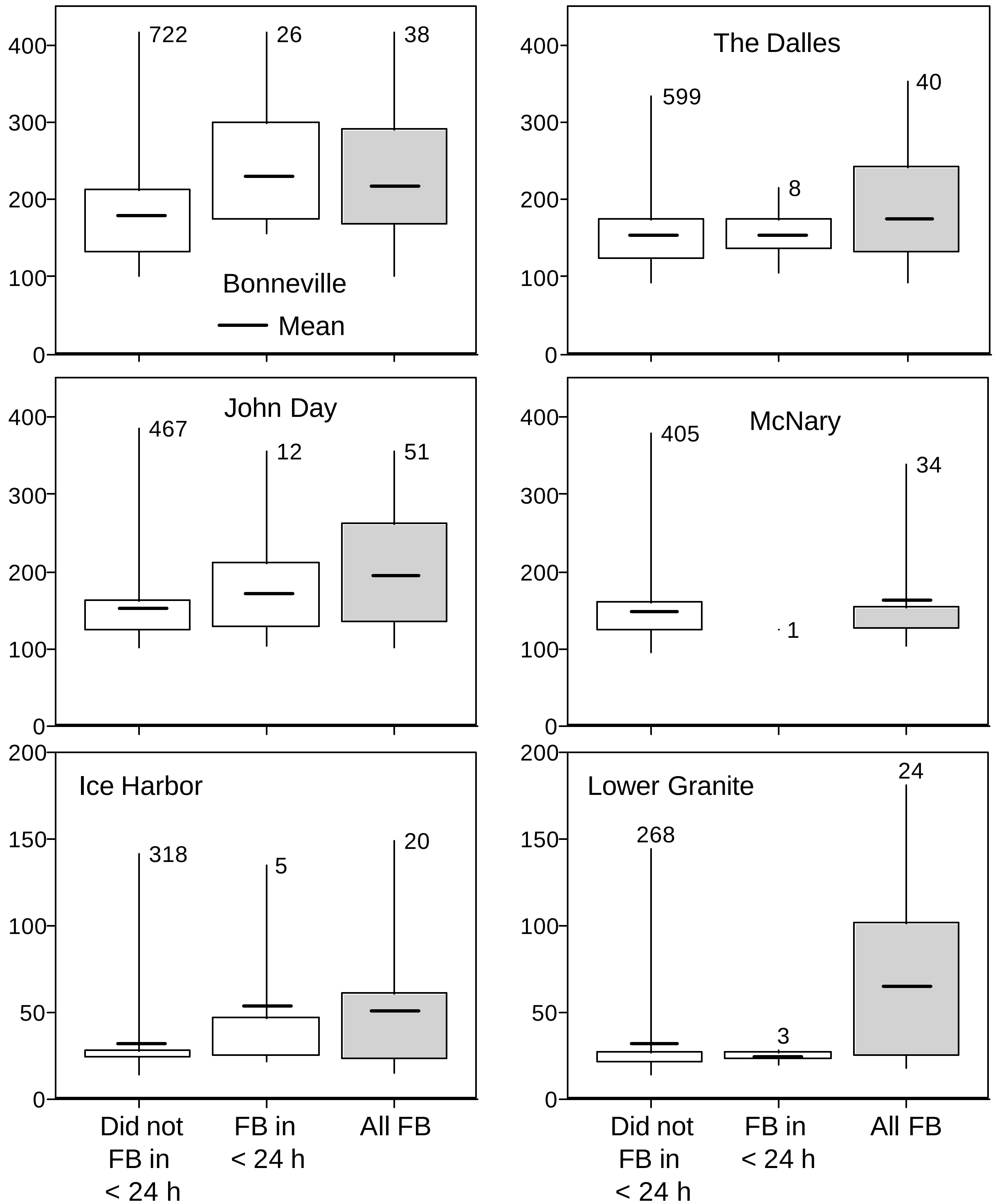

Figure 40. Minimum, maximum, quartile, and mean total daily flow on the date steelhead with transmitters passed dams and either did or did not fall back within 24 h in the run-year 1996-1997. Gray bar is mean daily flow on the date that all fallback events occurred.

qualitative view of the proportion of steelhead tagged in 1996 that fell back at dams.

At Bonneville Dam, 26 steelhead with transmitters fell back within 24 h of passage. Using only these fallback events and passage of steelhead with transmitters over the dam, the highest 5-d moving average fallback ratios occurred in late June/early July (Figure 41). Mean daily spill decreased from a mean of 171 kcfs during the second half of June to about 90 kcfs by early July and was held there for juvenile passage until 1 September. Steelhead fallback ratios were as high in early July after spill decreased to < 100 kcfs as in June when spill volumes were higher. No steelhead fell back within 24 h during the latter half of July, partly because of the period of no tagging, and none after 1 September when there was no spill.

At The Dalles Dam, 8 steelhead with transmitters fell back within 24 h of passage. The highest moving average fallback ratios occurred in late October when relatively few fish were passing the dam (Figure 41). Similarly, the highest moving average ratios at John Day Dam were in July and early August when few steelhead with transmitters were passing the dam. At Ice Harbor Dam, 5 steelhead fell back within 24 h of passage, four of which occurred when few fish were passing the dam (Figure 41).

Effects of Injury on Fallback

Almost 90% of the steelhead outfitted with transmitters in 1996 had fresh marine mammal scrapes or bites, and about 53% had some descaling. To evaluate the effects of these injuries on fallback, we compared fallback behavior by steelhead with fresh marine mammal marks or descaling to those without injuries. Of 718 steelhead that passed Bonneville Dam with transmitters, 25.3% of the fish with no fresh mammal marks fell back at one or more dams, 20.7% with fresh scrapes fell back, and 15.6% with fresh bites fell back (Figure 42). Differences in fallback proportions were not significant ($P = 0.14$, X^2 test). The fallback proportion for fish with no mammal marks (25.3%) was not significantly different than for fish with either fresh scrapes or bites (19.2%) ($P = 0.18$, Z test).

We found little evidence that fish with fresh mammal marks had higher fallback percentages at individual dams; however sample size for uninjured fish was low. At the four lower Columbia River dams, fallback percentages for fish with no mammal marks were higher or the same as percentages for fish with fresh scrapes or bites at Bonneville, John Day, and McNary dams, while fish with fresh scrapes had the highest fallback percentage at The Dalles Dam (Figure 42). Differences among the three categories were not significant at any of the lower Columbia River dams ($P > 0.63$, X^2 test); we also found no significant differences in fallback percentages between fish with no marks and fish with either fresh scrapes or bites ($P > 0.35$, Z test). At Ice Harbor and Lower Granite dams, fallback percentages were highest for fish with no fresh mammal marks and lowest for fish with fresh bites. In 3-category tests, a significantly higher percentage of fish with no marks fell back than fish with fresh bites ($P = 0.11$ at Ice Harbor Dam, $P = 0.02$ at Lower Granite Dam; X^2 tests). However, only one fish with a fresh bite at time of tagging was recorded falling back at Ice Harbor and Lower Granite dams, making statistical comparison difficult.

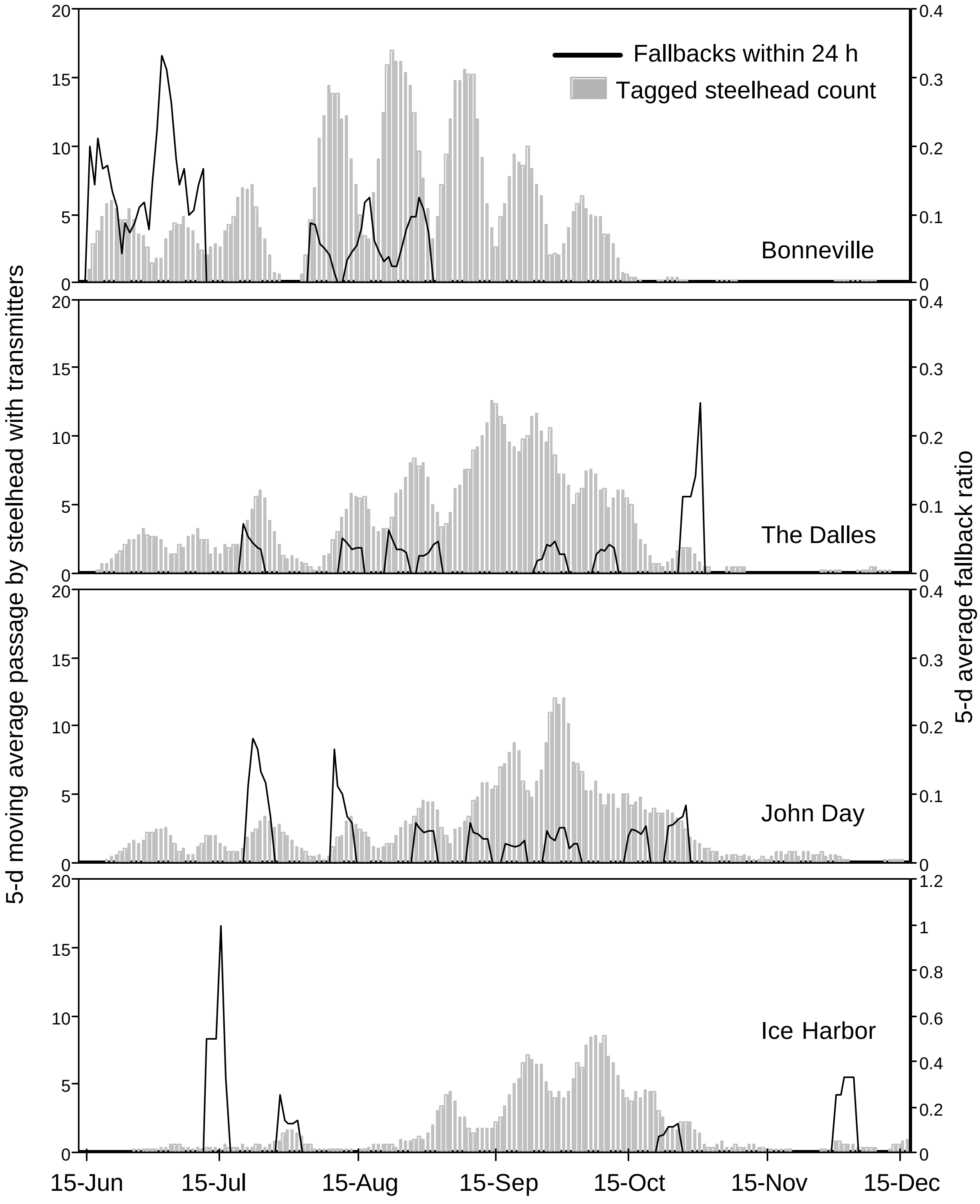

Figure 41. Five-day moving average of recorded passages at tops of fishways at Bonneville, The Dalles, John Day, and Ice Harbor dams, and the daily 5-d moving average ratio of fallbacks to passages for steelhead with transmitters in 1996. Only fallbacks within 24 h of passage included in ratios.

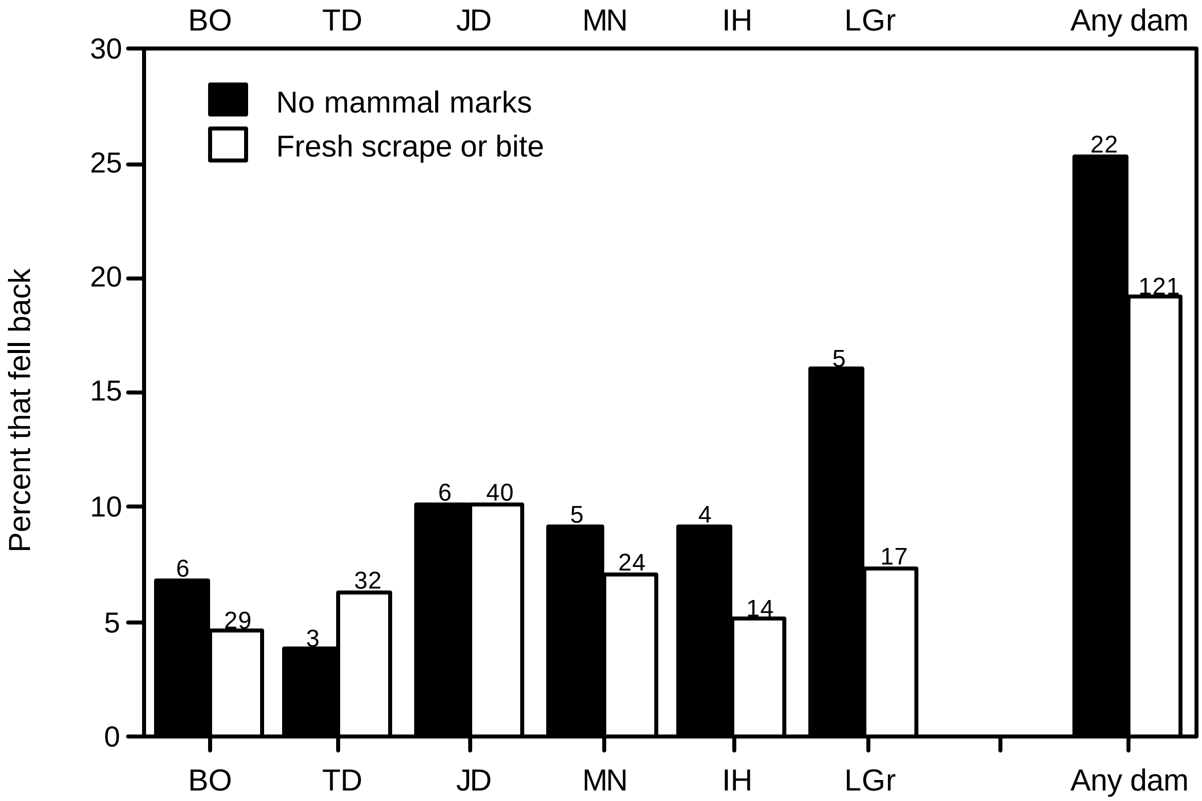

Figure 42. Proportion of steelhead that fell back at dams monitored in 1996, and did or did not have fresh marine mammal scrapes or bites at the time fish were outfitted with transmitters.

Descaling at the time steelhead were outfitted with transmitters also had little detectable affect on fallback. Among 718 fish that passed Bonneville Dam with transmitters, 22.9% with no descaling fell back at one or more dams, 17.8% with < 10% descaling fell back, and 12.8% of 39 fish with > 10% descaling fell back. Differences in 3-category tests were not significant (P = 0.13, X^2 test). The fallback percentage for fish with any descaling was 17.3%, significantly lower than for fish with no descaling (22.9%) at P = 0.06 (Figure 43).

We found no significant differences in fallback percentages at individual dams using 2-category (no descaling, any descaling) or 3-category (no descaling, < 10% descaling, > 10% descaling) tests (P > 0.26, X^2 and Z tests), except at Ice Harbor Dam, where no fish with > 10% descaling fell back. About 9.4% of fish with no descaling and 2.2% of fish with < 10% fell back at Ice Harbor Dam, a significant difference (P < 0.01, Z test) (Figure 43).

Forty-two steelhead fell back multiple times during their upstream migration. Of these fish, 19% had no fresh mammal marks, 64% had fresh scrapes, and 17% had fresh bites, a distribution that was not significantly different (P = 0.24, X^2 test) from proportions for all steelhead outfitted with transmitters (12% no marks, 63% fresh scrapes, 25% fresh bites). Of the 42 steelhead with multiple fallbacks, 50% had no

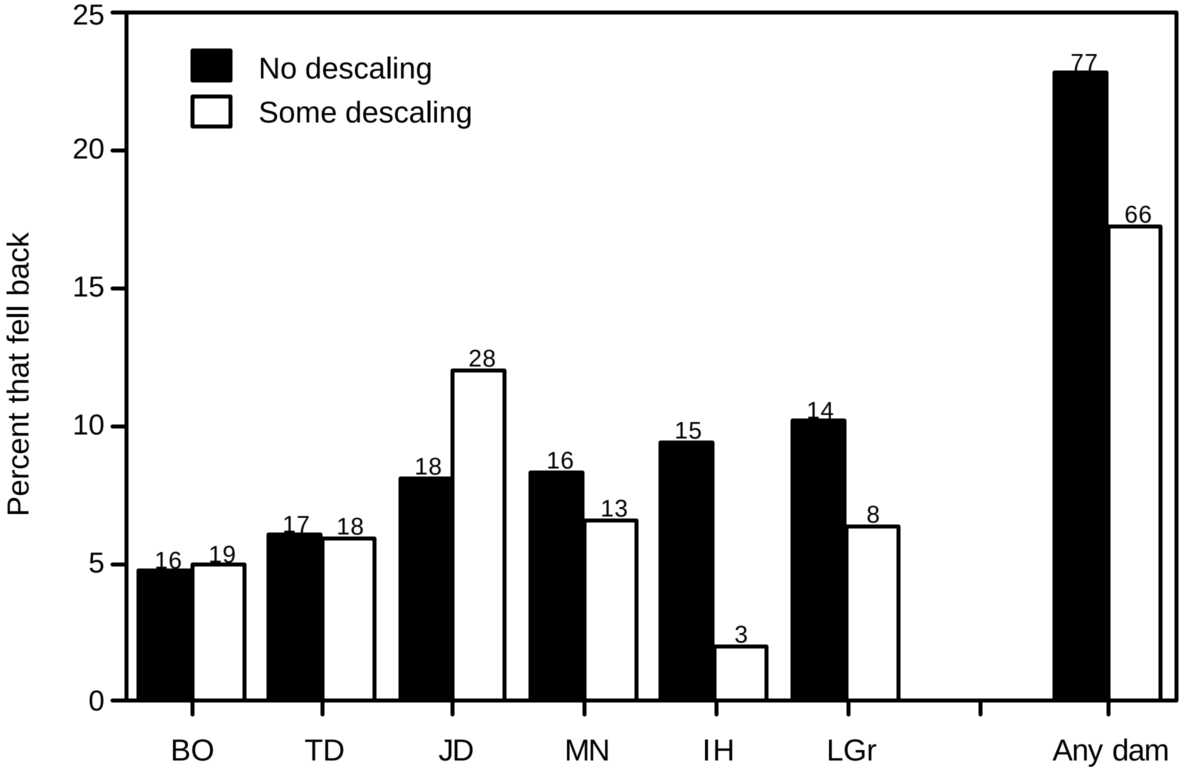

Figure 43. Proportion of steelhead that fell back at dams monitored in 1996, and did or did not have descaling at the time fish were outfitted with transmitters.

descaling, 48% had < 10% descaling, and 2% had > 10% descaling, a distribution not significantly different (P = 0.71, X^2 test) from the overall proportions (47% no descaling, 48% < 10% descaling, 5% > 10% descaling).

Effects of Fallbacks on Passage Time

Steelhead that fell back at any dam in 1996 had significantly longer median passage times past multiple dams than fish that did not fall back and passage times were longest for steelhead that fell back more than once (Figure 44.) We did not include overwintering steelhead in passage time summaries where the behavior affected upriver passage times. It is important to note that steelhead that fell back but did not survive to reascend dams were also not included in passage time analyses. While delayed passage may impact survival, we did not address direct and indirect mortality due to fallback in this section.

Median passage times, from release to the time that steelhead last exited from the top of a ladder at a dam, were 10.9 to 14.1 days longer for fish that fell back once versus those that did not fall back, except at Bonneville Dam where the difference was 0.8 d longer, and Priest Rapids Dam, where sample sizes were very small (Figure 44). Steelhead that fell back more than one time had median passage times 22 to 50 days

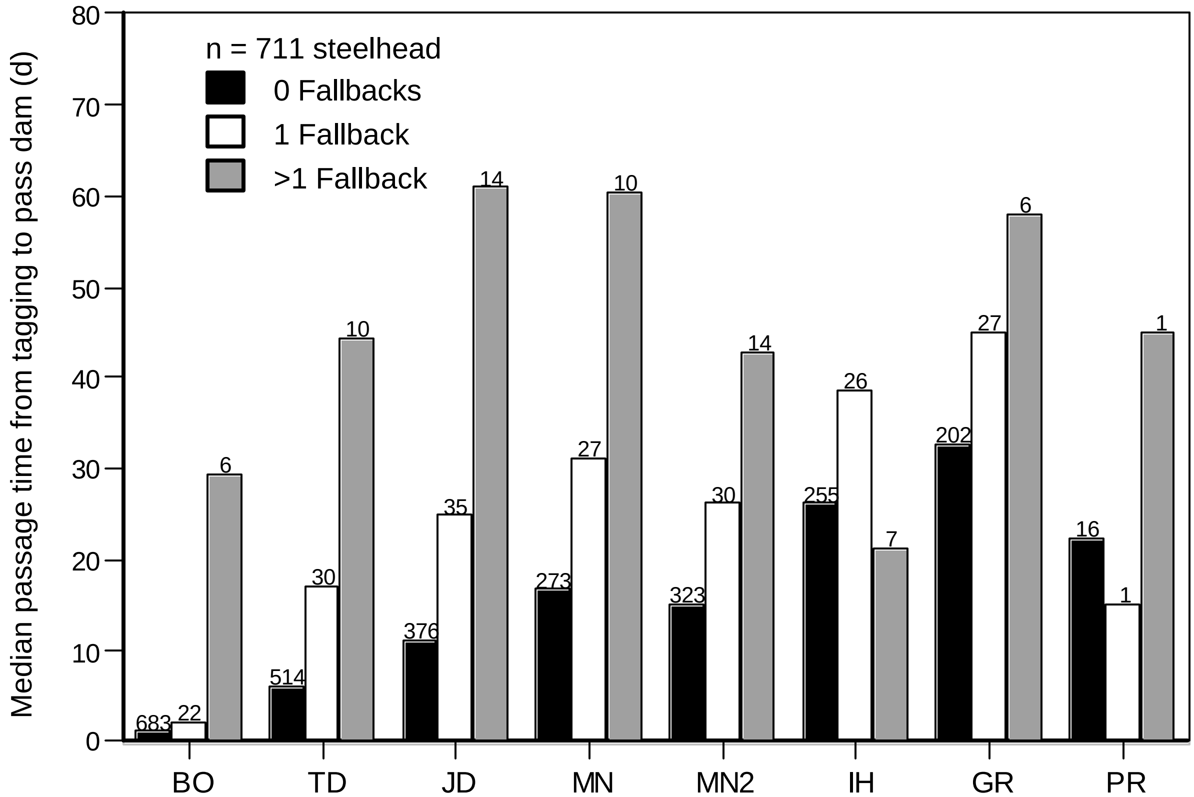

Figure 44. Median passage times from release after tagging to pass dams for steelhead that did not fall back, or fell back once or more than once. Numbers above the bars are number of fish in each category. Second McNary Dam category (MN2) includes fish with estimated passage times due to receiver outage.

longer than fish that did not fall back, with the exception of Ice Harbor Dam, where seven fish that fell back multiple times had median passage time 5 d shorter than fish that did not fall back. When all fish that fell back were combined, one or more fallbacks at any location added 12.0 to 20.8 d to median passage times from release to passage at an upstream dam, except at Bonneville Dam where the difference was 1.0 d and Priest Rapids Dam where the difference was 7.7 d (Figure 45).

Median passage times from release to the top of Bonneville, The Dalles, John Day, McNary, Ice Harbor, and Lower Granite dams were significantly (P = 0.02 for Ice Harbor Dam, P < 0.001 for other dams, K-W X^2 test) longer for fish that fell back one or more times than for those that did not fall back. We did not make statistical comparisons for fish that passed Priest Rapids Dam.

We also tested whether a single (not more than one) fallback at any location affected passage time from release to the tops of dams. For steelhead that passed Bonneville and The Dalles dams (P < 0.005, K-W X^2 test), John Day, Ice Harbor, and Lower Granite dams (P < 0.01), and McNary Dam (P = 0.02) median passage times were significantly longer for fish that fell back once at any location than for fish that did

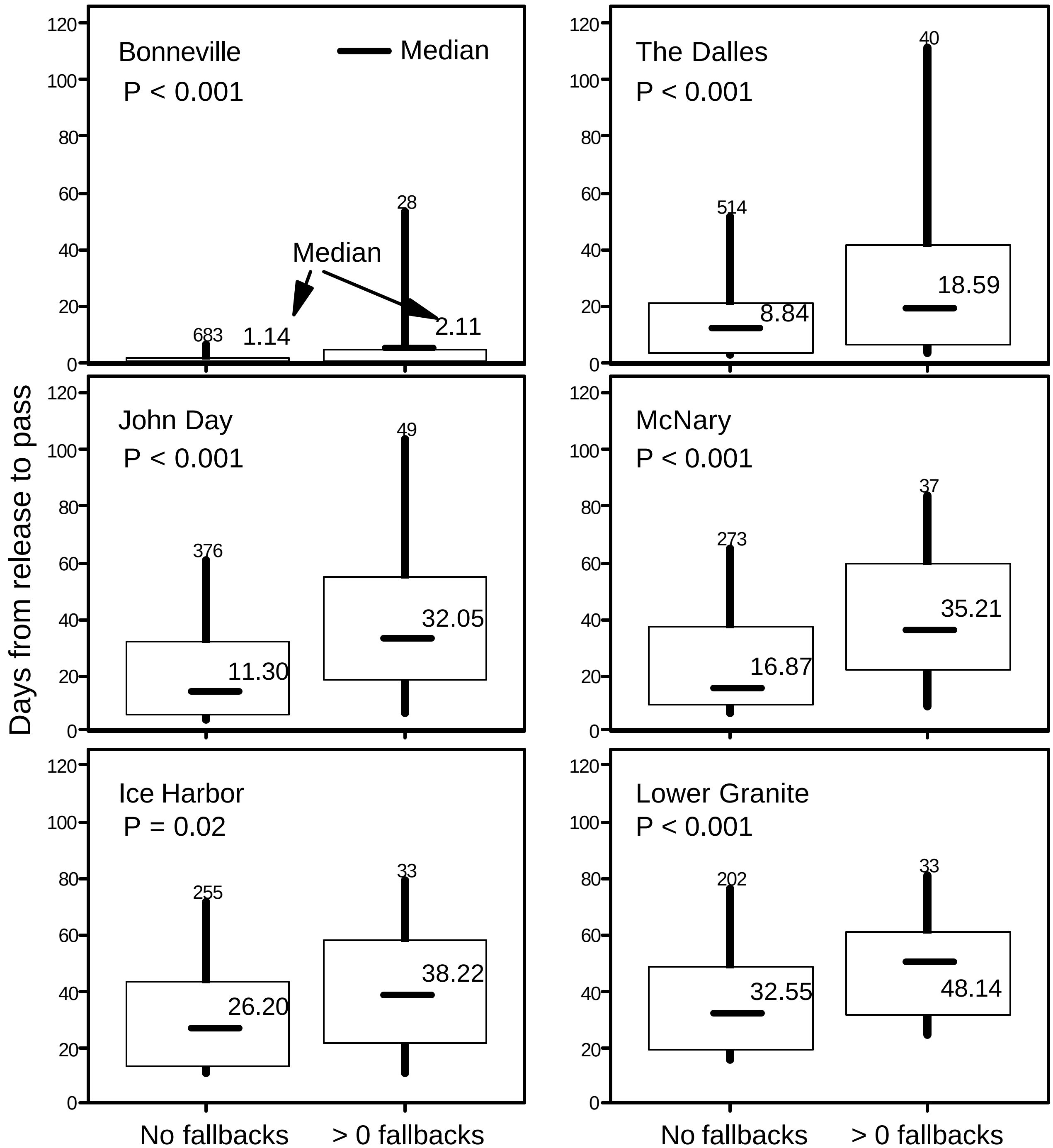

Figure 45. Median, 5% and 95% percentiles, and quartile passage times from release after tagging to pass dams for steelhead that did not fall back, or fell back one or more times. Number of fish above bars.

not fall back. Mean passage from release to the top of McNary Dam for fish that did not fall back was 24.7 d (median = 16.9 d) compared to mean passage of 41.4 d for fish that fell back (median = 35.2 d) (Figure 46). Steelhead that passed Ice Harbor Dam but did not fall back had mean passage of 29.1 d (median 26.2 d) from release, while those that fell back had mean passage of 40.5 d (median = 38.2 d) (Figure 46). Mean passage for fish that passed Lower Granite Dam and did not fall back was 34.6 d (median = 32.6 d) and mean passage for those that fell back was 49.0 d (median 48.1 d) (Figure 46).

As reported in sections on passage time, B-group steelhead migrated through the mainstem Columbia and Snake rivers more rapidly than A-group steelhead. We were concerned that different migration rates could skew fallback analyses. In particular, a comparison that included A-group steelhead that fell back and B-group steelhead that did not fall back could exaggerate the effects of fallback events on passage time. When we analyzed A-group and B-group steelhead separately, we found fallbacks caused delays in migration for both A-group and B-group fish, with slightly longer delays for B-group steelhead (Figure 47). For 450 A-group steelhead, one or more fallback events at any dam added 0.9 to 14.5 d to the median migration time from release to the last passage of an individual dam. The largest differences in median passage time for A-group steelhead were for fish that fell back before their last passage at John Day Dam (14.5 d longer than fish that did not fall back), and for fish that fell back before their last passage at The Dalles Dam (9.8 d longer) (Figure 47). Temporary straying into Lower Columbia River tributaries may have contributed to delays. The 102 A-group steelhead that passed Lower Granite Dam without falling back at any location had a median passage time of 47.2 d versus 50.7 d for 23 fish that passed Lower Granite Dam but fell back one or more times at any location, a 3.5 d difference. A-group steelhead that fell back at one or more dams and passed Ice Harbor Dam took 2.3 d longer than fish that did not fall back; differences were 0.9 d at Bonneville Dam and 6.5 d at McNary Dam (Figure 47). When we included estimated passage times past McNary Dam for A-group fish that passed during top-of-ladder receiver outages, fish that fell back took 12.0 d longer to pass than fish that did not fall back.

Median passage times for A-group steelhead that fell back one or more times at any location were significantly longer ($P < 0.02$, K-W X^2 test) from release to Bonneville, The Dalles, and John Day dams than for A-group fish that did not fall back. Although median times were longer for fallback fish, differences were not significant from release to the top of Ice Harbor ($P = 0.51$) or Lower Granite ($P = 0.16$) dams. Median times for A-group steelhead that fell back were 6.5 d longer to pass from release to the top of McNary Dam ladders ($P = 0.24$); when we included estimated times for fish that passed McNary Dam during top-of-ladder receiver outages the difference was 12 d ($P = 0.03$, K-W X^2 test) (Figure 47).

Smaller sample sizes for B-group steelhead made comparisons more difficult than for A-group fish. For example, no B-group fish fell back and reascended at Bonneville Dam, and between 4 and 10 fish fell back at upstream dams. Median passage times were from 13 d to 19 d longer for fish that fell back from release to the last passage of The Dalles, John Day, McNary, and Ice Harbor dams for B-group migrants (Figure 47). Median times past Lower Granite Dam were 24.2 d for B-group fish that did not fall

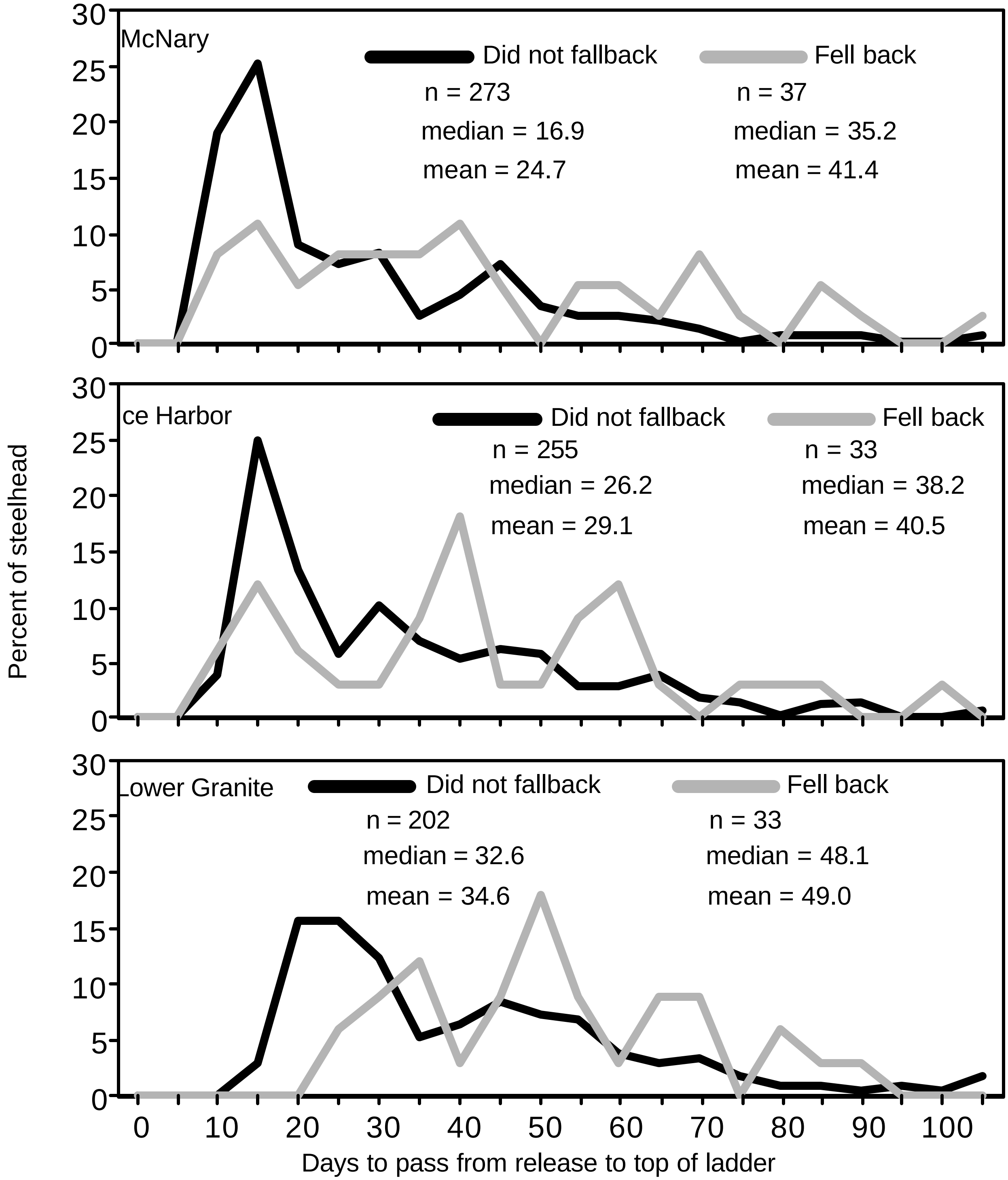

Figure 46. Distribution, mean and median passage times from release after tagging to pass McNary, Ice Harbor, and Lower Granite dams for steehead that did not fall back (FB), or fell back one or more times.

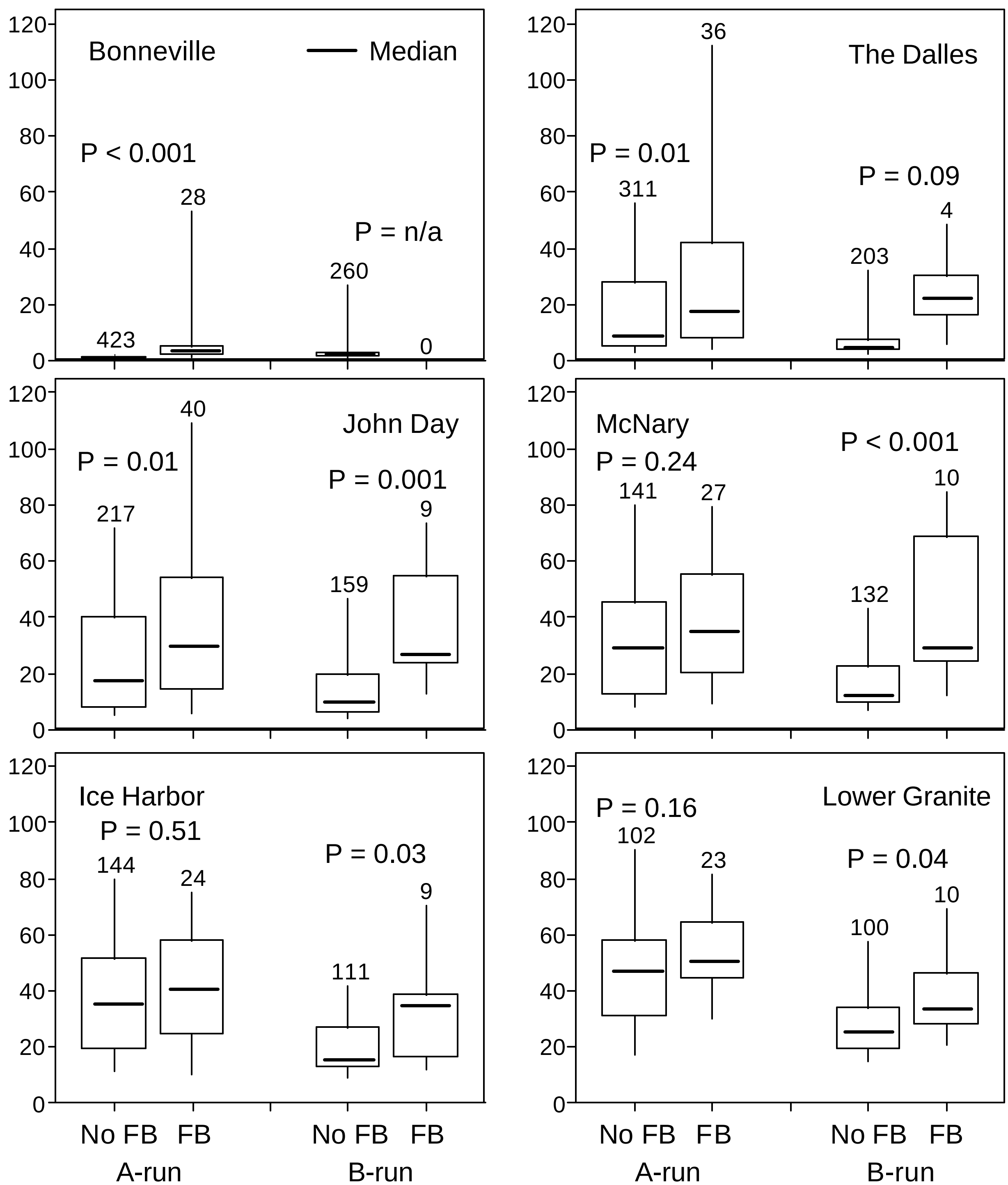

Figure 47. Days to pass from release to the top of McNary, Ice Harbor, and Lower Granite dams by steelhead that did or did not fall back at any location before passing dams for the last time in the run-year 1996-1997. Overwintering fish not included.

back at any location and 32.1 d for fish that did fall back, a difference of 7.9 d. Median passage times for B-group steelhead that fell back were significantly longer ($P < 0.05$, K-W X^2 test) than for fish that did not fall back that passed all dams except The Dalles Dam ($P = 0.09$); only four B-group steelhead fell back prior to their last passage of The Dalles Dam (Figure 47).

Relatively few steelhead were recorded at tailrace and top-of-ladder receivers on both first and second passages of individual dams. We recorded first and second passage times for between 6 and 16 fallback fish at lower Columbia River dams, and for 5 fish at Ice Harbor Dam and 3 at Lower Granite Dam. Median passage times from tailrace to top-of-ladder sites for steelhead that fell back and reascended were two or more days longer on the second passage at all dams; due to small samples, we did not test for statistical differences. Median times between first and second passages for fish that fell back and reascended were < 1 d at Bonneville and Ice Harbor dams, and between 4 d and 9 d at The Dalles, John Day, and McNary dams. Time fish spent between passages was primarily in reservoirs or passing upstream dams prior to falling back, and some fish entered tributaries before falling back.

We also calculated first and second passage times from the first recorded approach to the Bonneville Dam fishway to top-of-ladder sites for 25 steelhead that fell back and reascended. Median first passage time for the 25 fish was 6.0 h (mean = 9.6 h) and median second passage time was 10.6 h (mean = 20.6 h), a difference that was not significant ($P = 0.37$, K-W X^2 test); differences in mean time (9.6 h for first passage versus 20.6h for second passage) were significant (ANOVA $P = 0.09$). Small sample sizes precluded similar tests at upstream dams.

We further tested whether first passage times from tailrace to top-of-ladder receivers differed for fallback and non-fallback fish. At all dams except Lower Granite Dam, fish that subsequently fell back had lower first median passage times than fish that did not fall back, but differences were not significant ($P = 0.15$ at Bonneville Dam; $P > 0.42$ at all other dams, K-W X^2 tests).

Regressions of cumulative downstream fallbacks versus passage time past multiple dams produced positive slopes to regression lines, but r^2 values were less than 0.1 and fallbacks accounted for < 10% of the variation in passage time for steelhead with transmitters from release to pass McNary, Ice Harbor, and Lower Granite dams (Figure 48).

Reascension over Dams, Escapement and Final Distribution after Fallbacks

At least 81 (57%) of the 143 steelhead with transmitters that fell back one or more times in 1996 reascended all dams at which they fell back, based on fixed receiver, mobile-tracking and recapture records. Of the remaining 62 fish, some reascended dams after falling back, but did not reascend all dams at which they fell back (Some fish that fell back at one dam would continue moving downstream and fall back at additional dams). About 37% of the steelhead that did not reascend the most upriver dam they passed were subsequently recorded in tributaries downstream from the fallback location and potentially reached spawning sites.

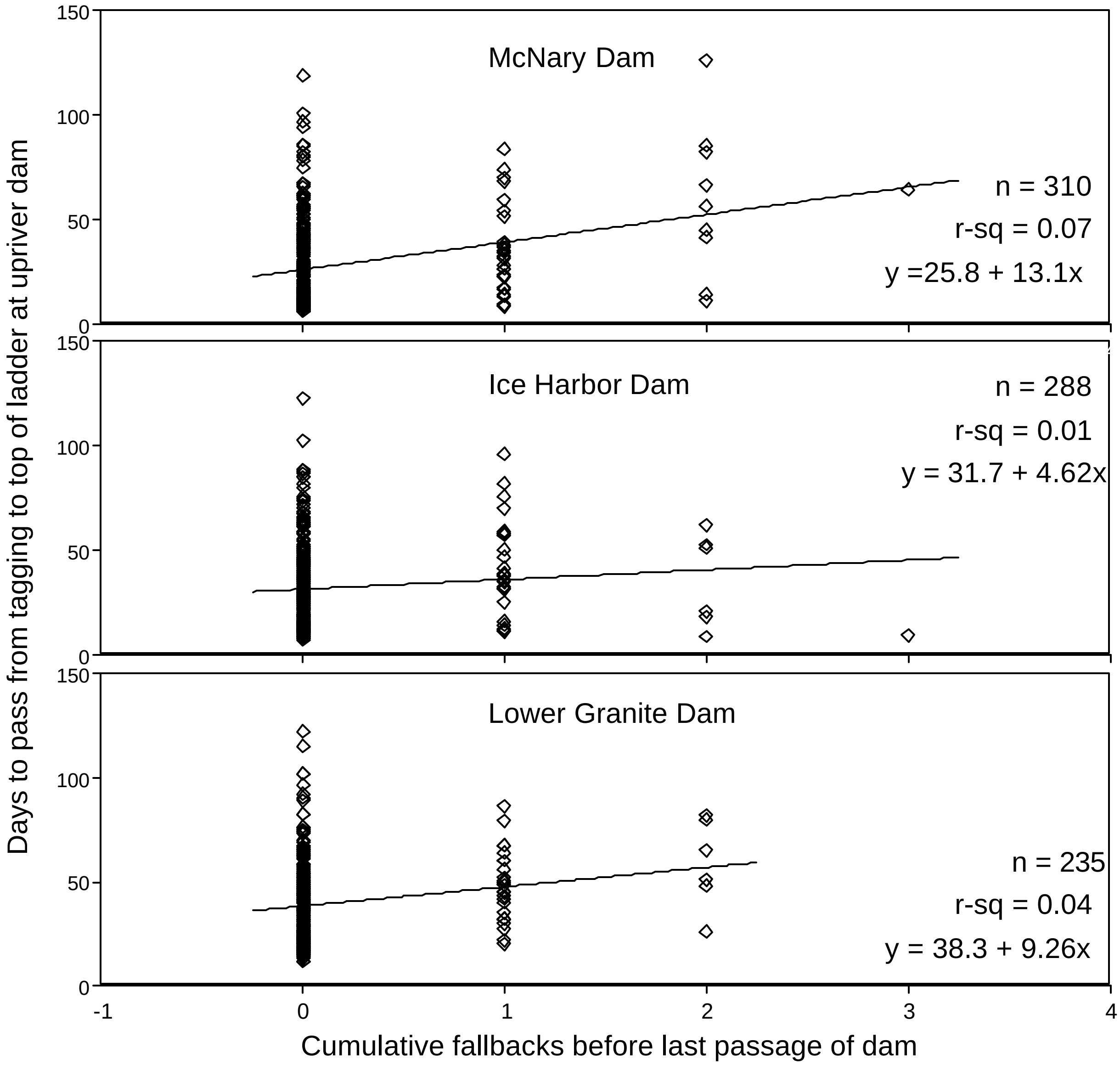

Figure 48. Cumulative fallback events by steelhead at downstream dams versus time to pass from release after tagging to top-of-ladder receivers at McNary, Ice Harbor, and Lower Granite dams in the run-year 1996-1997. Overwintering fish not included.

Fallbacks by fish that subsequently entered downstream tributaries were likely caused by fish migrating upstream past natal streams and then having to return downstream. They may also have been fish destined for other streams that permanently strayed into the tributary where they were last recorded. Most (~70%) of the fish only migrated past the dam immediately upriver from the tributary they eventually entered, but some (~30%) passed multiple dams upriver from the tributary they subsequently entered (Table 26).

Table 26. Number of steelhead that did not reascend dams where they fell back, and did or did not enter downstream tributaries after falling back in 1996.

	Fell back and did not reascend	Did not enter tributary	Entered downstream tributary	Final distribution (river entered)
All fish	62	39	23	Sandy (1), Washougal (1), Little White Salmon (1), Klickitat (3), Deschutes (10), John Day (2), Umatilla (1), Walla Walla (3), Tucannon (1)
Bonneville	5	3	2	Sandy (1), Washougal (1),
The Dalles	8	4	4	Klickitat (3), Little White Salmon (1)
John Day	25	13	12	Deschutes (10), Klickitat (1), Little White Salmon (1)
McNary	17	10	7	John Day (2), Deschutes (4), Umatilla (1)
Ice Harbor	11	7	4	Walla Walla (3), Deschutes (1)
Lower Granite	14	13	1	Tucannon (1)

Because we did less mobile tracking in Snake River tributaries in 1996-1997 than in previous years, steelhead recorded at receivers at the mouth of the Clearwater River or in the Snake River near Asotin, WA were classified as having reached tributary destinations. This differed from previous years, when Snake River tributaries with spawning areas were monitored more extensively and survival to known spawning grounds could be more accurately assessed. There were no fixed-site receivers and limited mobile tracking upriver from Priest Rapids Dam in 1996, but there were records from recaptures at weirs, hatcheries and in fisheries. Because of the limited upriver coverage, we treated steelhead that passed Priest Rapids Dam as a special case; as noted below, for purposes of our analysis, fish that passed Priest Rapids were some times considered to have reached tributary destinations.

An estimated 57% of all radio-tagged steelhead that fell back at any location eventually reached tributary sites, either upstream or downstream from the fallback location, 41% were not recorded at tributary sites, and 3% presumably regurgitated transmitters (Table 27). Escapement to tributaries by fallback fish was based primarily on telemetry or recapture records that indicated a fish had entered and remained in a tributary long enough to spawn (through fall) or be recaptured. The escapement rate also included fish last recorded in the Snake River near Asotin, at the mouth of the Clearwater River, in the lower Deschutes River, and at or upstream from the top of Priest Rapids Dam. It is likely that some steelhead with last records in tributaries did not spawn or were recaptured before spawning occurred. It was also possible that a few fish that were last recorded at dams or at mainstem sites and classified as not

Table 27. Escapement to major tributaries[1] by 718 steelhead with transmitters that passed Bonneville Dam in 1996 and either did or did not fall back at any dam during their migration, and escapement to tributaries for 704 steelhead that we believed retained transmitters for their entire migration.

	Did not fall back		Fell back one or more times	
	Number	Percent	Number	Percent
Escapement for 718 fish that passed Bonneville Dam with transmitters				
Survived	363[2]	63.1	82	57.3
Did not survive	196	34.1	57	39.9
Survival unknown[3]	16	2.8	4	2.8
Total	(575)		(143)	
Escapement for 704 fish that retained transmitters for entire known migration				
Survived	361	63.9	82	59.0
Did not survive	204	36.1	57	41.0
Total	(565)		(139)	

[1] Due to limited mobile tracking of tributaries in 1996, survival to 'major tributaries' included all fish that were recorded in tributaries with fixed receivers at their mouths, including the Clearwater River, the Snake River near Asotin, WA, and the top of Priest Rapids Dam. Only fish that remained in tributaries through the fall spawning season were considered to have survived.
[2] Includes 4 fish recaptured at Lower Granite adult trap without transmitters
[3] Fish that regurgitated transmitters during migration, not recaptured

escaping eventually reached tributaries or spawning areas undetected (most likely if they lost their transmitter), or returned to small unmonitored tributaries. With those qualifications, escapement to major tributaries ranged from 55% to 57% for fish that fell back at lower Columbia River dams to less than 40% for fish that fell back at Ice Harbor or Lower Granite dams (Table 28). By comparison, escapement to major tributaries for all 704 steelhead that retained transmitters after release in 1996 (including fallback fish) was 60.4% (Table 28). A small number of fish entered tributaries downstream from Bonneville Dam and did not have an opportunity to fall back. We found no difference in transmitter regurgitation rates between fallback (2.8%) and non-fallback (2.8%) fish (Table 27).

Steelhead that passed individual dams and did not fall back escaped to tributaries at higher rates than fish that passed dams and fell back, but differences were not significant (Table 27). Of 718 steelhead that passed Bonneville Dam with transmitters in place, 575 were not recorded falling back at any location and 143 fell back at one or more dams. Escapement for the 575 fish that did not fall back at any monitored dam was 63.1% versus 57.3% for the 143 fish that fell back at a dam, a difference that was not significant ($P = 0.20$, Z test). About 3% of the fish that passed Bonneville Dam with transmitters subsequently regurgitated their tags; we found no difference in regurgitation rates between fallback and non-fallback fish.

We also calculated escapement to tributaries for 704 steelhead that we believed retained transmitters throughout their migration, of which 565 did not fall back at any location and 139 fell back over one or more dams (Table 27). Escapement was 63.9%

Table 28. Final location of steelhead with transmitters that fell back (FB) over monitored dams in 1996 and percent that reached tributaries, based on final fate for fish and/or evidence that fish reached spawning areas before returning to mainstem sites. (Note: totals do not add up because some fish fell back at more than one dam.)

	All Fish	FB at BON	FB at TD	FB at JD	FB at McN	FB at IH	FB at GR
Total FB fish	143	35	35	46	29	18	22
Final location							
Washougal River	1	1					
Sandy River	1	1					
Little White Salmon R.	1		1	1			
Klickitat River	4	1	3	1			
Deschutes River	15	2	3	10	4	1	
John Day River	9	3	3	4	2		
Umatilla River	1	1		1	1		
Walla Walla River	4		1		1	3	
Yakima River	1	1					
Near Ringold trap	1		1				
Tucannon River	3	1				1	1
Clearwater River	12	1	3	3	1	1	4
Snake R. at Asotin	9	1	1	2	3	1	2
Grande Ronde River	3		1	2			
Salmon River	14	6	3	1	4		1
Number at tributary sites, including Lower Granite Trap and Wells Dam	79	19	20	25	16	7	7
Number with last record at a dam or mainstem site	64	15	15	20	13	11	14
Number with last record at/upstream from top of Priest Rapids Dam[1]	2	1		1			
Percent with records at tributaries or hatcheries	55.2	54.3	57.1	54.3	55.2	38.9	31.8
Percent with records at tributaries, hatcheries or at/upstream from top of Priest Rapids Dam	56.6	57.1	57.1	56.5	55.2	38.9	31.8

[1] No fish fell back at Priest Rapids Dam

for fish that did not fall back versus 59.0 for those that fell back, a difference that was not significant (P = 0.29, Z test).

Of 35 steelhead that fell back at Bonneville Dam, 6% were later recorded in tributaries downstream from the dam, 54% were last recorded at tributary sites, the most being in the Salmon (17%) and in the Deschutes and John Day rivers (14%). Last records for the 15 steelhead that fell back at Bonneville Dam and did not reach tributary sites or pass Priest Rapids Dam were mostly (80%) at dams or in reservoirs in the lower Columbia River. Two fish (13%) were last recorded at dams in the lower Snake River, and one fish was last recorded in the Hanford Reach.

Of 35 steelhead that fell back at The Dalles Dam, 57% were last recorded in tributariy streams; 10 from lower Columbia River tributaries and 8 from the Snake River. (Table 28). Fifteen fish (43%) fell back at The Dalles Dam and were not recorded in tributaries, of which about 73% were last recorded at dams or in reservoirs in the lower Columbia River, and 27% were last recorded at dams in the lower Snake River.

Of 46 steelhead that fell back at John Day Dam, 54% were last recorded in tributaries, 35% in lower Columbia River tributaries, including 10 fish (22%) in the Deschutes River, and 17% in the Snake River. Twenty of the 46 fish (43%) that fell back at John Day Dam were not recorded in tributaries, of which 10 (50%) were last recorded between The Dalles and John Day dams, 2 (10%) were last recorded downstream from The Dalles Dam, and 5 (25%) were last recorded at dams in the lower Snake River.

Of 29 steelhead that fell back at McNary Dam, 55% were last recorded in tributaries, 7 (24%) were recorded in tributaries downstream from McNary Dam and 8 (27%) were in Snake River tributaries (Table 28). Of the 13 not recorded in tributaries, 7 were recorded at McNary Dam or in the McNary pool, 2 were between The Dalles and John Day dams, 2 were downstream from The Dalles Dam, and 2 were last recorded at the top of Ice Harbor Dam.

Of 18 steelhead that fell back at Ice Harbor Dam, 7 were last recorded in tributary streams, 4 downstream from the dam and 3 in the Snake River. Eleven of the 18 fish that fell back at Ice Harbor Dam (61%) were not recorded in tributaries after falling back; 6 were last recorded at Ice Harbor Dam, 3 at Lower Granite Dam or in the Lower Granite pool, and 2 at McNary Dam.

Of 22 steelhead that fell back at Lower Granite Dam, 8 were last recorded in Snake River tributaries, including 4 in the Clearwater River. Of the 14 not recorded in tributaries, 10 (67%) were last recorded at Lower Granite Dam, 2 were last recorded at Ice Harbor Dam, and 1 each in the Lower Monumental pool and at McNary Dam.

Overwintering Behavior by Steelhead

All adult steelhead that survive to spawn must overwinter somewhere in the Columbia River system. Most (93.5%) steelhead were last recorded in their final tributaries or upstream from Lower Granite and Priest Rapids dams prior to the onset of winter and so potentially selected those areas to overwinter. Little information has been collected on steelhead that overwinter at mainstem Columbia and Snake River sites or in lower river tributaries before migrating past dams and into upstream tributaries the following spring (i.e. those that stopped in the Columbia River hydrosystem enroute to overwinter). We used radio telemetry data from steelhead outfitted with transmitters in 1996 to describe overwintering by steelhead during the 1996-1997 run-year, including when and where steelhead overwintered, up- and downstream movement during winter months, winter harvest rates, and final fate for overwintering fish.

Overwintering steelhead we were interested in were identified using the following three criteria: fish had to pass one or more dams after 1-December, fish had to have some movement within the mainstem Columbia or Snake rivers downstream from Lower Granite or Priest Rapids dams after 1-February, and fish had to have at least one 14 d period of no significant detectable movement after 1-December. Not included in this analysis were steelhead that overwintered in the lower reaches of major tributaries before they migrated to spawning areas in the same basin (i.e. fish that overwintered in the lower Deschutes River before migrating to upper Deschutes River sites to spawn) due to limitations in telemetry coverage. We also did not identify fish that overwintered in the Lower Granite Dam pool before migrating to Snake River tributaries due to limited telemetry coverage upstream from Lower Granite Dam.

A total of 47 unique steelhead (6.5% of those that passed Bonneville Dam with transmitters) passed one or more dams after 1-December, and 36 (5.0%) passed individual dams for the first time after 1-December. Less than 0.5% of the radio-tagged steelhead first passed Bonneville and The Dalles dams after 1-December, compared to 2.6% at John Day Dam, 2.3% at McNary Dam, 7.2% at Ice Harbor Dam, and 9.2% at Lower Granite Dam. When we considered all passages at dams, including those after fallback, 0.6% of all unique fish passed Bonneville Dam, 1.2% passed The Dalles, 3.7% passed John Day, 2.7% passed McNary, 7.8% passed Ice Harbor, and 10.7% passed Lower Granite Dam at least once after 1-December. Note that our estimate of fish that made their first passage at dams in winter is biased because we stopped tagging fish at Bonneville Dam in October of 1996.

Thirty-seven fish, 5.2% of those that passed Bonneville Dam, met all three criteria for overwintering classification. Fifteen (41%) of the 37 overwintering fish were A-group steelhead, and 22 (59%) were B-group fish. Of fish that passed Bonneville Dam with transmitters, a significantly higher proportion of B-group steelhead (8.3%) overwintered than A-group steelhead (3.3%) ($P = 0.004$, Z test). Thirty overwintering fish (81%) had fin clips, and 7 (19%) did not. About 6.1% of fish without fin clips and 5.0% with clips that passed Bonneville Dam overwintered, a difference that was not significant ($P = 0.34$).

Approximately 94% of all dam passages by steelhead with transmitters occurred before 1 November, and 61% were in September and October (Figure 49). About 2.2% of all passages occurred in November, 1.2% in December, 0.1% in January, 0.6% in February, 1.7% in March, and 0.2% in April. Most overwintering steelhead passed at least one dam in October or November before starting a period of little or no upstream movement. After periods (> 14 d) of relatively little detectable movement in November, many overwintering steelhead passed additional dams in December (Figures 50, 51, 52). The 37 overwintering steelhead all last passed a dam in 1997, 5% in January, 24% in February, 59% in March, and 11% in April. More than half of overwintering fish also moved downstream after 1 November, and 20 (54%) fell back over at least one dam after 1-November. Overall, 21 overwintering steelhead fell back a total of 42 times, with 36 of the events after 1 November. Fallback percentages and rates for overwintering steelhead were significantly higher ($P < 0.001$, Z tests) than for all steelhead that passed Bonneville Dam with transmitters and for all non-overwintering steelhead that passed Bonneville Dam.

The resumption of upriver movement by overwintering steelhead may have been related to increasing water temperatures. Nadirs for mean daily water temperatures (3° to 4°C) occurred at most Columbia and Snake River sites in January, coincident with the lowest

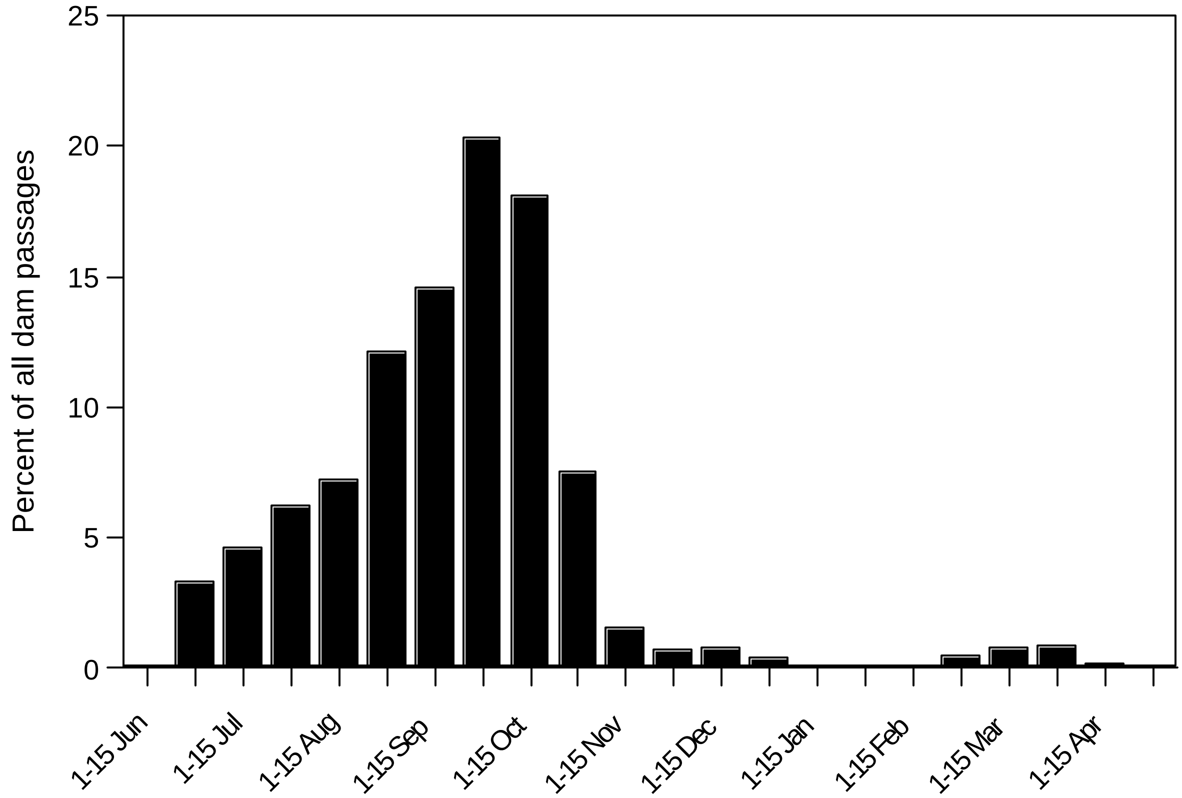

Figure 49. Percent of all recorded dam passages by steelhead with transmitters during semi-monthy intervals from June, 1996 through April, 1997.

number of recorded dam passages by steelhead with transmitters. Mean water temperatures began to increase in early February, and 33 of 37 (89%) overwintering steelhead last passed a dam after 15-February. Mainstem water temperatures were approximately 8°C by early April, when the last overwintering steelhead were recorded passing dams.

Due to monitoring limitations, we were not able to identify exactly when or where overwintering behavior began and ended for individual radio-tagged steelhead. We estimated overwintering time by counting days between the last dam passage prior to the period of no significant movement to the time that fish resumed upstream migration by passing dams in the spring. Overwintering times were likely overestimates by days or weeks because we could not identify the exact time that fish stopped upstream movements after passing dams in the fall, nor when they resumed moving in the winter or spring. In addition, most fish had some localized movements (i.e. within reservoirs or tributaries or passing dams) that may or may not have been related to overwintering behavior. For example, some fish may also have been delayed by injury or straying rather than exhibiting overwintering behavior.

Our best estimates for overwintering times ranged from 53 d to 211 d, with a median time of 146 d (mean = 138 d). About 73% (27 of 37 fish) of the overwintering steelhead spent some time between Bonneville and McNary dams, 5 (14%) spent overwintering time

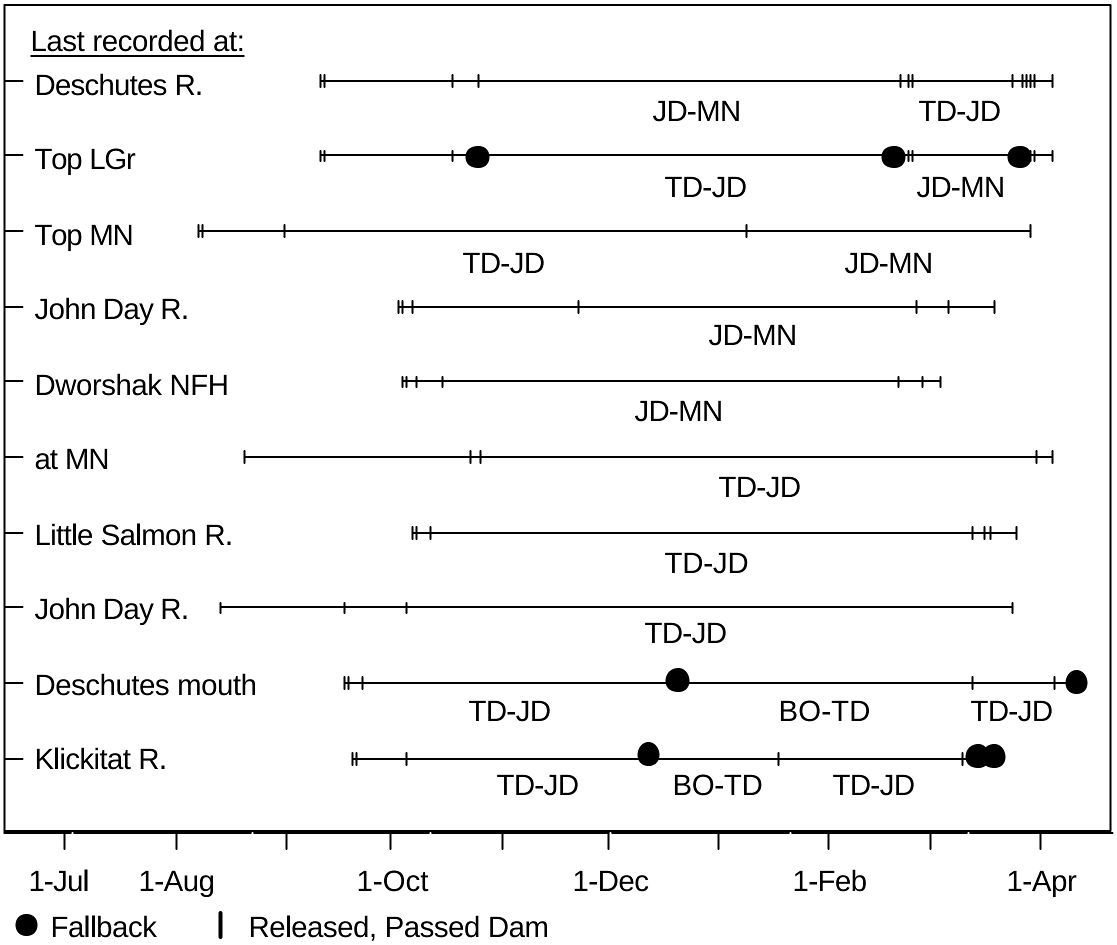

Figure 50. Timeline examples for 10 individual steelhead with transmitters that overwintered in the lower Columbia River during the 1996-1997 run-year, with final recorded location for each fish. First vertical tick on each line indicate release time. Subsequent vertical ticks indicate dam passages. Solid balls indicate fallback events.

in the Columbia River upstream from McNary Dam, and 15 (41%) spent overwintering time in the Snake River. Some fish spent time in more than one portion of the river.

We further partitioned overwintering behavior by time fish spent between individual dams, including time in tributaries. The largest number of fish (18) spent some or all of their overwintering time between The Dalles and John Day dams, with a median time of 131 d (Figure 53). Thirteen fish spent a median of 79 d between John Day and McNary dams, 5 fish spent a median of 47 d between Bonneville and The Dalles dams, and 5 spent a median of 64 d between McNary and Ice Harbor dams. In the Snake River, 14 fish spent a median of 68 d between Ice Harbor and Lower Granite dams, and 4 steelhead spent a median of 146 d upstream from Lower Granite Dam before falling back at the dam, then resuming upstream movement. Seventeen steelhead overwintered in just one basin subsection, 17 overwintered in two subsections, and 3

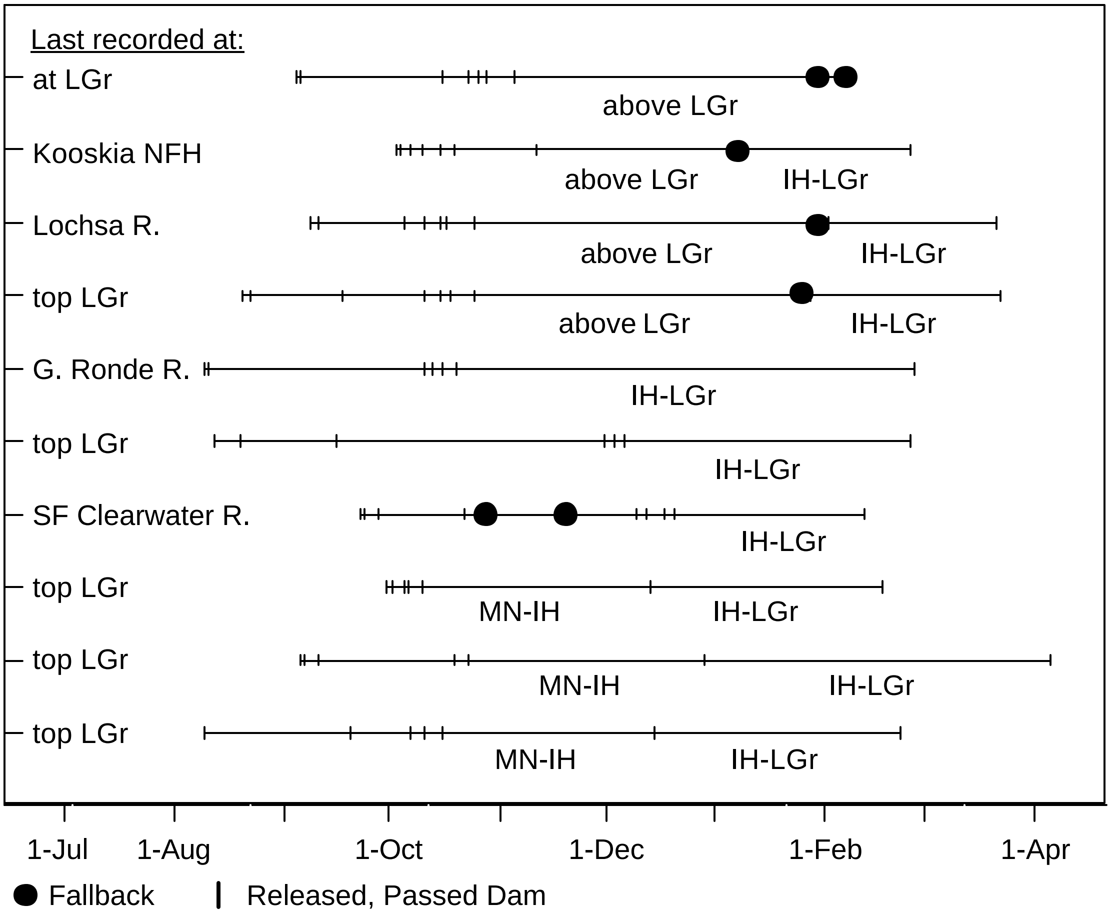

Figure 51. Timeline examples for steelhead with transmitters that overwintered upstream from McNary Dam or in the lower Snake River during the 1996-1997 run-year, with final recorded location for each fish. First vertical tick on each line indicate release time. Subsequent vertical ticks indicate dam passages. Solid balls indicate fallback events.

overwintered in three or four basin subsections (see Figures 50, 51, and 52 for examples). About 25% of overwintering steelhead spent more than 14 d overwintering in tributaries, mostly the Deschutes and John Day rivers, before returning to the Columbia River and migrating upstream in the spring (Figure 52). Some fish also entered lower Columbia River tributaries in September and October, causing migration delays that may have contributed to overwintering behavior.

Our best estimate for the final fate of 37 overwintering steelhead was 7 (19%) returned to tributaries, 6 (16%) were recaptured at hatcheries, 5 (14%) were recaptured in sport or tribal fisheries, and 19 (51%) were unaccounted for. By comparison, 189 of 765 (24.7%) steelhead released with transmitters were unaccounted for, a significantly lower proportion ($P < 0.001$, Z test) than for overwintering steelhead. Thirteen of 19 (68%) unaccounted for overwintering steelhead were last recorded at lower Snake

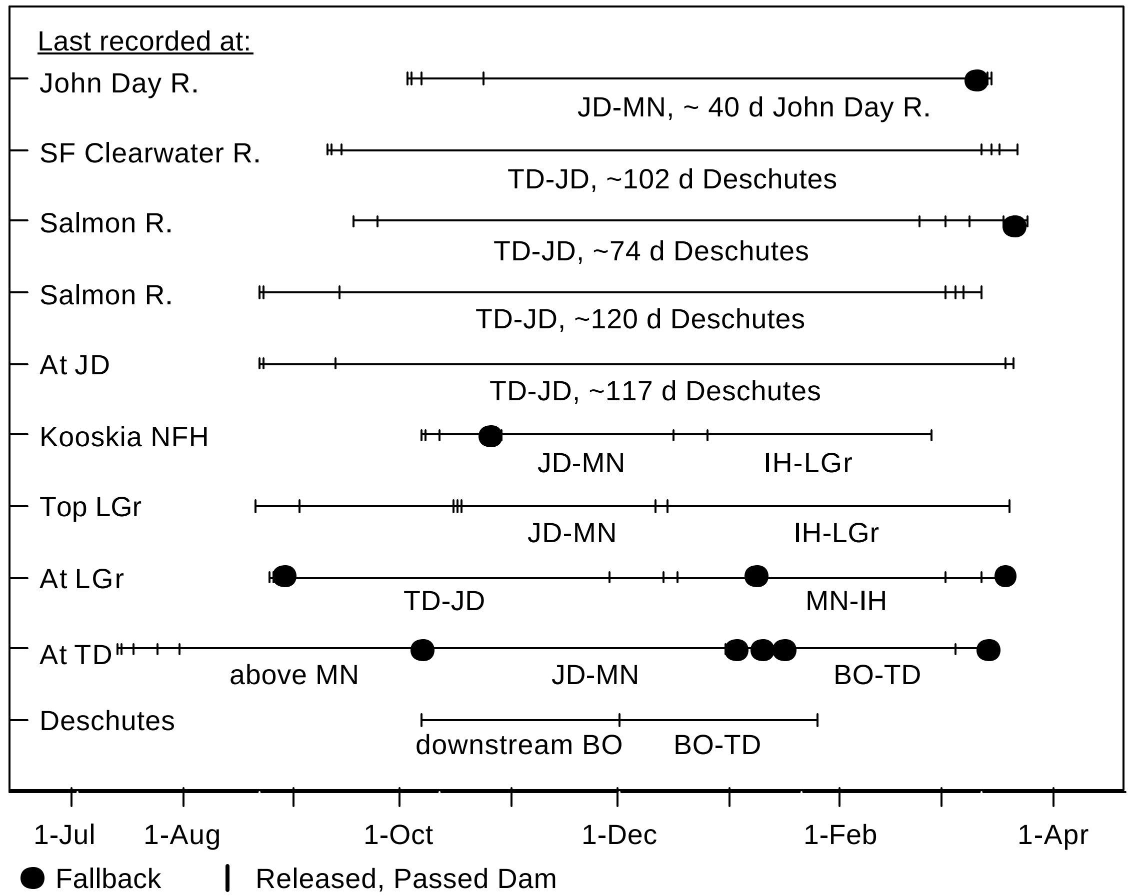

Figure 52. Timeline examples for steelhead with transmitters that overwintered in the John Day or Deschutes rivers or overwintered at sites both up and downstream from McNary Dam during the 1996-1997 run-year, with final recorded location for each fish. First vertical tick on each line indicate release time. Susequent vertical ticks indicate dam passages. Solid balls indicate fallback events.

River dams, and 6 were last recorded at dams or in reservoirs in the lower Columbia River. Unaccounted for fish may have entered tributaries undetected, may have regurgitated transmitters, may have been recaptured but not reported, or may have been mortalities.

Eight overwintering steelhead returned to the Clearwater River where 5 were recaptured at hatcheries and 2 were recaptured in fisheries. Three fish returned to the Salmon River (1 harvested), 3 returned to the Deschutes River (1 harvested), 2 returned to the John Day River, 1 returned to a Grande Ronde River hatchery, and 1 was harvested in the Klickitat River.

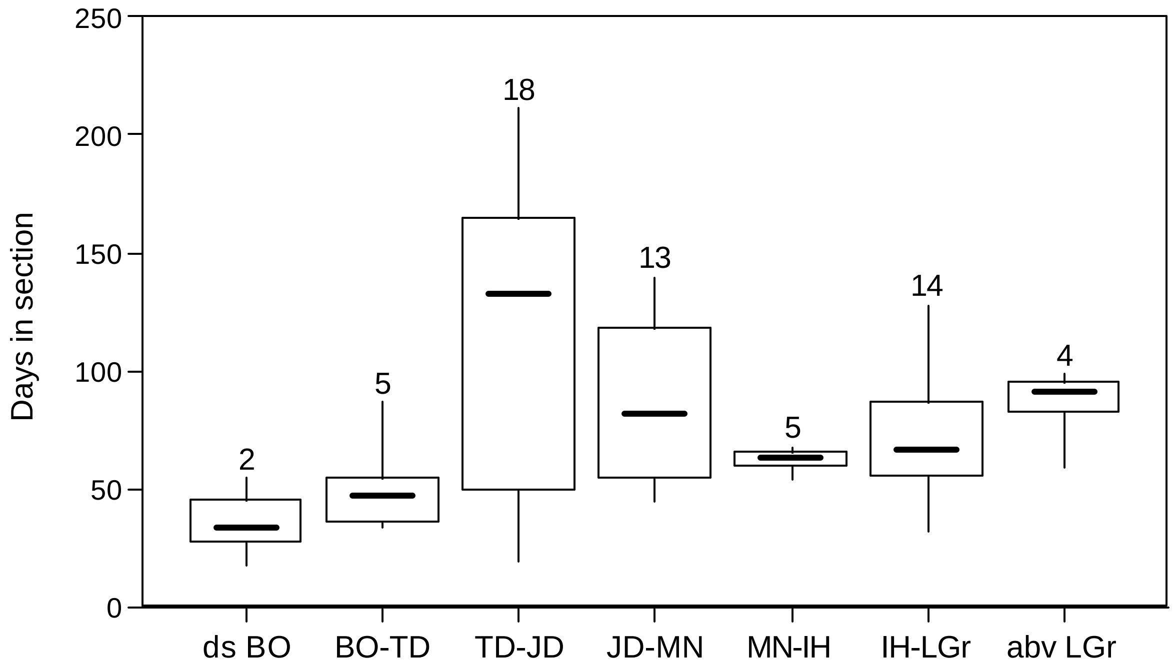

Figure 53. Median, minimum, maximum, and quartile number of days that overwintering steelhead with transmitters spent in each subsection of the Columbia and Snake rivers in the 1996-1997 run-year. Number of fish are above each bar.

Timing of Migration Past Dams and into Tributaries

Adult steelhead with transmitters started migrating into the tributaries where they were last recorded in mid-July, 1996 and continued to enter tributaries through April, 1997. Most fish that entered and remained in lower Columbia River tributaries were first recorded passing fixed receivers near tributary mouths before 1 November (Figure 54). Median arrival dates were in early to mid-August for fish last recorded in the Little White Salmon, White Salmon, and Klickitat rivers and in late August to early September at the Deschutes and Wind rivers. Median first arrival dates were in mid-October for fish that returned to the Hood and John Day rivers (Figure 54).

Median arrival dates for steelhead with transmitters were 3 October for the Yakima River returns, 25 November for the Umatilla River returns and 12 December for steelhead that returned to the Walla Walla River (Figure 55). Median arrival date at Ice Harbor Dam for all steelhead that passed the dam was 2 October, and the median arrival at Lower Granite Dam was 11 October. The median recorded first arrival date at the Clearwater River was 26 October, and was 13 October at the Snake River site near Asotin. We did not monitor the mouths of the Tucannon, Grande Ronde, Imnaha, or Salmon rivers with fixed receivers during the 1996-1997 steelhead migration.

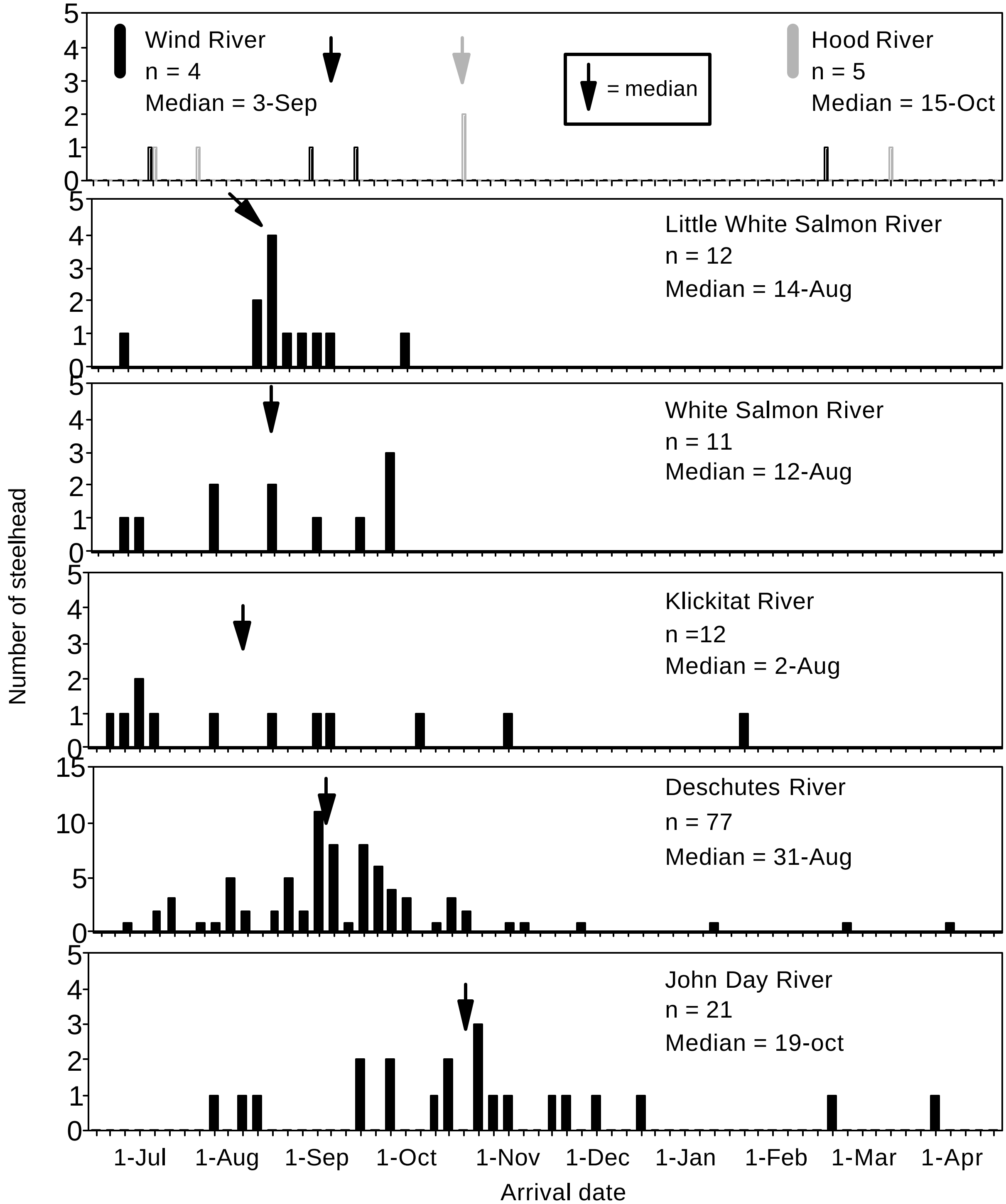

Figure 54. Number of steelhead and date of first record at fixed receiver sites near the mouths of the Wind, Hood, Little White Salmon, White Salmon, Klickitat, Deschutes, and John Day rivers in the run-year 1996-1997. Does not include fish temporarily straying into tributaries other then their final destination.

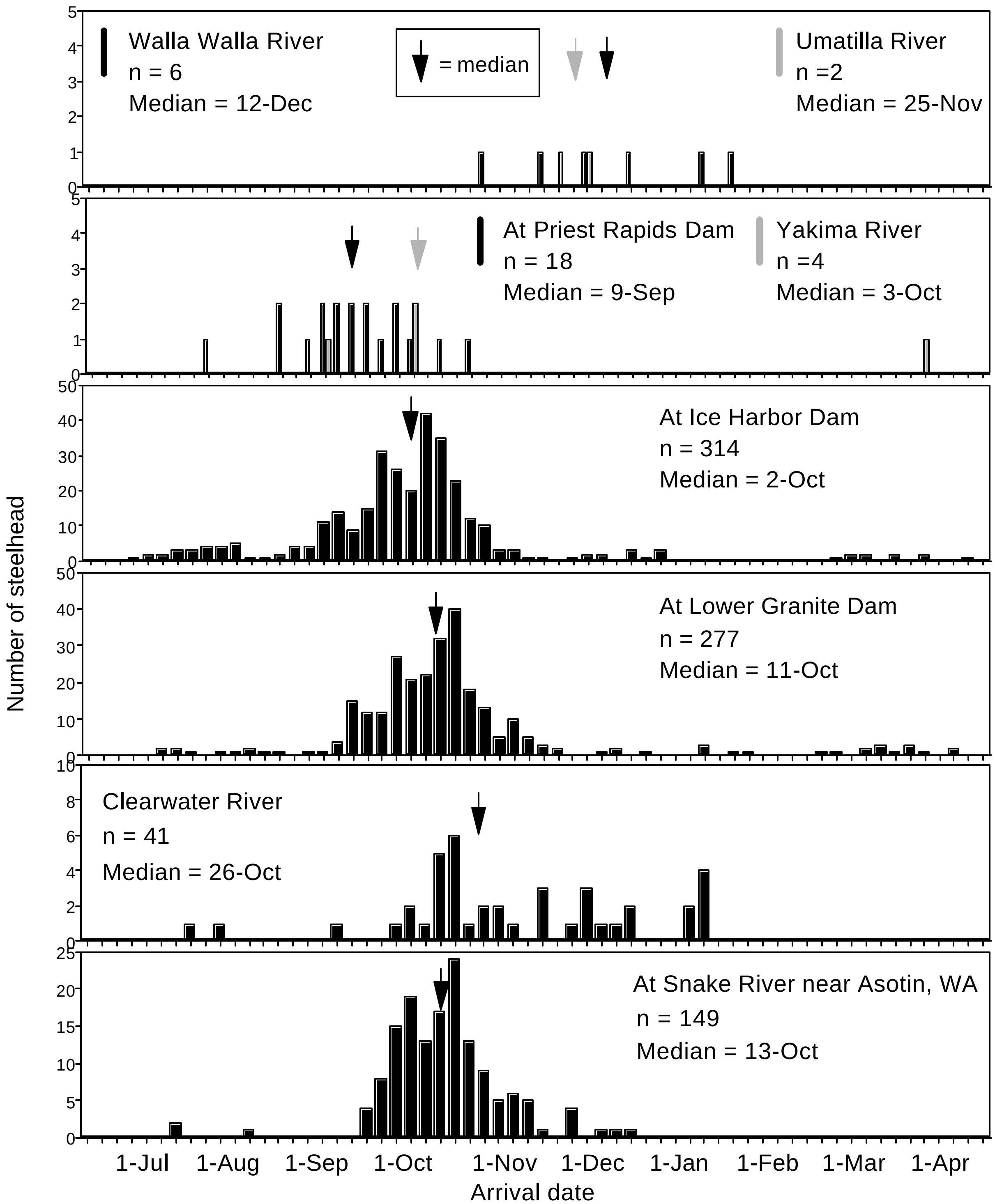

Figure 55. Number of steelhead and date of first record at fixed receiver sites near the mouths of the Umatilla, Yakima, Walla Walla and Clearwater rivers, at Lower Granite and Priest Rapids dams and in the Snake River near Asotin, WA in the run-year 1996-1997. Does not include fish temporarily in tributaries other then their final destination.

Steelhead migrated into tributaries throughout day and nighttime hours, but most were first recorded at fixed receivers during daylight hours (Figure 56). The highest number of first entries were during morning hours, with a second peak in late afternoon or early evening. Relatively lower numbers of fish first entered the Little White Salmon, Klickitat, Deschutes, John Day, and Clearwater rivers during mid-day. To give a more complete picture of when steelhead entered tributaries, we included all fish recorded passing tributary fixed sites, including those that entered temporarily en route to other sites (Figure 56). Distributions for first entries by fish that remained in tributaries were similar to all entries.

Length frequencies of steelhead with transmitters differed among major tributaries and at Priest Rapids Dam, primarily because the larger B-group steelhead were not present in all tributaries (Figure 57; also see Figure 9 for lengths of all steelhead tagged in 1996). We included fish at each site based on the location of their last known record, excluding post-spawn records. Steelhead that returned to the Clearwater River, mostly B-group fish, had the longest median fork length (81.5 cm) among all tributary returns. Yakima, John Day, Hood, White Salmon, and Klickitat river returns had median fork lengths of approximately 70 cm or greater, and returns to the Wind and Little White Salmon rivers had median lengths between 66 cm and 69 cm. Median fork lengths were between 62 cm and 64 cm for returns to the Salmon, Umatilla, Walla Walla, and Deschutes rivers, as well as for all fish recorded at the Snake River site near Asotin, WA and for steelhead that passed Priest Rapids Dam. The shortest median fork lengths were for returns to the Grande Ronde and Tucannon rivers, as well as to Lyon's Ferry Hatchery (Figure 57).

Tag Dates for Specific Stocks of Steelhead with Transmitters

Identifying distinct adult salmon and steelhead stocks at lower Columbia River dams during annual runs has been a management challenge. In 1996, we used tag dates and final distribution records for radio-tagged steelhead to identify when specific upriver stocks passed Bonneville Dam. Although sample sizes of radio-tagged fish were low for some tributaries, we did find that some stocks predominantly passed Bonneville Dam in either early or late portions of the steelhead run; other stocks, like those bound for the Snake and Deschutes rivers, were distributed throughout the migration season. Steelhead that returned to tributaries in the Bonneville Dam pool were primarily A-group steelhead outfitted with transmitters at Bonneville Dam in July and August. Median tag dates were in mid-July for fish last recorded in the Hood and Klickitat rivers, and in the first half of August for returns to the Little White Salmon and White Salmon rivers (Figure 58). Steelhead that returned to the Deschutes, John Day, and Walla Walla rivers were outfitted with transmitters throughout the migration season, from the onset of tagging in June, through early October. Median tag dates were 21 August for fish last recorded in the Deschutes River, 19 August for John Day River returns, and 14 August for Walla Walla River returns (Figure 59). Due to temporary straying, some fish may have been recaptured in tributaries other than their final destination.

Fish last recorded in the Yakima and Umatilla rivers were mostly A-group steelhead outfitted with transmitters in July and August, as were steelhead that passed Priest

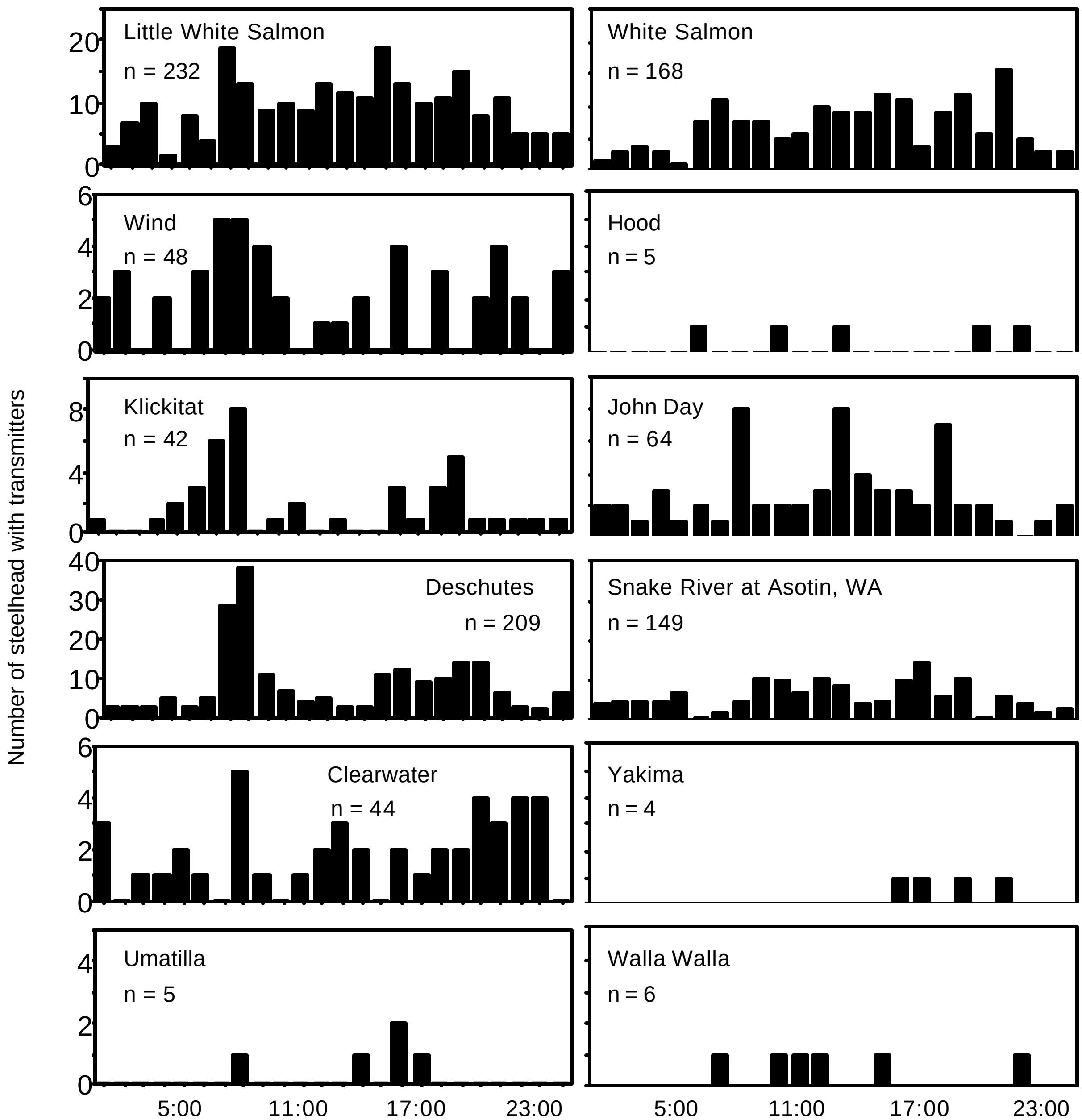

Figure 56. Diel arrival times for steelhead at tributaries, using the first record at receiver sites in tributaries and at the Snake River site near Asotin, WA in the run-year 1996-1997. Includes fish that strayed temporarily into tributaries en route to other sites.

Rapids Dam (median tag date = 13 August) (Figure 59). The 322 steelhead that passed Ice Harbor Dam had a median tag date of 25 August; less than 13% were tagged in June or July. Steelhead that returned to Lyon's Ferry hatchery or the Tucannon River were mainly A-group fish with median tag dates around 21 July.

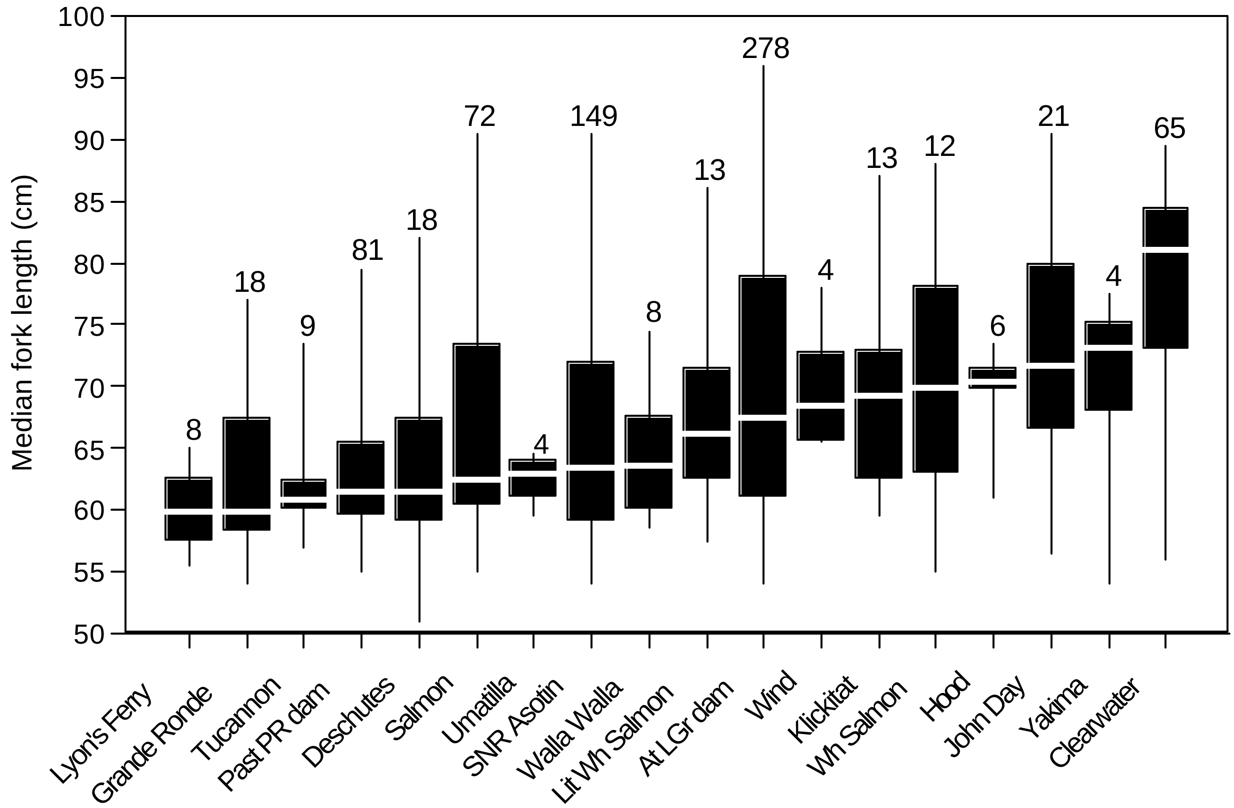

Figure 57. Median, minimum, maximum, and quartile fork lengths for steelhead at time of tagging for fish that returned to individual tributaries or Priest Rapids Dam. Includes bars for fish known to pass Lower Granite Dam and for fish recorded at the Snake River receiver near Asotin, WA. Number of fish next to bar.

Radio-tagged steelhead recorded at Lower Granite Dam were tagged at Bonneville Dam throughout the migration, but just 19 of 278 (7%) were tagged in June or July, of which 8 (42%) were last recorded at sites downstream from Lower Granite Dam. The median tag date for all fish recorded at the Lower Granite Dam was 24 August, and the highest numbers of fish were tagged in late August and early September. Returns to the Clearwater River were almost all B-group steelhead tagged after 1 September (median tag date = 10 September). Median tag date for all fish recorded at the Snake River receiver site near Asotin was 24 August, and median tag dates were 22 August for fish last recorded in the Grande Ronde River, and 24 August for Salmon River fish (Figure 60). About two-thirds of the steelhead last recorded in the Grande Ronde and Salmon rivers were outfitted with transmitters before 1 September.

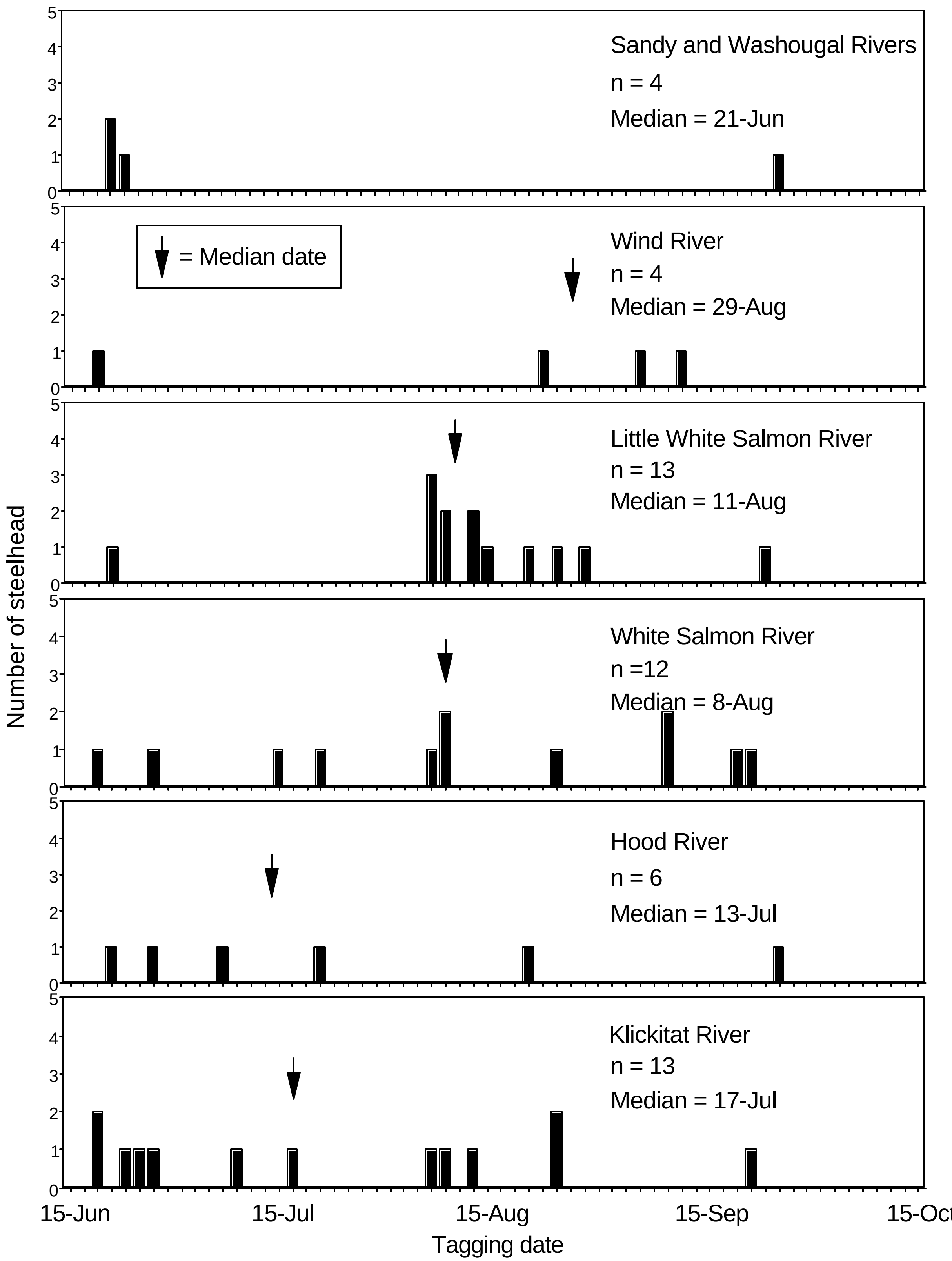

Figure 58. Tagging dates for steelhead with transmitters last recorded in the Sandy, Washougal, Wind, Little White Salmon, White Salmon, Hood, and Klickitat rivers.

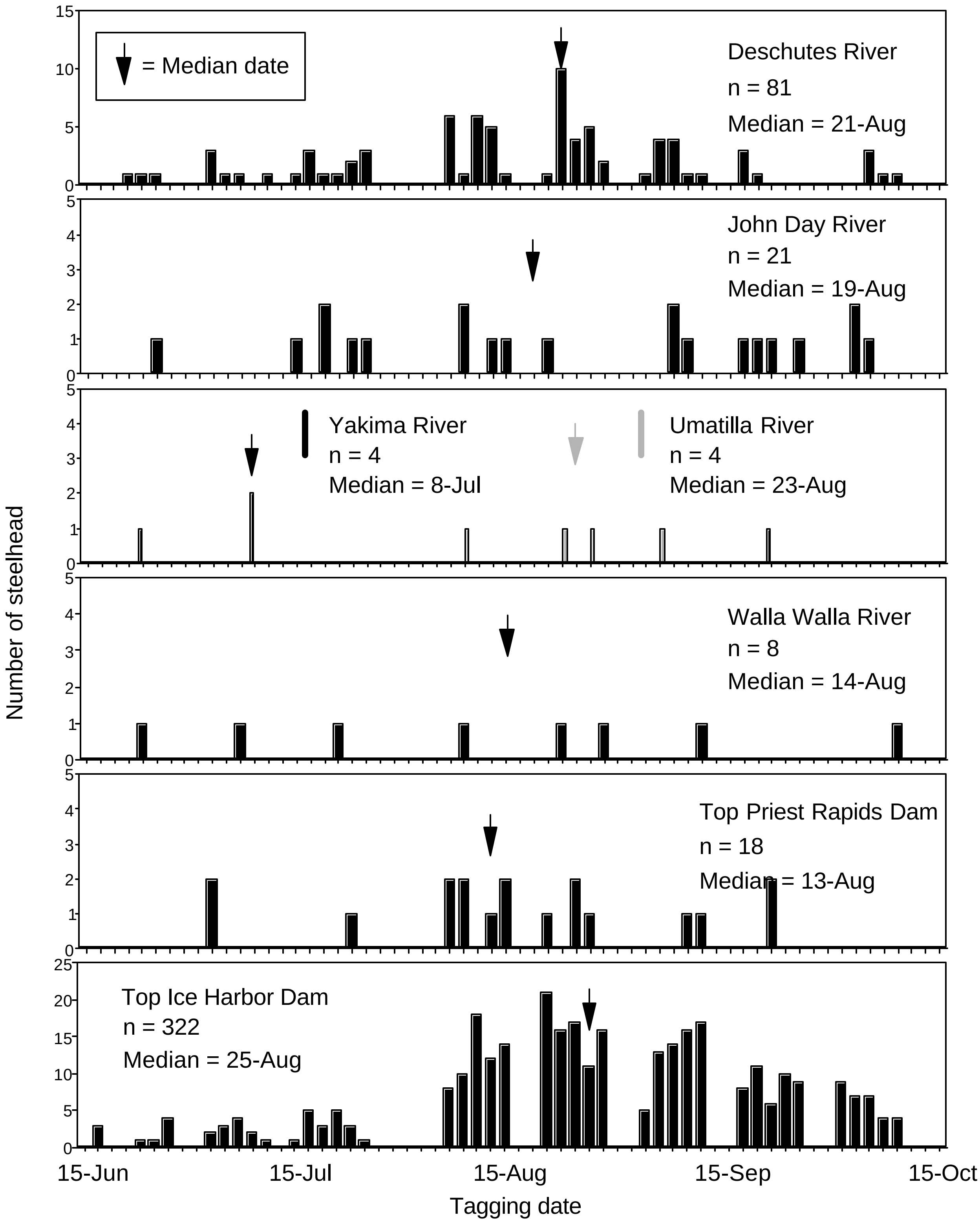

Figure 59. Tagging dates for steelhead with transmitters last recorded in the Deschutes, John Day, Umatilla, Yakima, and Walla Walla rivers and for fish that were recorded passing Priest Rapids and Ice Harbor dams.

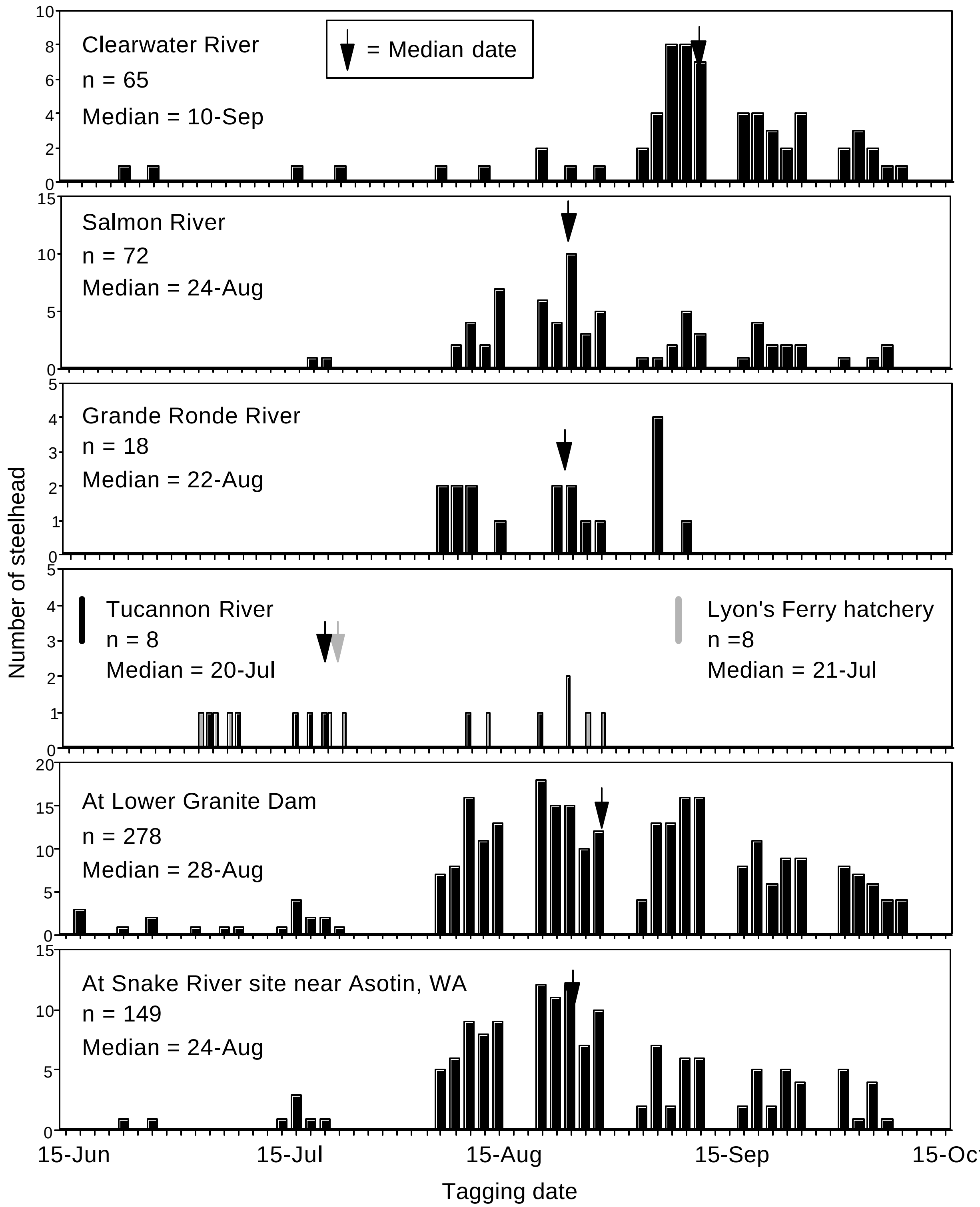

Figure 60. Tagging dates for steelhead with transmitters last recorded in the Clearwater, Salmon, Grande Ronde and Tucannon rivers or at Lyon's Ferry hatchery, and for fish recorded at Lower Granite Dam and at the Snake River site near Asotin, WA.

Temporary Straying by Steelhead with Transmitters

A large number of steelhead outfitted with transmitters in 1996 entered lower Columbia River tributaries en route to final destinations at other locations. We summarized the number of steelhead recorded in each lower Columbia River tributary, their final distribution and time spent in the tributary before migrating to different locations.

We used SRX receivers with aerial Yagi antennas 1 to 2 km upstream from the mouths of tributaries ('tributary receivers') to monitor when fish entered and exited tributaries. We also monitored fish with receivers and aerial antennas in the Columbia River up- and/or downstream from the mouths of the Deschutes, Little White Salmon, White Salmon, and Wind rivers ('confluence receivers') to track fish behavior in confluence areas. When steelhead were first recorded at tributary receivers we assumed fish were moving upstream in the tributary. When records at tributary receivers were followed by records at dams, confluence receivers, or in other tributaries, we assumed fish were exiting the tributary. In some cases, however, we could not determine conclusively if fish were in tributaries between consecutive groups of records. For example, telemetry records would appear similar for fish that exited tributaries to the mainstem Columbia River undetected, then re-entered, and for fish that migrated further upstream in tributaries before moving downstream past receiver sites. Ambiguity regarding exact fish location occurred at all sites, but particularly at tributaries without confluence receivers (Klickitat, John Day, Umatilla, Walla Walla, and Yakima rivers).

Our best estimates of the time steelhead spent in tributaries were calculated from: a) the first to the last record at the tributary receiver when there were no intervening records at dams, confluence receivers, or other tributaries; b) the sum of individual times between first and last records at tributary receivers when fish had intervening records at dams, confluence sites, or other tributaries. With this methodology, we may have overestimated time fish spent in tributaries when fish exited to the mainstem, were not recorded at other locations, and subsequently re-entered the same tributary. Other fish may have spent time in tributaries downstream from tributary receivers without being detected. Overall, however, we believe reported median times were representative of most fish behavior.

Lower Columbia River Tributary Use by Snake River Steelhead. **-** Of 262 steelhead with transmitters known to pass Lower Granite Dam, 169 (65%) were recorded in one or more lower Columbia River tributaries, 32% in the Little White Salmon River, 30% in the Deschutes River, 23% in the White Salmon River, 6% to 9% in the Wind, Klickitat and John Day rivers, and < 1% in the Lewis, Sandy and Umatilla rivers (Table 29). Thirty-five percent were not recorded in any lower Columbia River tributaries, 34% were recorded in one tributary, 22% in two tributaries, 6% in three tributaries, and 2% in four or five tributaries. A significantly higher proportion of A-group steelhead (74%) that passed Lower Granite Dam entered lower Columbia River tributaries than B-group steelhead (55%) (P = 0.002, Z test). About 65% of fin-clipped and 62% of unclipped fish entered tributaries, a non-significant difference (P = 0.68).

Table 29. Number, percent, and median and mean time (d) 262 steelhead with transmitters spent in lower Columbia River tributaries prior to migrating past Lower Granite Dam in the run-year 1996-1997.

	Total	All[1] tributaries	Wind	L. White Salmon	White Salmon	Klickitat	Deschutes	John Day
All	**262**	169	16	85	59	16	78	23
Percent		64.5	6.1	32.4	22.5	6.1	29.8	8.8
Median stay		7.7	2.3	4.8	3.0	1.6	1.3	0.7
Mean stay		11.6	5.0	12.0	10.9	3.6	13.0	8.7
Number of A-group and B-group steelhead recorded in tributary								
A-group	**136**	100	16	44	38	11	49	9
Percent		73.5	11.8	32.4	27.9	8.1	36.0	6.6
B-group	**126**	69	0	41	21	5	29	14
Percent		54.8	0.0	32.5	16.7	7.2	23.0	11.1
Median days in tributary								
A-group		15.3*	2.3	15.4*	4.5	2.1	1.2	0.5
B-group		4.7*		0.8*	3.0	0.1	1.7	0.7
Number of steelhead with and without fin clips recorded in tributary								
Clipped	**223**	145	15	72	50	14	66	22
Percent		65.0	6.7	32.3	22.4	6.3	29.6	9.9
No clip	**39**	24	1	13	9	2	12	1
Percent		61.5	2.6	33.3	23.1	5.1	30.8	2.6
Median days in tributary								
Clipped		6.0*	2.5	4.4	2.6	1.6	1.2	0.7
No clip		20.7*	1.3	15.7	6.2	1.3	6.10.5	

[1] includes single fish that entered the Lewis (0.4 d), Sandy (22.0 d), and Umatilla (1.8 d) rivers

* significantly different, K-W X^2 $P < 0.05$

The 169 steelhead that passed Lower Granite Dam and entered one or more lower Columbia River tributaries spent a median of 7.7 d (mean = 11.6 d) in monitored tributaries (Table 29). A-group steelhead stayed a median of 15.3 d in tributaries, significantly longer than the median of 4.7 d for B-group fish ($P = 0.001$, K-W X^2 test) (Table 29). Steelhead without fin clips stayed a median of 20.7 d, significantly longer than the median of 6.0 d for fin-clipped fish ($P = 0.04$, K-W X^2 test). The longest median stays for all fish were in the Little White Salmon (4.8 d) and White Salmon (3.0 d) rivers. Mean times in tributaries were longer than medians, and times for individual fish ranged from a few minutes to more than 100 d (Figure 61). The longest mean stays for all fish were in the Deschutes (13.0 d), Little White Salmon (12.0 d), and White Salmon (10.9 d) rivers.

Of the 136 A-group steelhead that passed Lower Granite Dam, 36% entered the Deschutes, 32% the Little White Salmon, 28% the White Salmon, and 7% to 11% the

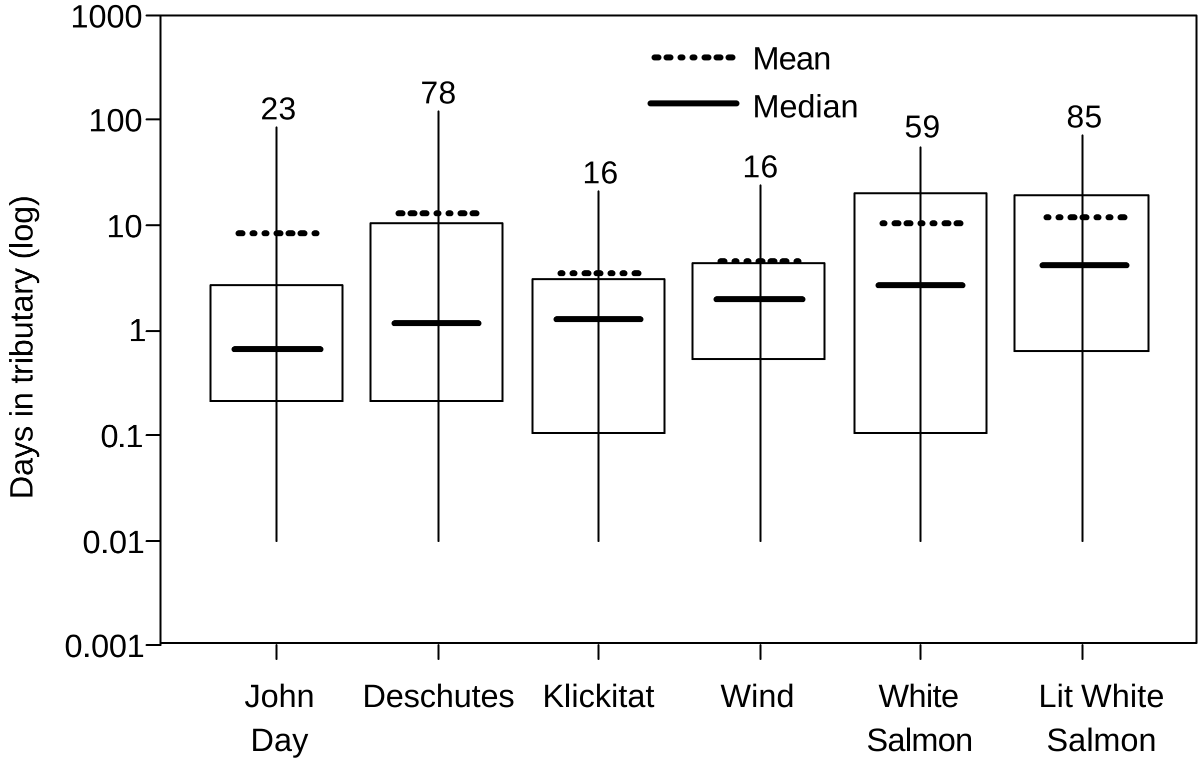

Figure 61. Mean, median, quartile, and range of time steelhead with transmitters spent in the John Day, Deschutes, Klickitat, Wind, White Salmon, and Little White Salmon rivers before passing Lower Granite Dam in the run-year 1996-1997.

Wind, Klickitat and John Day rivers (Table 29). Of the 126 B-group steelhead, 33% entered the Little White Salmon, 23% the Deschutes, 17% the White Salmon, 11% the John Day, and 7% the Klickitat rivers. The longest median stays for A-group fish were 15.4 d in the Little White Salmon River and 4.5 d in the White Salmon River. Median stays for A-group fish were 1.2 to 2.3 d in the Wind, Deschutes, and Klickitat rivers and 0.5 d in the John Day River. B-group steelhead strayed temporarily into tributaries at lower rates and for less time than A-group fish. Median stays for B-group steelhead were 3.0 d in the White Salmon River and < 2 d at all other sites (Table 29). Maximum times in tributaries for individual A-group steelhead ranged from 21 d in the Klickitat River to 71 d in the Little White Salmon River and 120 d in the Deschutes River (Figure 62). Maximum stays for B-group fish ranged from < 3 d in the Klickitat River to 84 d in the John Day River and 102 d in the Deschutes River.

Of 24 steelhead without fin clips that passed Lower Granite Dam and entered lower Columbia River tributaries, 54% entered the Little White Salmon, 50% entered the Deschutes, 38% entered the White Salmon, and < 10% entered the Wind, Klickitat, and John Day rivers (Table 29). The longest median stays for unclipped fish were 15.7 d in the Little White Salmon and about 6 d in the White Salmon and Deschutes rivers. Of 145 fin-clipped steelhead that entered tributaries, 50% entered the Little White Salmon, 46% entered the Deschutes, 34% entered the White Salmon, 15% entered the John

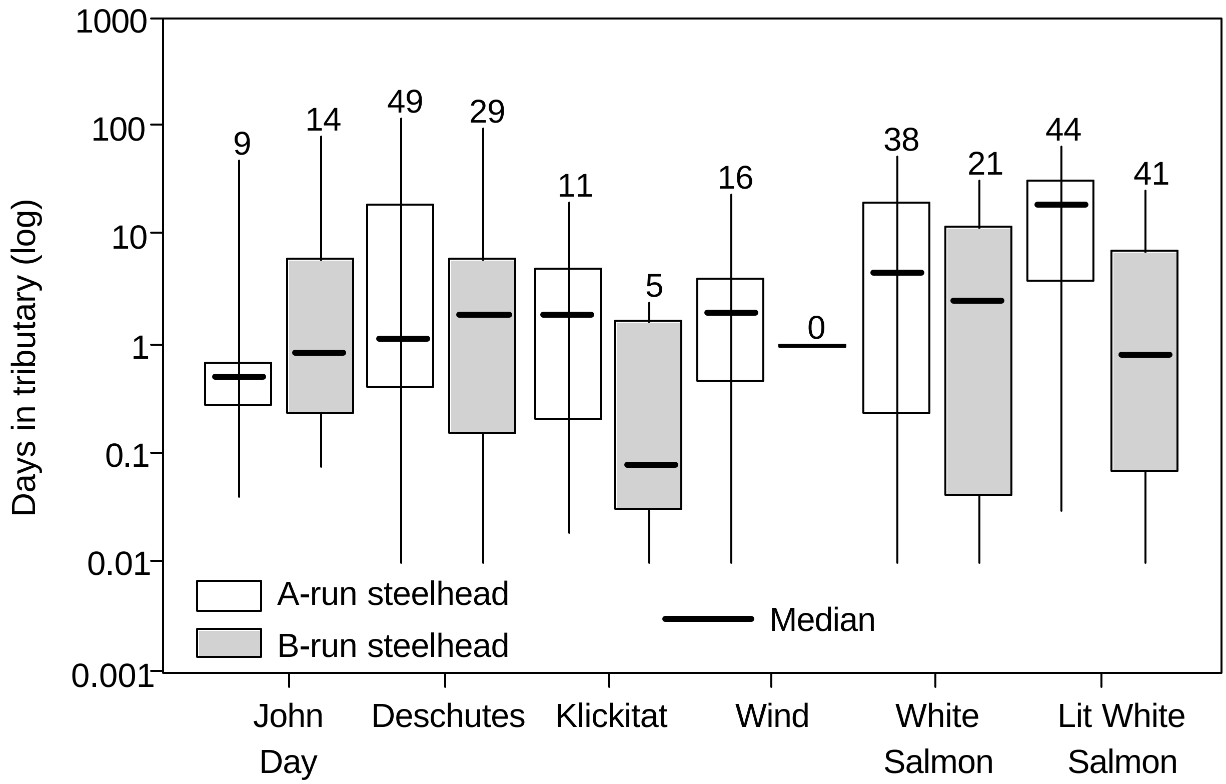

Figure 62. Median, quartile, and range of times A-group and B-group steelhead with transmitters spent in the John Day, Deschutes, Klickitat, Wind, White Salmon, and Little White Salmon rivers before passing Lower Granite Dam in the run-year 1996-1997.

Day, and about 10% entered the Wind and Klickitat rivers. The longest median stays for fin-clipped fish were 4.4 d in the Little White Salmon, 2.6 d in the White Salmon River, and 2.5 d in the Wind River (Table 29). Although unclipped steelhead had significantly longer overall median times in tributaries than clipped fish (20.7 d versus 6.0 d), differences at individual tributaries were not significant at $P < 0.05$, (K-W X^2 tests).

Of 65 steelhead last recorded in the Clearwater River, 59% entered lower Columbia River tributaries. Sixty-eight percent of 72 fish last recorded in the Salmon River, 72% of 18 last recorded in the Grande Ronde River, and 65% of 66 last recorded at or upstream from the Snake River receiver near Asotin were recorded in lower Columbia River tributaries.

To evaluate usage of tributaries, we calculated the number of radio-tagged steelhead that eventually passed Lower Granite Dam that were detected in lower Columbia River tributaries during each day of the migration. Fish were included in daily tributary counts if they were recorded that day at tributary receivers, or if they were presumed to be upstream from tributary receivers. One or more fish were at or upstream from tributary receivers from 21 July, 1996 to 15 February, 1997, with a peak of 73 fish on 15 September (Figure 63). Forty or more radio-tagged steelhead were in tributaries every day from 25 August to 29 September.

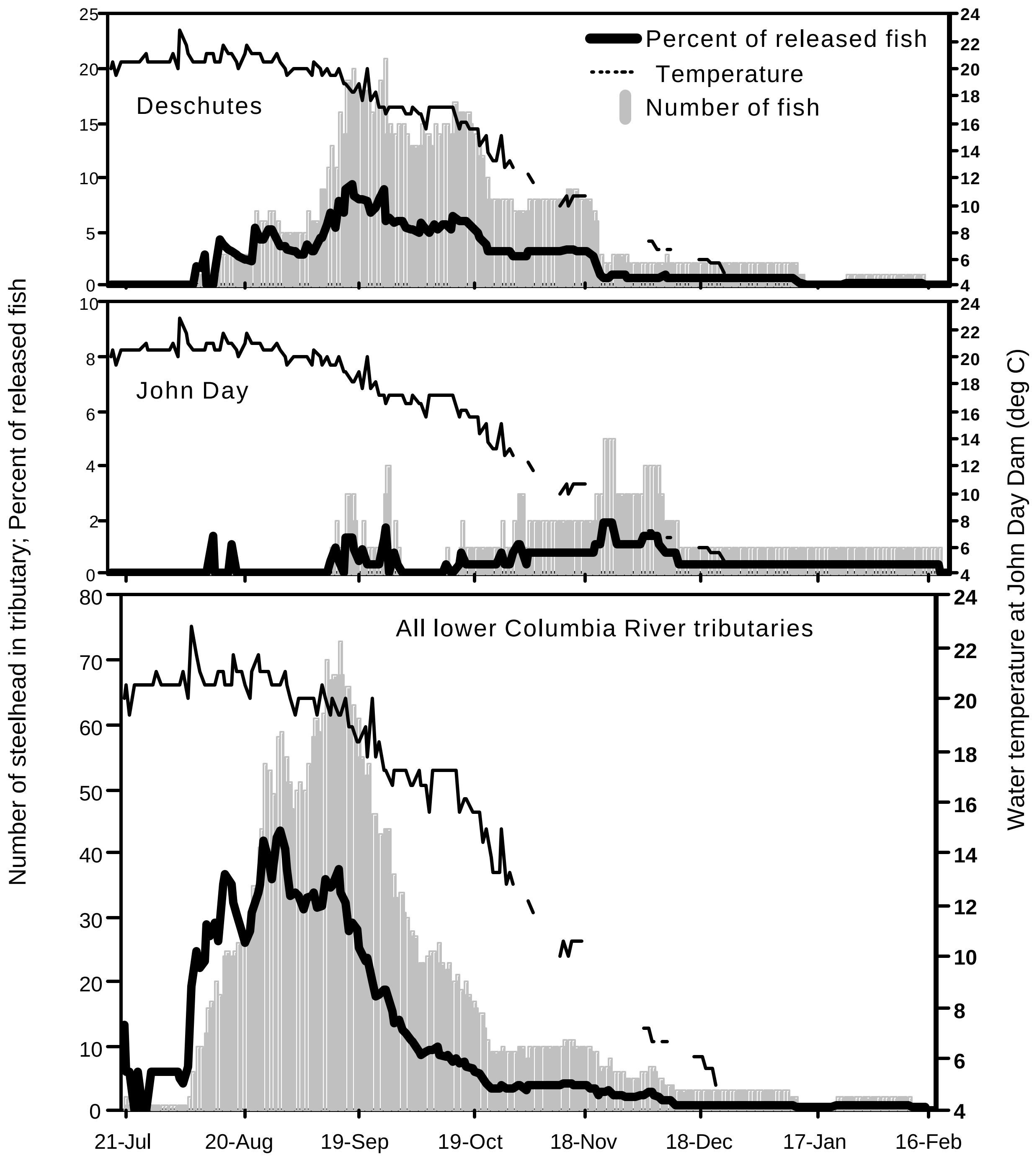

Figure 63. Daily number and percentage of steelhead released to date that were recorded in the Deschutes River, John Day River, and in all lower Columbia River tributaries en route to Lower Granite Dam, with mean daily water temperatures at John Day Dam in the run-year 1996-1997.

Because we released steelhead with transmitters from 17 June to 9 October, the number of in-river fish increased during the time fish were entering lower Columbia River tributaries. As a result, the proportion of released fish in tributaries was a better indicator of tributary use than total tributary counts. We calculated daily proportions of steelhead in tributaries by dividing the number that eventually passed Lower Granite Dam that were detected in tributaries by the number bound for Lower Granite Dam that had been released through that day. The peak proportion in tributaries was on 31 August, when 59 of 136 fish (43.3%) that eventually passed Lower Granite Dam were recorded in Lower Columbia River tributaries (Figure 63). Between 22% and 43% were in tributaries from 9 August through 21 September. The peak count of 73 fish in tributaries on 15 September was 37% of the steelhead that we had released through that day.

Because most steelhead did not reach tributary sites until a day or more after release, we also calculated proportions in tributaries using a 1 d lag for the number released (number in tributaries/number released through previous day). With the lag, daily proportions in tributaries were approximately 1% to 2% higher than without the lag. Peak numbers of steelhead bound for Lower Granite Dam in individual tributaries were 33 in the Little White Salmon River on 11 September, 21 in the White Salmon River on 14 September, 21 in the Deschutes River on 28 September, 10 in the Wind River on 31 August, 5 in the John Day River in late November, and 4 in the Klickitat River on 15 September (Figures 63 and 64). Peak proportions in individual tributaries were earlier than peak counts, 22.1% in the Little White Salmon River on 16 August, 12.5% in the White Salmon River on 28 August, 9.3% in the Deschutes River on 20 September, and 7.4% in the Wind River on 31 August. The peak number and proportion of A-group steelhead in tributaries was 59 fish (43.4%) on 31 August, and was 25 fish (42.4%) on 15 September for B-group steelhead (Figure 65).

We also counted the total daily number of radio-tagged steelhead in each lower Columbia River tributary recorded at tributary receivers or presumed upstream from receivers and the number of those that eventually passed Lower Granite Dam. Fish were counted regardless of their final destination, and those recaptured in tributaries were not included in subsequent daily counts. The highest count of steelhead with transmitters in the Wind River was 17 fish on 5 September, of which 35% eventually passed Lower Granite Dam; between 40% and 75% of the fish in the Wind River were bound for Lower Granite Dam on most days from 17 August to 13 September (Figure 66). Thirteen steelhead with transmitters were last recorded in the Little White Salmon River, but more than 60 fish were recorded in the river from 24 August to 16 September. From 25% to 46% of the fish in the Little White Salmon River between from 7 August to 5 October eventually passed Lower Granite Dam. Similarly, of the 20 to 45 steelhead in the White Salmon River between 12 August and 14 October, 25% to 50% eventually passed Lower Granite Dam. Daily counts in the Klickitat River were less than 15 fish, and the proportion that passed Lower Granite Dam was erratic (Figure 66). Counts of steelhead with transmitters in the Deschutes River peaked at 104 fish in mid-September. Between 10% and 21% of the fish in the Deschutes River were bound for Lower Granite Dam in late August and from 12 September to 19 November (Figure 67). Peak counts in the John Day River were about 20 fish in mid-November, when the proportion of fish bound for Lower Granite Dam was < 25%. The

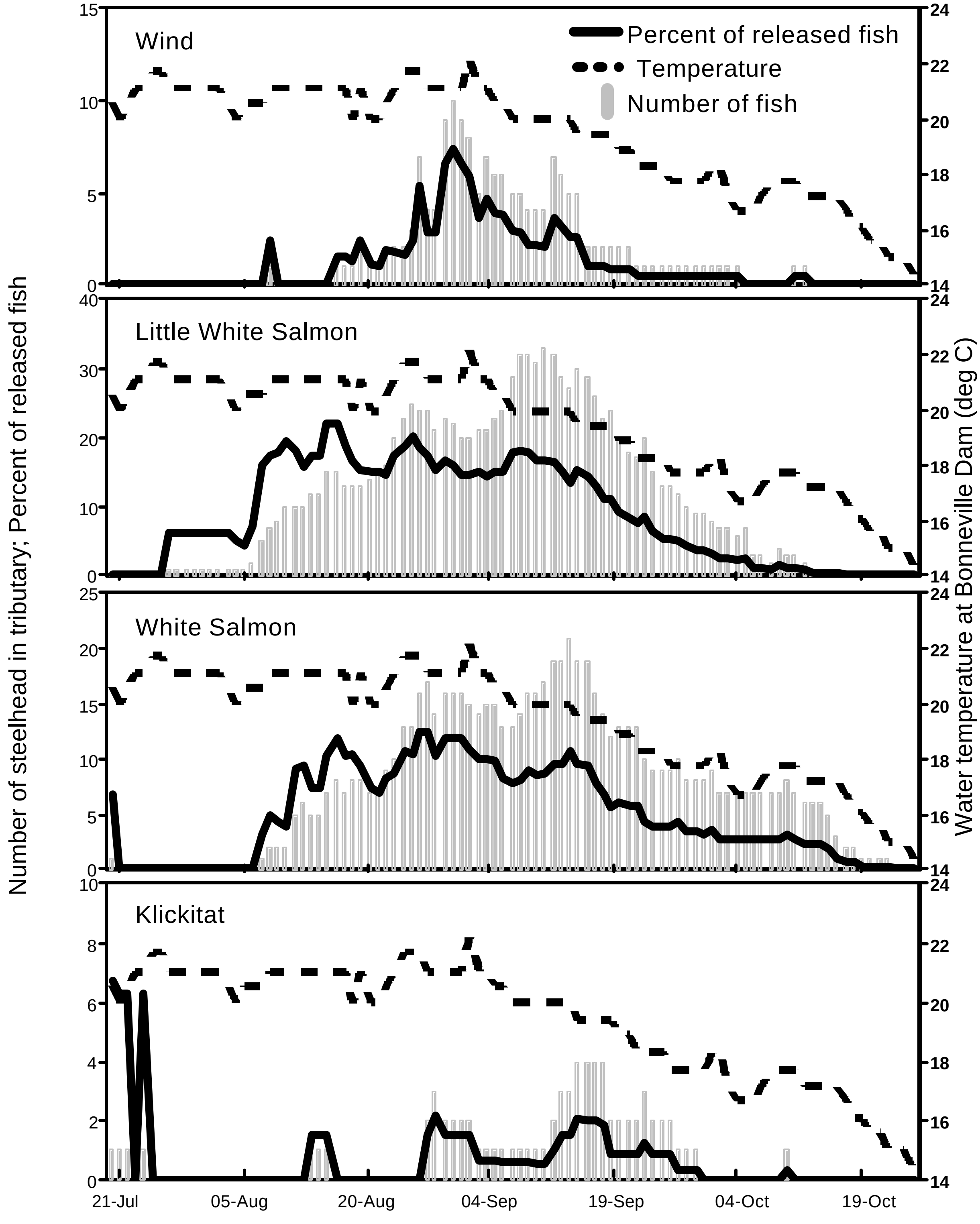

Figure 64. Daily number and percentage of steelhead released to date that were recorded in the Wind, Little White Salmon, White Salmon, and Klickitat rivers en route to Lower Granite Dam, with mean daily water temperature at Bonneville Dam in the run-year 1996-1997.

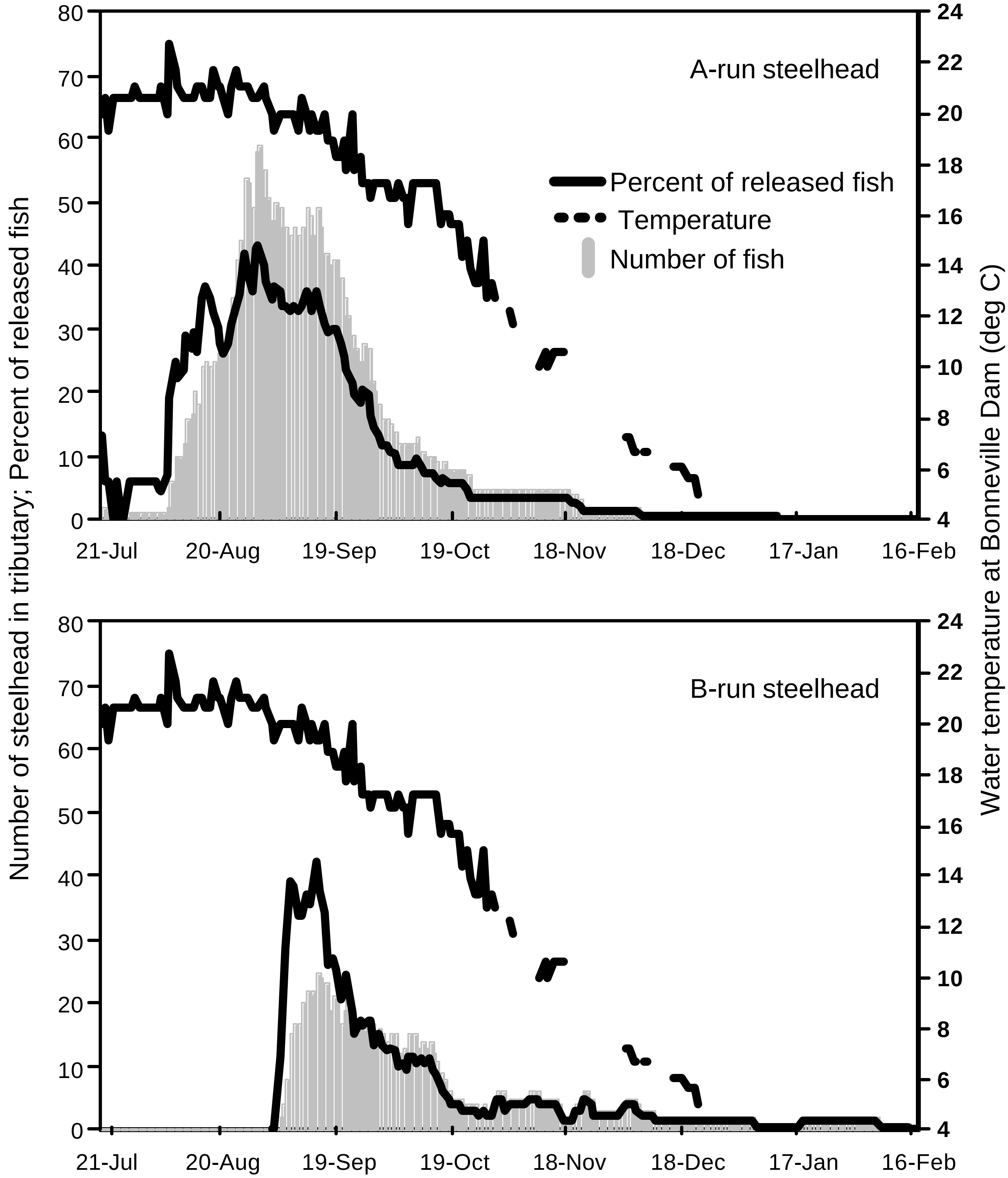

Figure 65. Daily number and percentage of A-group and B-group steelhead released to date that were recorded in all lower Columbia River tributaries en route to Lower Granite Dam, with mean daily water temperatures at Bonneville Dam in the run-year 1996-1997.

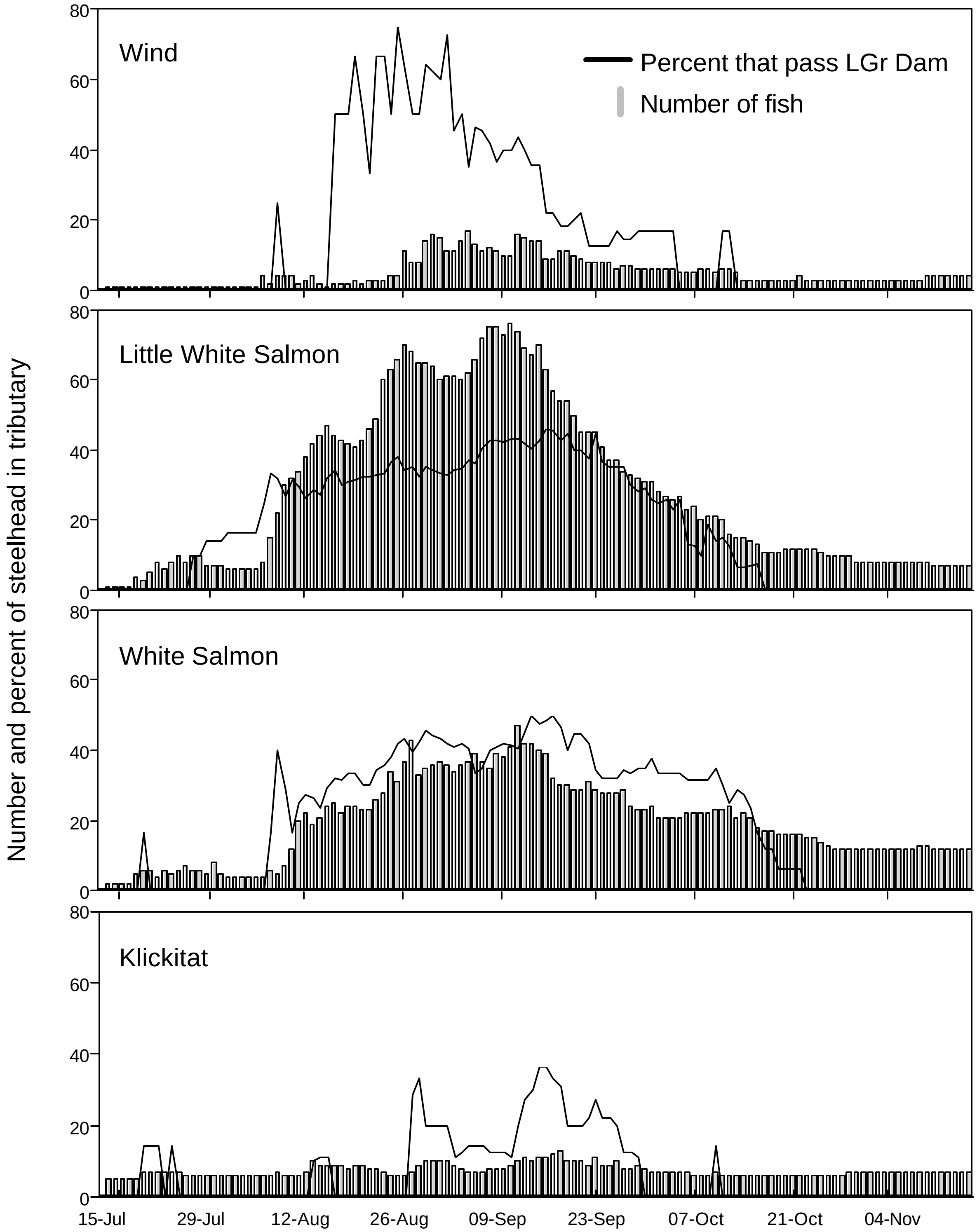

Figure 66. Total daily number of steelhead with transmitters recorded in the Wind, Little White Salmon, White Salmon, and Klickitat rivers and the proportion of fish in tributaries that eventually passed Lower Granite Dam in the run-year 1996-1997.

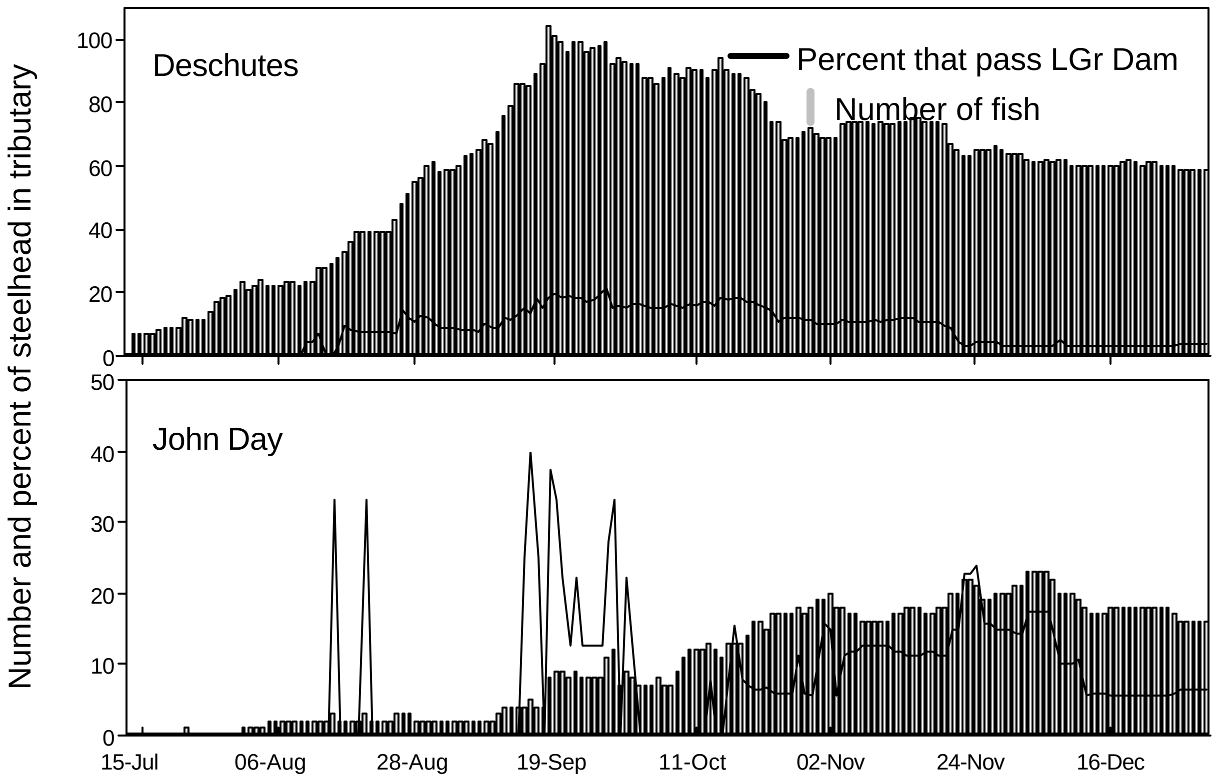

Figure 67. Total daily number of steelhead with transmitters recorded in the Deschutes and John Day rivers and the proportion of fish in tributaries that eventually passed Lower Granite Dam in the run-year 1996-1997.

proportion of upriver fish was more than 30% on some days in August and September, when total counts in the John Day River were low (Figure 67).

Temporary straying by steelhead into lower Columbia River tributaries may have been a response to high water temperatures in the mainstem Columbia River, and more favorable temperatures in tributaries. Peak mean daily temperatures recorded at Bonneville, The Dalles, and John Day dams were near 22°C during the end of August and were > 20°C from mid-July to approximately 15 September, coincident with peak tributary use by steelhead with transmitters.

We collected hourly temperature data in tributaries from early July through the first week of November, 1996. Mean daily values were < 20°C in all tributaries except the John Day River during the period of peak use by steelhead bound for Lower Granite Dam. Mean daily temperatures in lower Columbia tributaries were 1° to 9°C cooler than those recorded at Bonneville, The Dalles, and John Day dams throughout the monitoring period, except in the John Day River, where water temperatures were higher than at mainstem sites from July through mid-September (Figures 68 and 69). During peak tributary use by steelhead with transmitters (~ 10 August to 25 September), mean daily temperatures in the Wind and Klickitat rivers were 3° to 9°C cooler than at The Dalles and Bonneville dams, and

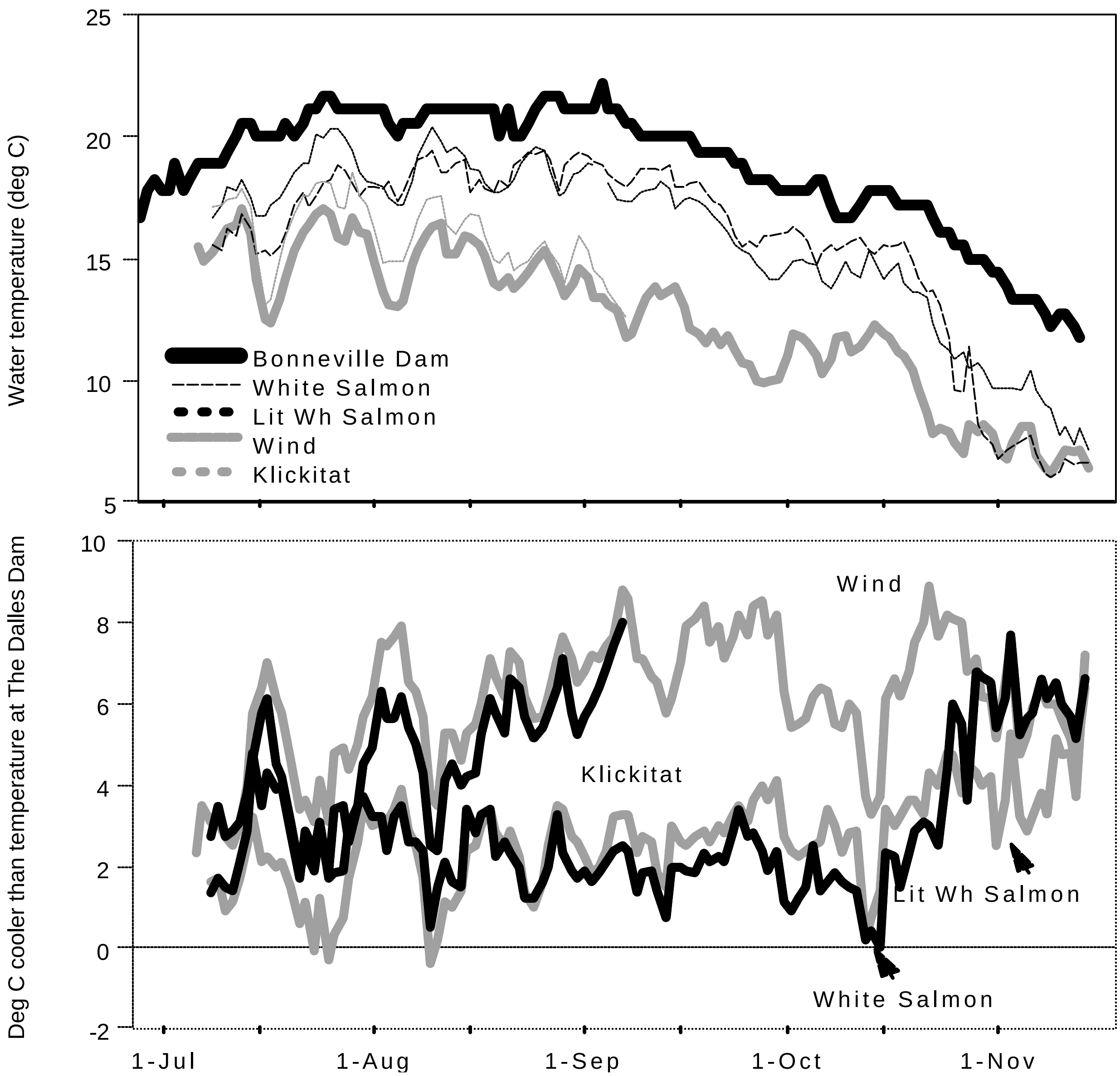

Figure 68. Mean daily water temperatures at Bonneville Dam and in the Wind, Little White Salmon, White Salmon, and Klickitat rivers from July to November, 1996 (top), and differences between mean daily temperatures in tributaries and the mainstem Columbia River (bottom).

temperatures in the Little White Salmon and White Salmon rivers were 1° to 4°C cooler than at dams (Figure 68). During peak use by steelhead, temperatures in the lower Deschutes River were 1° to 5°C cooler and temperatures near Sherars Falls (68 km upstream from the mouth of the Deschutes River) were 5° to 11°C cooler than those recorded at The Dalles Dam (Figure 69).

Use of lower Columbia River tributaries by steelhead with transmitters decreased as water temperatures in the mainstem Columbia River decreased. The number of

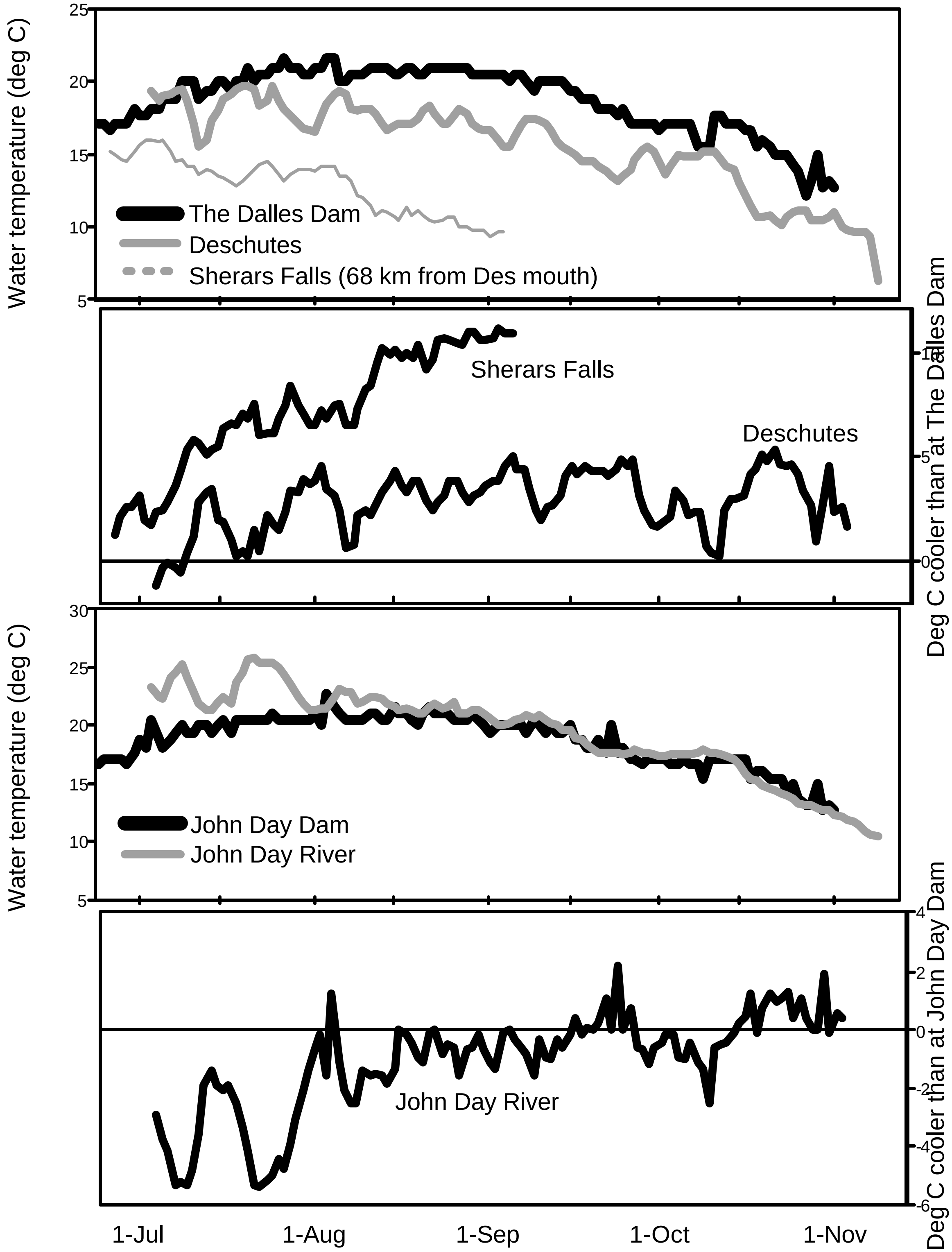

Figure 69. Mean daily water temperatures at John Day Dam and in the Deschutes and John Day rivers from July to November, 1996, and differences between mean daily temperatures in tributaries and the mainstem Columbia River.

steelhead bound for Lower Granite Dam in tributaries dropped from a peak of 73 on 15 September to 34 on 1 October and 10 on 1 November, while the proportion in tributaries dropped from a peak of 43% on 31 August to 14% on 1 October and 3.4% on 1 November (Figure 63). Mean daily water temperatures dropped to < 20°C at Bonneville, The Dalles, and John Day dams by 18 September and were < 18° C by 3 October.

Steelhead migration delays associated with water temperatures in excess of 20°C were also recorded by Stuehrenberg et al. (1978), who reported that steelhead with transmitters concentrated downstream from the confluence of the Columbia and Snake rivers in July and August when temperatures were 22°C in the Snake River and 17°C in the Columbia River. The migration delay diminished when temperatures in both rivers were 21°C, and passage at Ice Harbor Dam resumed by an order of magnitude when temperatures decreased in early September.

Steelhead that entered lower Columbia River tributaries in 1996 had significantly longer passage from release to the top of Lower Granite Dam than fish that did not enter tributaries. Median passage times for 93 steelhead with transmitters that did not enter tributaries en route to Lower Granite Dam was 23.1 d, significantly shorter than the 47.1 d for 169 fish that entered one or more tributaries ($P < 0.001$, K-W X^2 tests) (Figure 70). Time steelhead spent in lower Columbia River tributaries explained more than 45% of the variability in total passage time from release to the top of Lower Granite Dam (Figure 70). Total passage time increased with total time in tributaries for 235 non-overwintering fish ($r^2 = 0.42$), and for all 257 steelhead that passed Lower Granite Dam ($r^2 = 0.48$).

Median times from release to the top of Lower Granite Dam were 32.1 d for 35 A-group steelhead and 21.9 d for 57 B-group steelhead that did not enter tributaries versus 51.0 d for A-group steelhead and 35.6 d for B-group steelhead that entered one or more tributaries; times were significantly shorter for fish that did not enter tributaries ($P < 0.005$, K-W X^2 tests) (Figure 71). The median passage time for 51 A-group steelhead that entered one tributary, 53.6 d, was significantly longer ($P = 0.002$, K-W X^2 test) than that for A-group steelhead that did not enter tributaries. But median times for 33 B-group steelhead that entered a single tributary (26.2 d), were not significantly different from steelhead that did not enter tributaries ($P = 0.14$, K-W X^2 test). Among fish with and without fin clips, we found similar significant patterns of longer passage times for fish that entered lower Columbia River tributaries en route to Lower Granite Dam. Median passage times were 20.3 d for unclipped and 23.1 d for fin-clipped steelhead that did not enter tributaries, versus 49.1 d for unclipped and 46.9 d for fin-clipped fish that entered one or more tributaries.

The 164 steelhead with records at the top of Lower Granite Dam that entered lower Columbia River tributaries spent a median of 19.1% (mean = 24.5%) of their migration time in tributaries (Figure 72). Median times in tributaries were 28.5% for A-group steelhead, significantly longer than the median of 12.3% for B-group steelhead ($P = 0.0002$, K-W X^2 test); the median was 14.8% for fin-clipped fish, significantly shorter than the median of 30.3% for fish without fin clips ($P = 0.04$). Twenty-five percent of all fish that entered lower Columbia River tributaries spent > 41% of their total migration time in tributaries, and 25% spent < 4% of total migration time in tributaries (Figure 72).

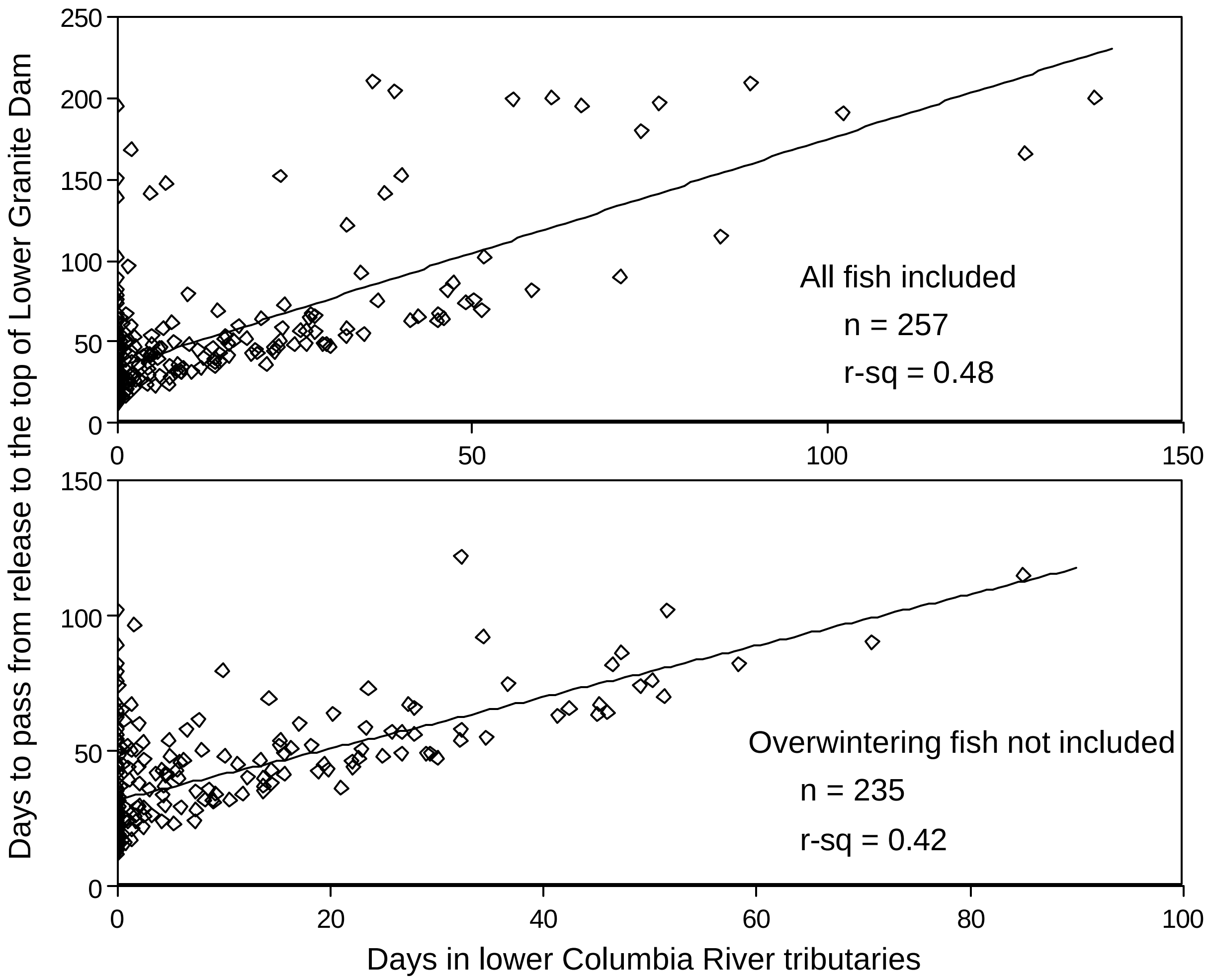

Figure 70. Median, first and third quartile, and range of passage time from release after tagging to the top of Lower Granite Dam for all steelhead and A-group and B-group that either did or did not enter lower Columbia River tributaries in the run-year 1996-1997.

Twenty-two of the steelhead that passed Lower Granite Dam overwintered, of which 18 (82%) entered lower Columbia River tributaries during their migration. Median time in tributaries was 47.9 d (mean = 55.9 d) for fish that overwintered, and many spent part or all of their time in tributaries prior to the onset of overwintering behavior. Temporary straying into lower Columbia River tributaries may have been related to overwintering.

Median times in tributaries for steelhead that overwintered (55.9 d), were significantly longer than the median of 6.0 d for steelhead that entered tributaries but did not overwinter ($P < 0.001$, K-W X^2 test). The rate of tributary use by steelhead that passed Lower Granite Dam and did not overwinter (151 of 240 = 63%) was lower than the rate for steelhead that passed Lower Granite Dam and did overwinter (18 of 22 = 82%), a difference that approached significance ($P = 0.08$ Z test).

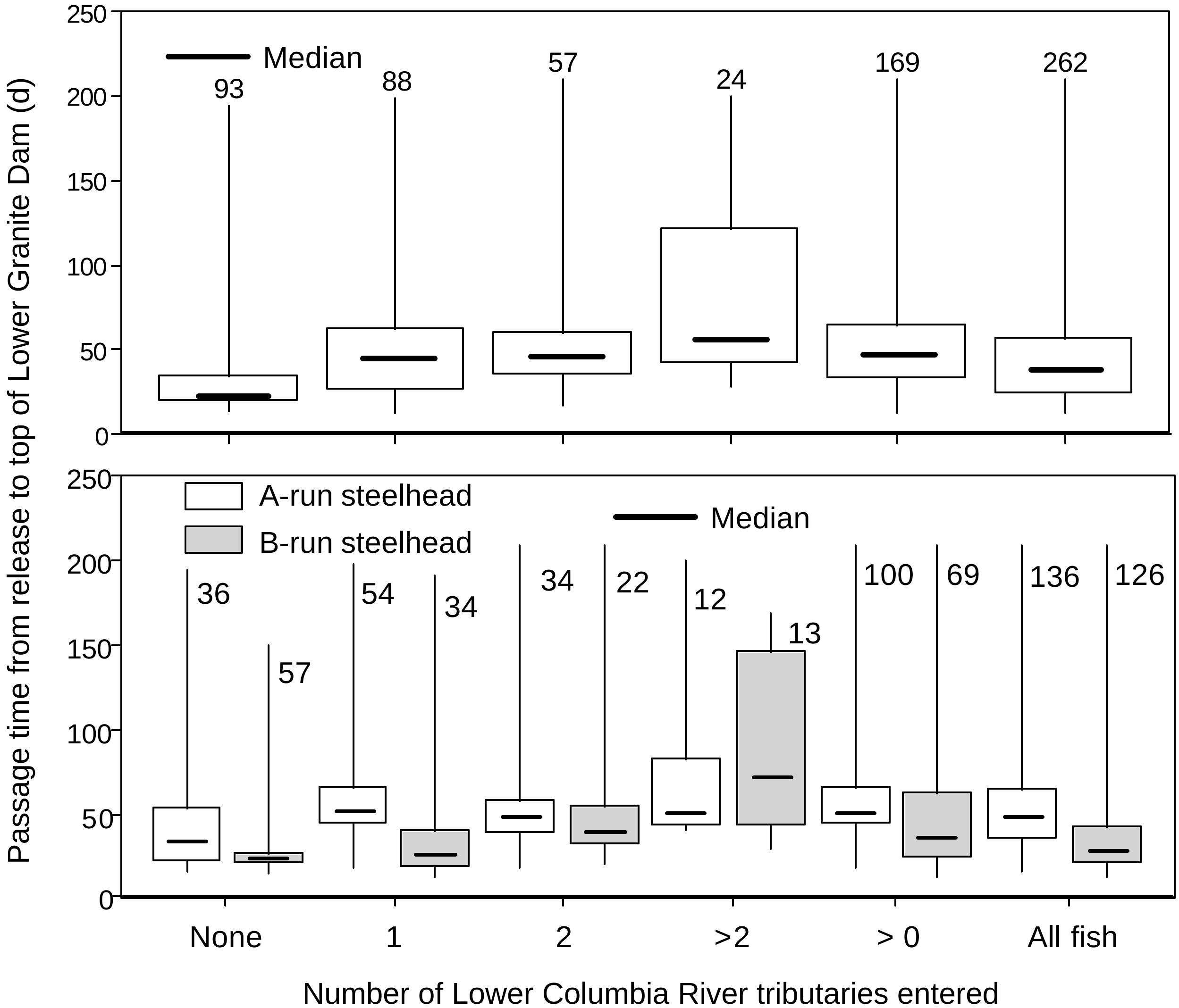

Figure 71. Regressions for time steelhead with transmitters spent in lower Columbia River tributaries and total passage time from release to the top of Lower Granite Dam in the run-year 1996-1997. Overwintering fish not included in bottom graph.

Lower Columbia River Tributary Use by All Steelhead. - Temporary straying by steelhead with transmitters was not limited to Snake River fish. Of the 18 steelhead with transmitters that passed Priest Rapids Dam, 11 (61%) entered lower Columbia River tributaries, 8 in the Little White Salmon, 4 in the Deschutes, 3 in the White Salmon, and 1 in the Wind rivers. Fish that passed Priest Rapids Dam spent a median of 2.0 d (mean = 3.2 d) in lower Columbia River tributaries. Based on last records for radio- tagged fish, proportions of the following stocks also entered lower Columbia River tributaries: Tucannon River (44%), Lyons Ferry hatchery (38%), Yakima River (50%), Walla Walla River (50%), and Umatilla River (100%).

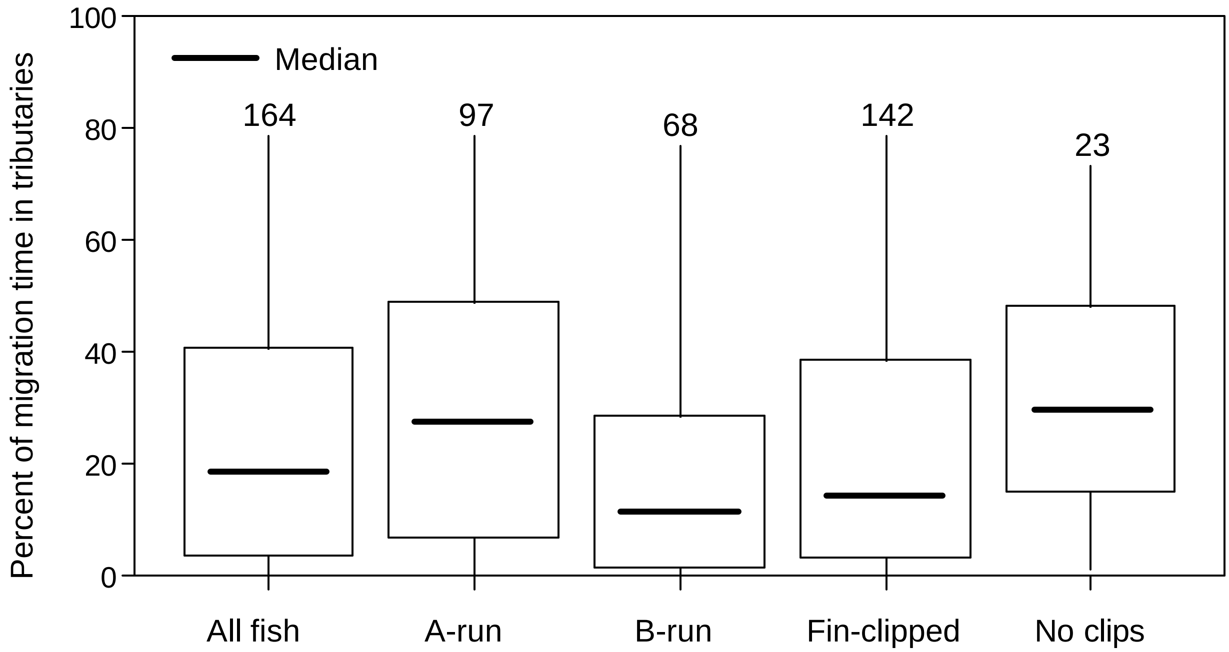

Figure 72. Median, quartile, and range of the proportion of total migration time from release to the top of Lower Granite Dam that steelhead spent in lower Columbia River tributaries in the run-year 1996-1997. Steelhead that did not enter tributaries not included.

Seventeen of 21 (81%) steelhead with transmitters last recorded in the John Day River were recorded in other lower Columbia River tributaries, 62% in the Little White Salmon, 48% in the Deschutes, 38% in the White Salmon, and < 4% in the Klickitat and Umatilla rivers. Six steelhead (29%) entered 1 tributary, 7 (33%) entered 2 tributaries, and 4 (21%) entered 3 or more en route to the John Day River. The 17 fish spent a median of 10.9 d (mean = 21.0 d) in other lower Columbia River tributaries, with medians of 2.3 d in the Little White Salmon River (13 fish), 1.3 d in the Deschutes River (10 fish), 0.9 d in the White Salmon River (8 fish).

Fifty-four of 81 (67%) steelhead with transmitters last recorded in the Deschutes River were recorded in other lower Columbia River tributaries, a rate comparable to those for fish that passed Lower Granite (65%) or Priest Rapids dams (61%). Median stays for fish that entered one or more tributaries were 2.6 d (mean = 11.8 d). Forty-one percent of those last recorded in the Deschutes River entered 1 tributary and stayed a median of 0.4 d (mean = 10.9 d), and 26% entered 2 tributaries and stayed a median of 3.7 d (mean = 13.2 d). Deschutes River steelhead primarily strayed into the Little White Salmon (35 fish) and White Salmon (25 fish) rivers, where median stays were 2.1 d (mean = 11.7 d) and 1.1 d (mean = 6.5 d), respectively.

The highest proportions of Deschutes River fish recorded in the Little White Salmon and White Salmon rivers were in July, when proportions were > 30%, but relatively few steelhead were in the tributaries (Figure 73). From early August through the end of October between 10% and 20% of the fish with transmitters in the Little White Salmon

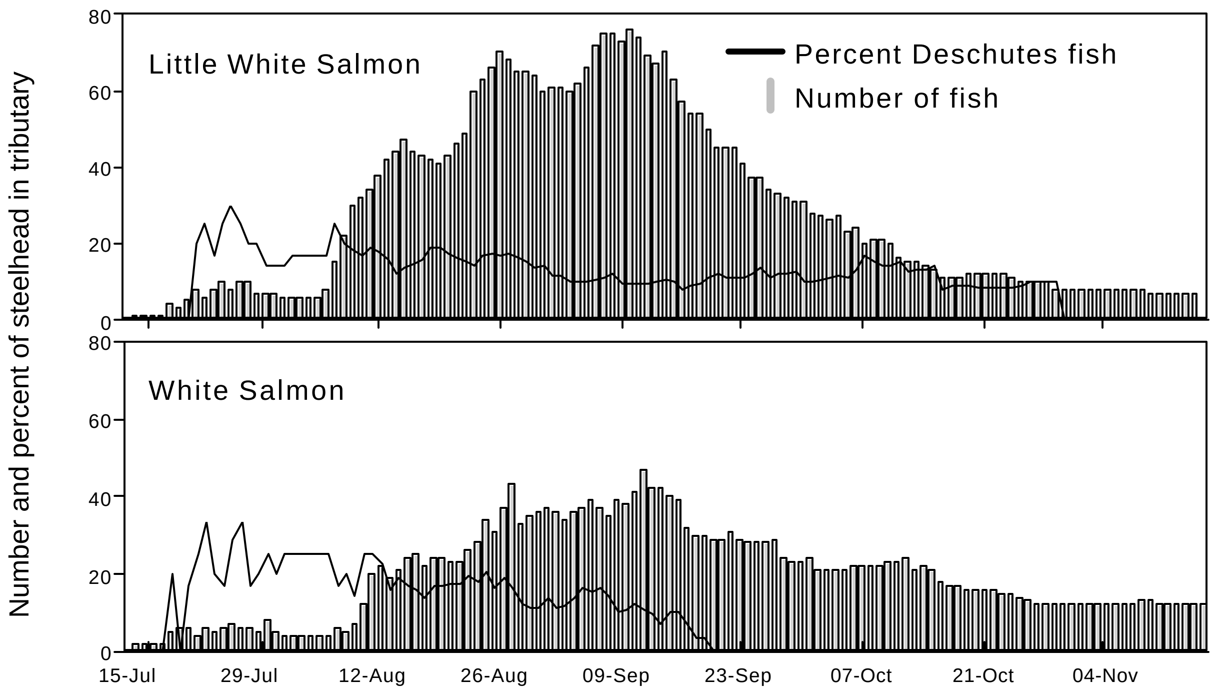

Figure 73. Total daily number of steelhead with transmitters recorded in the Little White Salmon and White Salmon rivers and proportion of fish in tributaries that were last recorded in the Deschutes River in the run-year 1996-1997.

were destined for the Deschutes River. From early August through mid- September between 10% and 25% of the steelhead in the White Salmon River eventually ended up in the Deschutes River (Figure 73).

In a summary analysis of temporary straying into lower Columbia River tributaries, we calculated the proportion of fish recorded in each tributary that remained in the tributary as well as the final distribution for fish that exited. Less than 8% of the steelhead with transmitters that entered the Wind, Little White Salmon, and White Salmon rivers were last recorded in those tributaries (Figure 74). About 29% of the steelhead that entered the Klickitat River and 75% that entered the Hood River stayed in those tributaries. Between 33% and 36% of the fish recorded in the Deschutes and John Day rivers stayed in those tributaries, 57% stayed in the Umatilla River, 67% stayed in the Yakima River, and 100% stayed in the Walla Walla River (Figure 74).

Of 51 steelhead recorded in the Wind River, 15 (29%) were last recorded upstream from Lower Granite Dam, and 12 (24%) were last recorded at dams or in reservoirs on the mainstem Columbia River (Figure 75). Eighty of 234 fish (34%) recorded in the Little White Salmon River were last recorded upstream from Lower Granite Dam, 45 (19%) were last recorded in the mainstem Columbia River, and 35 (15%) were last recorded in the Deschutes River. Similarly, 33% of 169 fish recorded in the White Salmon River were last recorded upstream from Lower Granite Dam, 21% were last recorded in the mainstem Columbia River, and 15% were last recorded in the

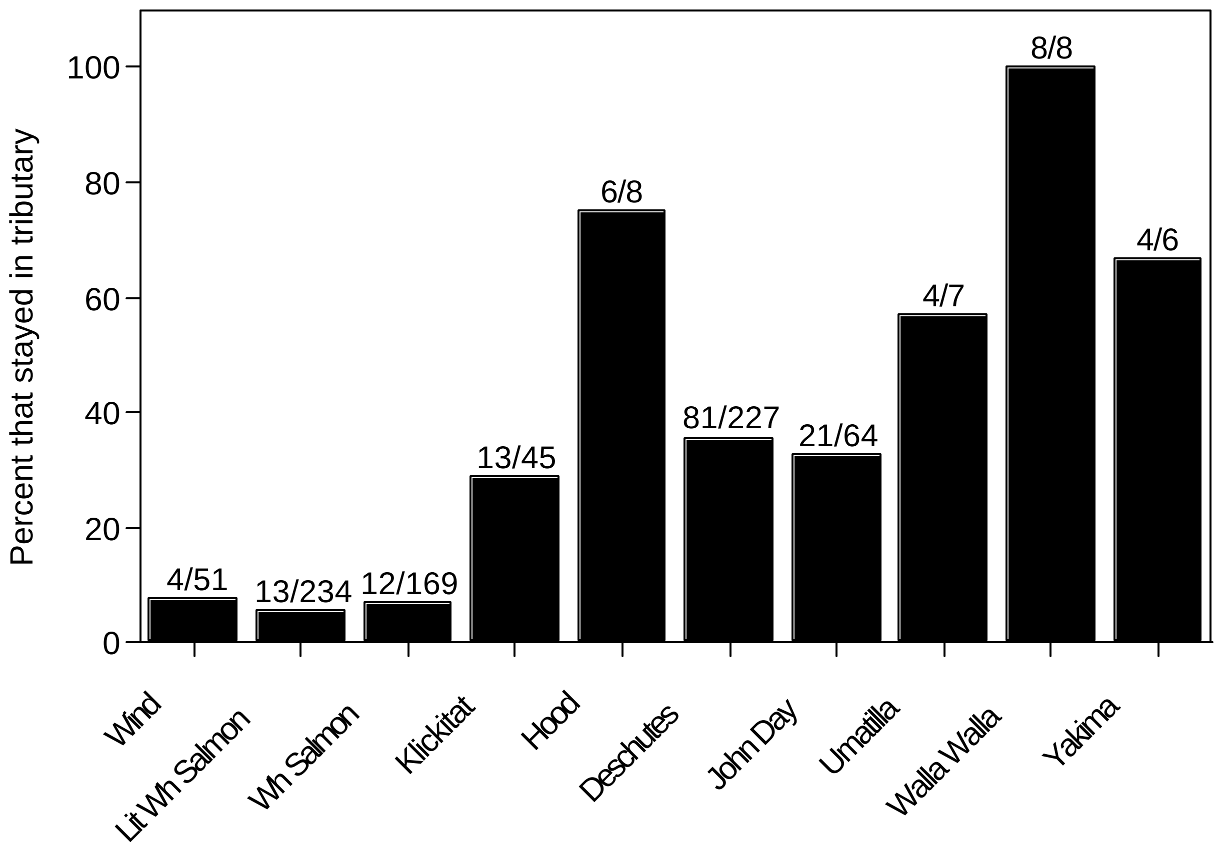

Figure 74. Percent of steelhead with transmitters that were last recorded in lower Columbia River tributaries after being recorded at tributary fixed receiver sites in the run-year 1996-1997. Proportion last recorded in tributary above bar.

Deschutes River. About 36% of 45 fish recorded in the Klickitat River were last recorded upstream from Lower Granite Dam, and 29% were last recorded in the Klickitat River (Figure 75). Of 227 steelhead with transmitters recorded in the Deschutes River, 36% stayed, 33% were last recorded upstream from Lower Granite Dam, and 15% were last recorded at mainstem Columbia River sites (Figure 76). Of the 64 steelhead recorded in the John Day River, 36% were last recorded upstream from Lower Granite Dam, and 33% stayed in the John Day River. More than half of the fish recorded in the Umatilla, Walla Walla, and Yakima rivers stayed in those tributaries (Figure 76).

Escapement to Tributaries by Steelhead with Transmitters

We assessed detectable escapement past dams to tributaries and final distribution of steelhead with transmitters by recording fish as they passed receivers at dams and near the mouths of major tributaries, and as they were recorded by mobile trackers or

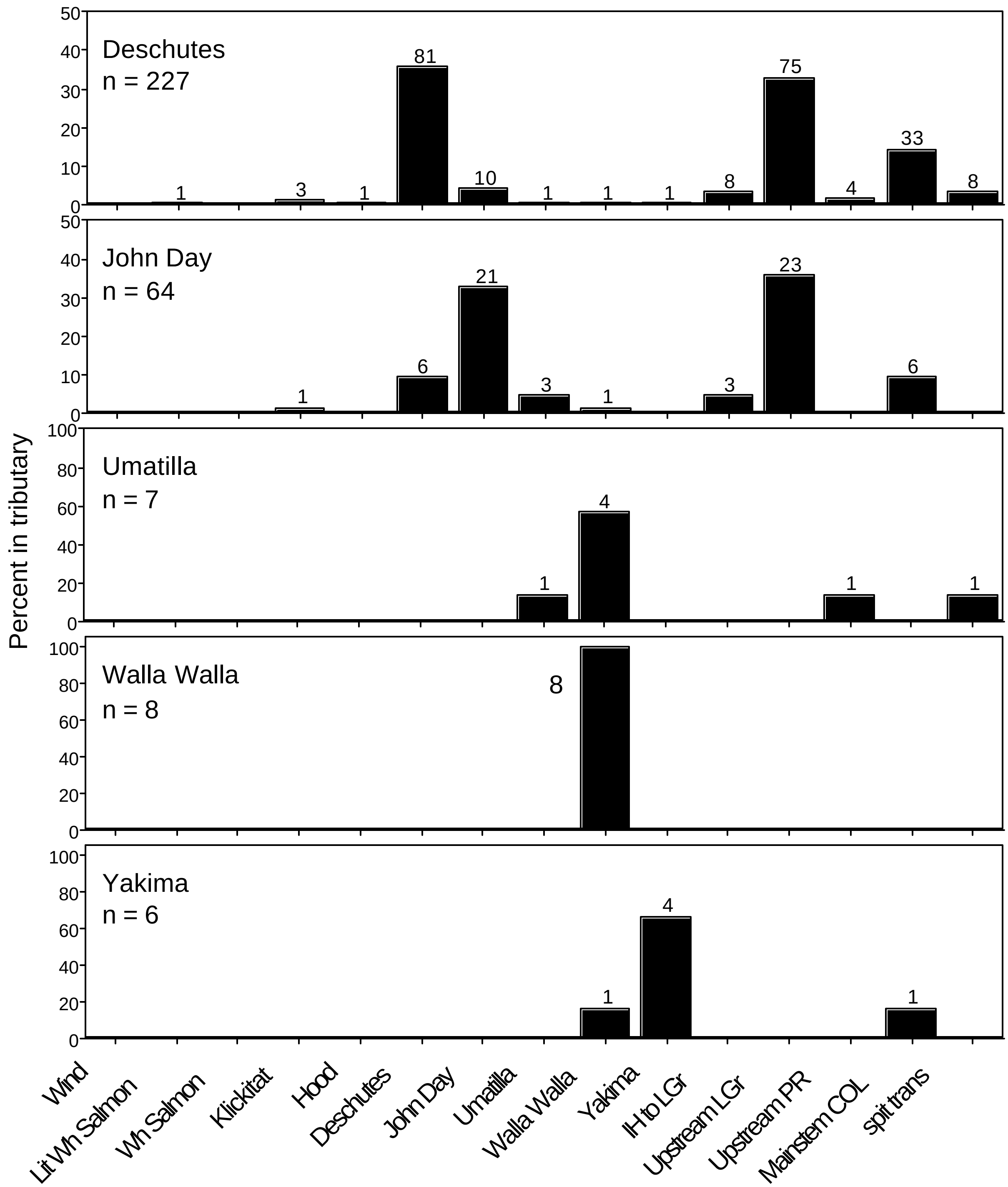

Figure 75. Last recorded location (x-axis) for steelhead with transmitters that entered the Wind, Little White Salmon, White Salmon, Klickitat, or Hood rivers in the run-year 1996-1997.

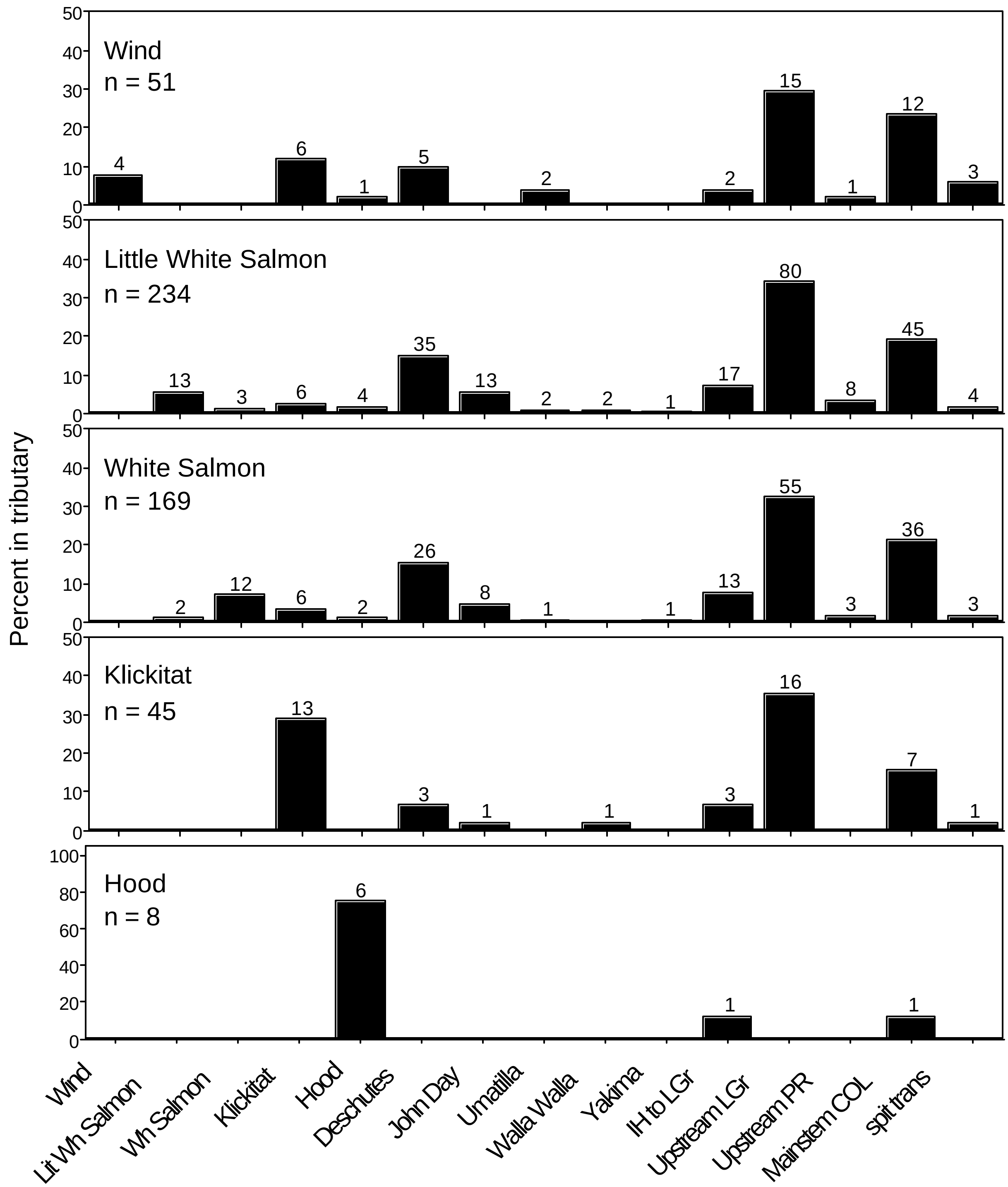

Figure 76. Last recorded location (x-axis) for steelhead with transmitters that entered the Deschutes, John Day, Umatilla, Walla Walla, or Yakima rivers in the run-year 1996-1997.

were recaptured at hatcheries, weirs or in tributary fisheries. We primarily determined escapement using the last known record or final fate for each steelhead, except in cases where fish (kelts) were recorded after likely spawning (Figure 77). We also described escapements for A-group and B-group steelhead, and steelhead with and without fin clips separately. It was possible that some steelhead were recaptured in fisheries and radio transmitters were not returned to the ICFWRU and that incorrect capture locations and times were provided. Transmitters were occasionally recorded as they were transported in autos or boats past receiver sites, and although we could sometimes identify that transmitters were not in fish, there was a small degree of uncertainty about some transmitters and records at some fixed-site receivers.

Using final fate locations for 704 steelhead that we believe retained transmitters throughout their migration in 1996, regardless of fallbacks, 60.4% escaped to be recorded in major tributaries and another 2.6% survived to pass Priest Rapids Dam, for an overall rate of 62.9% (Table 30). Fish last recorded at the mouth of the Clearwater River, the Snake River near Asotin, and the lower Deschutes River were considered to have reached tributary destinations, a broader definition than in previous years when we had more receivers and did more mobile tracking in tributaries used for spawning. Because of limited receiver coverage and few additional records upriver from Priest Rapids Dam, we could not identify whether steelhead that passed Priest Rapids escaped to tributaries. For ease of comparison, we present two survival rates, one that included and one that did not include fish that passed Priest Rapids Dam as reaching tributary sites (Table 30). Based on survival rates for fish that passed other upriver dams, it is likely that many fish last recorded at the top of Priest Rapids Dam did reach a tributary. We did not include fish with known or presumed regurgitated transmitters (based on circumstances of the transmitter) in survival-to-tributary summaries.

Nine steelhead were recaptured without transmitters at the Lower Granite adult trap and identified by secondary tags. When we classified these fish as having survived, survival to tributaries increased 0.5% to 63.4%. Overall survival to tributaries was likely slightly higher than we report, as some fish may have entered tributaries undetected or entered unmonitored tributaries. The estimate was not a measure of escapement to spawning areas and does not suggest that fish that escaped to enter tributaries subsequently spawned.

Steelhead without fin clips escaped to tributaries or past Priest Rapids Dam at slightly higher rates than steelhead with fin clips, a difference that was not significant ($P = 0.87$, Z test). Similarly, we found no difference ($P = 0.79$) in survival rates for A-group versus B-group steelhead (Table 30). Although the top of Priest Rapids Dam was a less rigorous measure of survival than survival to tributaries, just 18 fish passed the dam and their inclusion had little impact on statistical comparisons.

Of 261 steelhead with last records at mainstem or dam receiver sites other than the top of Priest Rapids Dam, 190 (73%) were unaccounted for and 71 (27%) were reported recaptured in sport or tribal fisheries. Thirty-four (48%) were reported recaptured in the Bonneville Dam pool, 14 (20%) in The Dalles Dam pool, 8 (11%) upstream from McNary Dam, 7 (10%) between Ice Harbor and Lower Granite dams, and 5 (7%) in the Lower Granite Dam pool.

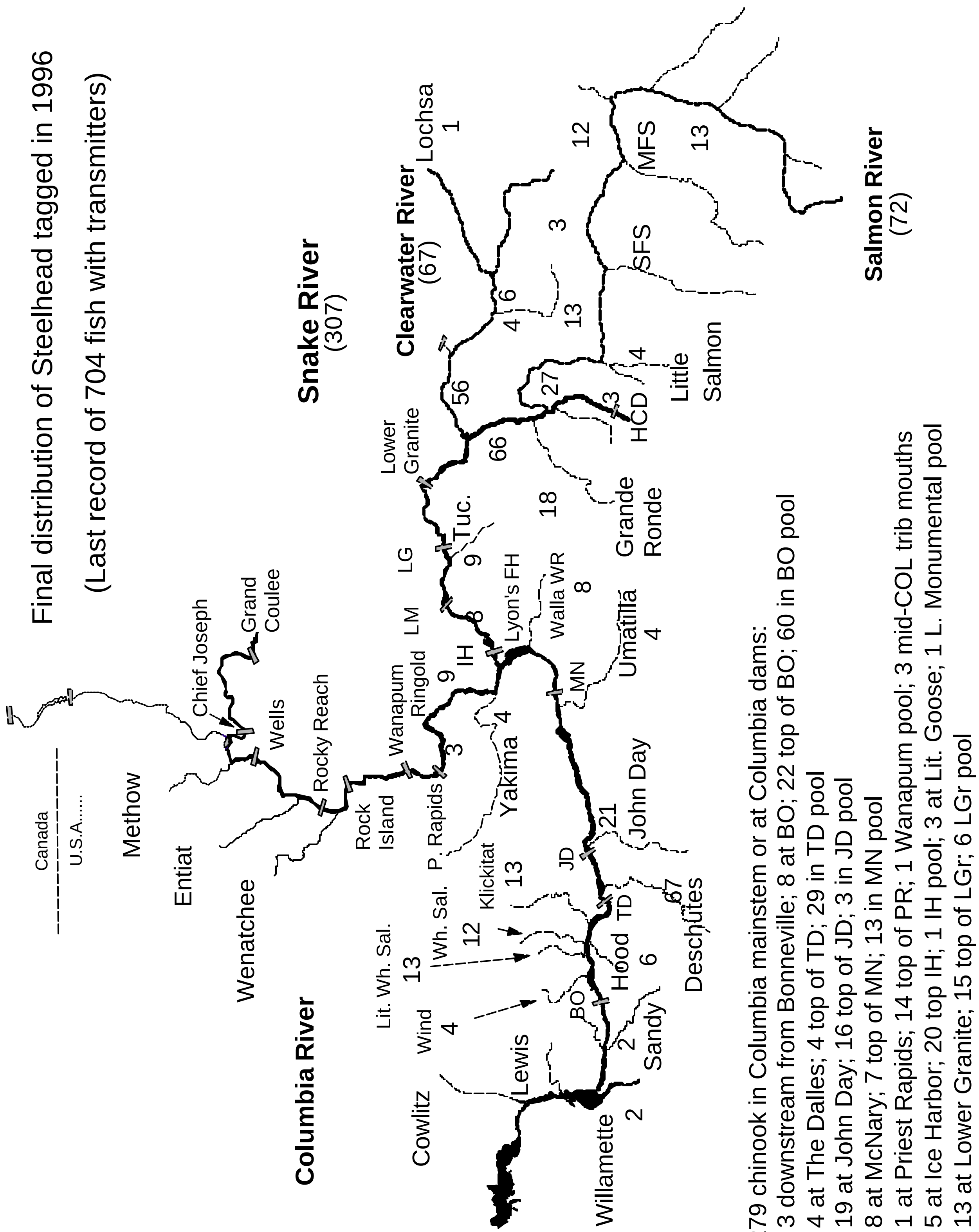

Figure 77. Final distribution of 704 steelhead outfitted with transmitters at Bonneville Dam in 1996 based on last known records of each fish.

Table 30. Number and percent of 704 steelhead that survived to major tributaries, based on last records, and/or evidence that fish spawned in a tributary but drifted to the mainstem in the run-year 1996-1997. Fish that passed Priest Rapids Dam were treated as a special case.

	All Steelhead	A-group Steelhead	B-group Steelhead	Clipped Steelhead	Unclipped Steelhead
Number that retained transmitters after release	704	445	259	590	114
Number that survived to major tributaries (does not include top of Priest Rapids Dam)	425	268	157	354	71
Percent that survived to major tributaries (does not include top of Priest Rapids Dam)	**60.4**	**60.2**	**60.6**	**60.0**	**62.3**
Number that survived to major tributaries (includes top of Priest Rapids Dam)	443	281	162	370	73
Percent that survived to major tributaries (includes top of Priest Rapids Dam)	**62.9**	**63.1**	**62.5**	**62.7**	**64.0**

Reach Survival Estimates

In addition to overall estimates of escapement to tributaries, we calculated reach survival estimates through each hydrosystem segment to partition the loss of fish not accounted for by recapture or entry into tributaries. We calculated reach survival (S_R) with the formula:

$$S_R = (UD_P + POOL_R + POOL_T + DS_R + DS_T) / DD_P$$

where:

UD_P was the number of fish known to have passed the upstream dam,

$POOL_R$ was the number of fish reported recaptured in the reach reservoir,

$POOL_T$ was the number of fish that entered monitored tributaries in the reach,

DS_R was the number of fish that passed the downstream dam but then fell back and were reported recaptured downstream from the downstream dam,

DS_T was the number of fish that passed the downstream dam but then fell back and entered tributaries downstream from the downstream dam, and

DD_P was the number of fish known to have passed the downstream dam.

All fish recaptured in fisheries or at hatcheries were considered to have survived. Fish that passed the dam at the upstream end of a reach were considered to have survived through the reach regardless of subsequent fallback. The small number of transmitters found at mainstem sites and returned were considered non-survivors (unaccounted for). Other fish unaccounted for in tributaries or by recaptures were last recorded primarily at dams or in reservoirs. Some unaccounted-for fish may have been recaptured but not reported, entered tributaries undetected, or entered unmonitored tributaries, but we believe most did not survive.

Reach survival estimates for steelhead in 1996 ranged from 0.901 to 0.942 (Table 31). Survival estimates were 0.920 between Bonneville and The Dalles dams, 0.942 between The Dalles and John Day dams, 0.935 between John Day and McNary dams, and 0.940 between McNary and either Ice Harbor or Priest Rapids dams. The reach survival estimate from the top of Ice Harbor Dam to the top of Lower Granite Dam (includes two intermediate dams) was 0.922; 8 fish recaptured at the Lower Granite trap without transmitters were designated as survived.

At least 263 fish with transmitters passed Lower Granite Dam. The reach survival estimate for those fish, through the Lower Granite pool and past receivers at either the lower Clearwater River or the Snake River near Asotin, WA was 0.901 (Table 31). We did not calculate reach survival estimates through the mid-Columbia River upstream from Priest Rapids Dam.

Final Distribution of Steelhead with Transmitters

We based this summary of the final distribution of steelhead primarily on the last telemetry or recapture record for each fish. Fish that spawned (resided in spawning stream through spawning period) and then migrated back to mainstem sites were included in counts for the tributary where they spawned. Because the final distribution of 61 steelhead with known or presumably regurgitated transmitters was unknown, those fish were not included in this summary (see Table 5 for the last recorded sites for those fish). Of 704 steelhead that we believe retained transmitters in 1996, 4 (< 1%) had last records in tributaries downstream from Bonneville Dam, 3 were last recorded in the Columbia River downstream from the dam, and 8 (1%) had last records at Bonneville Dam or in the tailrace (Table 32). About 18% (126 fish) of the radio-tagged steelhead had last records in the Columbia River or its tributaries between the top of Bonneville Dam and The Dalles Dam. Twenty-two (3%) were last recorded at the top of Bonneville Dam, 61 (9%) in the Bonneville pool, 4 (< 1%) in the Wind River, 13 (2%) in the Little White Salmon River, 12 (2%) in the White Salmon River, 6 (1%) in the Hood River, 13 (2%) in the Klickitat River and 4 (< 1%) at The Dalles Dam.

Nineteen percent (133 fish) of the steelhead had last records in the Columbia River or its tributaries between the top of The Dalles Dam and John Day Dam (Table 32). Four (< 1%) were last recorded at the top of The Dalles Dam, 29 (4%) in The Dalles Dam pool, 69 (12%) in the Deschutes River, and 19 (3%) at John Day Dam. Fifty-two fish (7%) had last records between the top of John Day Dam and McNary Dam. Sixteen fish (2%) were last recorded at the top of John Day Dam, 3 (< 1%) in the John Day Dam pool, 21 (3%) in the John Day River, 4 (< 1%) in the Umatilla River and 8 (1%) at McNary Dam (Table 32).

Table 31. Number of steelhead known to have passed downstream dam (DD_P), number that passed upstream dam (UD_P), number recaptured in reach reservoir ($POOL_R$), number that entered monitored tributary in reach ($POOL_T$), number recaptured downstream from the downstream dam (DS_R), number that entered tributaries downstream from the downstream dam (DS_T), and reach survival estimates (S) for radio- tagged steelhead in 1996-1997.

DS dam	US dam	DD_P	UD_P	$POOL_R$	$POOL_T$	DS_R	DS_T	Reach Survival (S)
Bonneville	The Dalles	724	584	34	46	0	2	**0.920**
The Dalles	John Day	584	460	10	77	1	2	**0.942**
John Day	McNary	460	397	1	22	2	8	**0.935**
McNary	IH/PR[1]	397	340	16	10	1	6	**0.940**
Ice Harbor	L. Granite	322	271	14	8	0	4	**0.922**
L. Granite	SNR/CWR[2]	263	236	8	n/a	1	0	**0.901**

[1] Top of either Ice Harbor or Priest Rapids dams

[2] At either the lower Clearwater River receiver or the Snake River receiver near Asotin, WA

Seven (1%) radio-tagged steelhead were last recorded at the top of McNary Dam. Upstream from McNary Dam in the mid-Columbia River, 13 (2%) were last recorded in the McNary Dam pool, 8 (1%) in the Walla Walla River, 4 (< 1%) in the Yakima River, 9 (1%) near Ringold Trap, 3 in the free-flowing section of the Columbia River between the McNary pool and Priest Rapids Dam, and 1 at Priest Rapids Dam. Eighteen steelhead (3%) were last recorded at or upstream from the top of Priest Rapids Dam.

At least 309 (44%) of 704 steelhead that retained transmitters entered the Snake River, and an additional 9 fish that regurgitated transmitters were recaptured at the Lower Granite adult trap. Twenty-five (4%) fish were last recorded at Ice Harbor Dam or at the tops of ladders there, 8 (1%) at Lyons Ferry hatchery, 9 (1%) in the Tucannon River, 3 at Little Goose Dam, 13 (2%) at Lower Granite Dam, and 21 (3%) at the top of Lower Granite Dam or in the Lower Granite Dam pool (Table 32). Sixty-seven fish (10%) had last records in the Clearwater drainage, with 52 (75%) of the fish at or near Dworshak hatchery or the North Fork of the Clearwater River. Another 66 fish (9%) had last records in the mainstem of the Snake River at or upstream from the fixed receiver site near Asotin, WA. Eighteen (3%) fish were last recorded in the Grande Ronde River, 3 at Hell's Canyon Dam, and 72 (10%) were in the Salmon River basin. Of 72 fish in the Salmon River basin, 27 (38%) were last recorded downstream from the Little Salmon River, 4 (6%) were in the Little Salmon River, 13 (18%) were between the Little Salmon and South Fork Salmon rivers, 15 (21%) were between the South and North forks of the Salmon, and 13 (18%) were upstream from the North Fork (Table 32).

Table 32. Final distribution by location based on last records of all steelhead, A-group and B-group steelhead, and steelhead with or without fin clips that we believe retained transmitters in 1996. Records after potential spawning in tributaries (post-kelt), were disregarded. See Table 5 for fish that regurgitated transmitters.

	All steelhead	A-group steelhead	B-group steelhead	Clipped steelhead	Unclipped steelhead
All Fish	**704**	**445**	**259**	**590**	**114**
Lower Columbia River and Lower Columbia River Tributaries					
Downstream from Bonn.	3	3		2	1
Sandy River	2	2		2	
Washougal River	2	1	1	1	1
At Bonneville Dam	8	5	3	6	2
Top of Bonneville Dam	22	12	10	16	6
Bonneville Pool	43	27	16	37	6
Mouth of Wind River	3	2	1	3	
Mouth of L. Wh. Salmon R.	11	6	5	10	1
Mouth of Wh. Salmon R.	3	3		2	1
Wind River	4	2	2	3	1
Little White Salmon R.	13	12	1	10	3
White Salmon River	12	8	4	11	1
Hood River	3	3		3	
Powerdale Dam Trap	3	2	1	3	
Klickitat River	13	12	1	11	2
At The Dalles Dam	4	2	2	2	2
Top of The Dalles Dam	4	4		2	2
The Dalles Pool	13	5	8	11	2
Mouth of Deschutes R.	16	8	8	13	3
Deschutes River	54	42	12	44	10
Sherars Falls	18	12	6	15	3
Pelton Dam Trap	9	7	2	8	1
At John Day Dam	19	12	7	18	1
Top of John Day Dam	16	8	8	14	2
John Day Pool	3	2	1	3	
John Day River	21	11	10	13	8
Umatilla River Trap	4	3	1	3	1
At McNary Dam	8	7	1	7	1
Top of McNary Dam	7	6	1	5	2
Mid-Columbia River and Mid-Columbia River Tributaries					
McNary Pool	12	8	4	11	1
Mouth of Walla Walla R.	1	1		1	
Walla Walla River	6	5	1	6	
Mill Creek	1	1		1	

Table 32. Continued.

	All steelhead	A-group steelhead	B-group steelhead	Clipped steelhead	Unclipped steelhead
Touchet River	1		1	1	
Yakima River	4	3	1		4
Near Ringold Trap	9	9		7	2
Hanford Reach	3	2	1	3	
At Priest Rapids Dam	1		1	1	
Top of Priest Rapids Dam	14	11	3	12	2
Wanapum Pool	1		1	1	
Near Mouth of Entiat River	1	1		1	
Near Mouth of Methow River	2	2		2	
Snake River and Snake River Tributaries					
At Ice Harbor Dam	5	5		5	
Top of Ice Harbor Dam	20	17	3	19	1
Lyons Ferry Hatchery	8	8		8	
Near Lyons Ferry Hatchery	1	1		1	
Tucannon River	9	9		8	1
Near Tucannon River	1	1		1	
At Little Goose Dam	3	1	2	3	
At Lower Granite Dam	13	8	5	9	4
Top of Lower Granite Dam	15	6	9	12	3
Lower Granite Pool	6	4	2	6	
Clearwater River					
Near Mouth Clearwater R.	2	1	1	2	
Mouth to NF Clearwater R.	33	9	24	22	11
Dworshak Natl. Hat.	10		10	10	
Near Dworshak NH	7		7	7	
North Fork Clearwater R.	2		2	2	
NF to SF Clearwater. R.	2	1	1	1	1
South Fork Clearwater R.	4		4	4	
Near Clear Creek	1		1	1	
Kooskia Natl. Hat.	5		5	5	
Lochsa River					
Fish Creek	1		1		1
Snake River at Asotin, WA	42	23	19	35	7
Snake River near Asotin	5	3	2	5	
Snake River above Asotin	19	16	3	16	3
Grande Ronde River	9	7	2	9	
Cottonwood Creek Weir	2	2		2	
Wallowa River	7	4	3	7	
Hells Canyon Dam	3	2	1	3	

Table 32. Continued.

	All steelhead	A-group steelhead	B-group steelhead	Clipped steelhead	Unclipped steelhead
Salmon River					
Mouth to Lit. Sal. R.	26	11	15	22	4
Grave Creek	1		1	1	
Little Salmon River	4	3	1	4	
L. Salmon to SF Salmon R.	13	9	4	11	2
SF to MF Salmon R.	3	1	2	3	
MF to NF Salmon R.	12	10	2	10	2
Upstream of NF Salmon R.	5	4	1	4	1
Pahsimeroi Hatchery	4	4		4	
Sawtooth Weir	4	3	1	3	1

The final distribution for 445 A-group steelhead that retained transmitters included 212 (48%) in the lower Columbia and its tributaries between Bonneville and McNary dams, a proportion comparable to B-group steelhead (108 of 259 fish = 42%) (Table 33). The proportion of A-group steelhead (9.0%) last recorded between the top of McNary Dam and the tailrace of either Ice Harbor or Priest Rapids dams was significantly ($P = 0.01$, Z test) higher than the proportion of B-group fish (3.9%) last recorded in that portion of the basin. A significantly ($P = 0.003$) higher proportion of A-group (10.1%) than B-group (3.9%) steelhead had final records between Ice Harbor and Lower Granite dams (Table 33). Conversely, the proportion of B-group steelhead with final distribution upstream from Lower Granite Dam was significantly ($P < 0.001$) higher than the proportion of A-group fish (B-group = 47.9%, A-group = 27.6%), primarily due to B-group returns to the Clearwater River basin. About 21.6% of all B-group steelhead that retained transmitters returned to the Clearwater River, compared to 2.5% of the A-group steelhead (Table 33). Proportions of A- and B-group fish that returned to the Salmon River were about 10%.

The highest number of A-group steelhead (61 fish, 14%) were last recorded in the Deschutes River. Forty-six (10%) A-group steelhead were last recorded in the Salmon River, 43 (10%) were last recorded at Bonneville Dam or in the Bonneville Dam pool, 42 (9%) were last recorded at or upstream from the Snake River receiver near Asotin, WA, and 22 (5%) were last recorded at Ice Harbor Dam (Table 32). Three A-group fish (1%) returned to tributaries downstream from Bonneville Dam, 39 (9%) to tributaries to the Bonneville Dam pool, 14 (3%) to the John Day and Umatilla rivers, 6 (1%) to the Walla Walla River, 10 (2%) to the Tucannon River, and 13 (3%) to the Grande Ronde River.

The highest number of B-group steelhead (56 fish, 22%) were last recorded in the Clearwater River, 36 (14%) were last recorded at Bonneville Dam or in the Bonneville Dam pool, 26 (10%) were in the Salmon River, 24 (9%) were at or upstream from the Snake River receiver near Asotin, WA, and 20 (8%) were in the Deschutes River (Table 32). Nine (3%) B-group steelhead returned to tributaries to the Bonneville Dam pool, 10 (4%) to the John Day River, 1 each to the Washougal, Umatilla, and Walla Walla rivers and 5 (2%) to the Grande Ronde River (Table 32).

Table 33. Final distribution by basin subsection based on last records for 704 A-group and B-group steelhead, and steelhead with or without fin clips that we believe retained transmitters in 1996, with percentage of totals. Records after potential spawning in tributaries (post-kelt), were disregarded.

	A-group steelhead	B-group steelhead	Clipped steelhead	Unclipped steelhead	
All Fish	**445**	**259**	**590**	**114**	
Downstream from Bonneville	**11**	**4**	**11**	**4**	
Percent	2.5	1.5	1.9	3.5	
Top of Bonneville to McNary	**212**	**108**	**262**	**58**	
Percent	47.6	41.7	44.4	50.9	
Top of Bonneville to The Dalles	91	44	111	24	
Percent	20.4	17.0	18.8	21.1	
Top of The Dalles to John Day	90	43	111	22	
Percent	20.2	16.6	18.8	19.3	
Top of John Day to McNary	31	21	40	12	
Percent	7.0	8.1	6.8	10.6	
Top of McNary to Ice Harbor or Priest Rapids dams	**40**	**10**	**41**	**9**	
Percent	9.0*	3.9*	6.9	7.9	
Top of Ice Harbor to L. Granite	**45**	**10**	**49**	**6**	
Percent	10.1*	3.9*	8.3	5.3	
Upstream from L. Granite	**123**	**124**	**211**	**36**	
Percent	27.6*	47.9*	35.8	31.6	
Clearwater River basin	11	56	54	13	
Percent	2.5*	21.6*	9.2	11.4	
Salmon River basin	45	27	62	10	
Percent	10.1	10.4	10.5	8.8	
Upstream from Priest Rapids		**14**	**4**	**16**	**2**
Percent	3.1	1.5	2.7	1.8	

* significantly different at $P < 0.05$

The proportion of A-group steelhead last recorded in individual tributaries ranged from about 15% in the Clearwater River to more than 80% in the Little White Salmon and Klickitat rivers and 100% in the Tucannon River and at Lyons Ferry hatchery (Figure 78). Between 70% and 80% of returns to the Grande Ronde, Yakima, Umatilla, Deschutes, and Hood rivers were A-group steelhead.

Steelhead with fin clips made up 84% of the fish tagged in 1996, and 84% of the fish that we believe retained transmitters (Table 32). Fin-clipped fish made up 83% to 85% of tagged steelhead last recorded in the Deschutes, Clearwater, and Salmon rivers, and at or upstream from the Snake River receiver site near Asotin (Figure 78). About 89% of the fish last recorded at or upstream from Priest Rapids Dam, 89% of the Tucannon River fish,

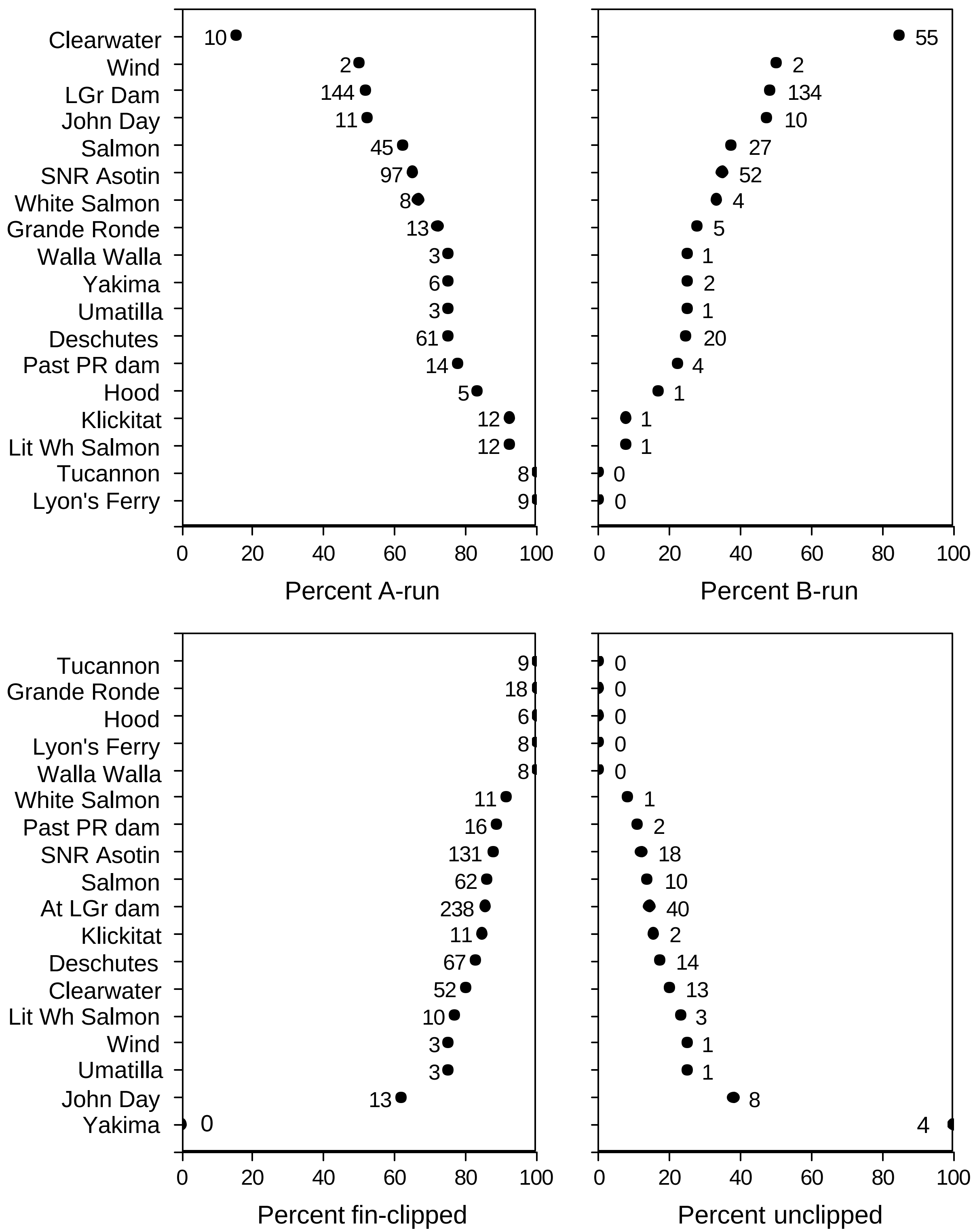

Figure 78. Percent of A-group and B-group steelhead, and percent with and without fin clips that made up returns to major tributaries in 1996-1997, based on final distribution of steelhead with transmitters. Numbers of fish in each group indicated to the left of symbols.

and 100% of the Grande Ronde River fish had fin clips. Proportions of fin-clipped fish were 75% in the Wind and Umatilla rivers, 77% in the Little White Salmon River, 92% in the Klickitat River, 62% in the John Day River, 100% in the Hood and Walla Walla rivers, and 0% in the Yakima River (Figure 78).

We found no significant differences in the proportions of fin-clipped and unclipped steelhead last recorded in the major basin subsections ($P > 0.20$, Z tests). About 44% of fin-clipped fish were last recorded between Bonneville and McNary dams, compared to 51% of unclipped fish (Table 33). Seven percent of clipped fish and 8% of unclipped fish were last recorded between McNary Dam and the tailrace of either Priest Rapids or Ice Harbor dams. About 8% of clipped and 5% of unclipped fish were last recorded between Ice Harbor and Lower Granite dams. Upstream from Lower Granite Dam, 36% were clipped and 32% were unclipped steelhead (Table 33).

Recaptures of Steelhead with Transmitters

A minimum of 32.4% (248 of 765) of the steelhead released with transmitters in 1996 were recaptured in fisheries, at hatcheries, traps or weirs, recovered at spawning grounds, recovered from dead fish or were transmitters found by people along rivers. Thirty-two percent was a minimum recapture rate because all recaptured fish were probably not reported to us. At least 32% of the released A-group steelhead and 34% of B-group steelhead were recaptured. Not included in the above were 8 fish recaptured in the Bonneville adult trap, and 222 fish recaptured at the Lower Granite adult trap that were released into ladders at the respective dams. Nine (4%) of the steelhead recaptured at the Lower Granite Trap had lost transmitters before recapture (Table 34).

Without including the Bonneville and Lower Granite traps, we recaptured 248 transmitters in 1996. Of the 248, 243 (98%) recaptures were the last records for fish and 5 (2%) were released with transmitters and subsequently recorded at other locations. In all, 113 (46%) were recaptured in sport fisheries, 52 (21%) in tribal fisheries, 64 (26%) at hatcheries, traps, and weirs, and 19 (7%) from spawning grounds, in dead fish, or transmitters were found along river corridors, or recapture was at unknown location (Table 34). Reported recaptures in sport fisheries accounted for 16.1% of the 704 steelhead that retained transmitters after release, and fish caught in tribal fisheries about 7.4%. Fish recaptured at hatcheries or other traps or weirs operated by researchers and managers made up 9.1% of the fish released that retained transmitters, and other types of recaptures amounted to 2.7% (Table 34).

About two-thirds of steelhead recaptured at hatcheries, traps and weirs were in the Snake River basin, with 10 at Dworshak and 5 at Kooskia national fish hatcheries on the Clearwater River, 9 at the Lyons Ferry Hatchery, 5 at the Wallowa Hatchery and 2 at the Cottonwood Creek facility on the Grande Ronde River, 3 at Hells Canyon Dam , and 4 each at the Pahsimeroi and Sawtooth hatcheries in the Salmon River basin. Ten steelhead were recaptured at the Pelton Dam Trap and 2 were recaptured and released from the Sherars Falls Trap on the Deschutes River, 4 were recaptured at the Powerdale Dam Trap on the Hood River, and 4 were recaptured at the Umatilla River weir at Three Mile Dam (Table 34).

Table 34. Number and percent of steelhead released with transmitters downstream from Bonneville Dam in 1996 with recaptures at all sites, recaptured and reported in sport and tribal fisheries, at hatcheries, weirs and other traps, and those recaptured in spawning areas, or found along rivers.

	All recaps	Sport fisheries	Tribal fisheries	Hatcheries weirs, traps	Other[1]
Unique Fish, incl Bonn, LGr traps	392				
Without Bonn, LGr traps	248	113	52	64	19
Percent of 248	100	45.6	21.0	25.8	7.7
Percent of 765	32.4	14.8	6.8	8.4	2.5
Lower Columbia and Lower Columbia Tributaries					
Downstream from Bonn. Dam	3	1	1		1
At/near release site	7				7
Bonneville Trap, released	8			8	
Bonneville Pool	34	2	32		
Little White Salmon	3	3			
White Salmon River	2	2			
Hood River	4			4	
Klickitat River	5	2	3		
The Dalles Pool	9	2	7		
Deschutes River	28	12	2	12	2
John Day Pool	6	1	5		
John Day River	4	2	2		
Umatilla River Trap	5			5	
Unknown mainstem	2				2
Mid-Columbia River and Mid-Columbia Tributaries					
McNary pool	8	8			
Walla Walla River	3	3			
Yakima River	1				1
Near Ringold Trap	4	4			
Near Entiat River	1	1			
Near Methow River	2	2			
Snake River					
Ice Harbor pool	3	3			
Lyons Ferry Hatchery	9[2]			9	
Tucannon River	4	4			
At Little Goose Dam	3	3			
At Lower Granite Dam	1	1			

Table 34. Continued

	All recaps	Sport fisheries	Tribal fisheries	Hatcheries weirs, traps	Other[1]
Lower Granite Trap (9 had lost transmitters)	222			222	
Lower Granite pool	7	7			
Clearwater River	11	10			1
Dworshak/Kooskia hatcheries	15			15	
North Fork	2	2			
South Fork	3	3			
Lochsa River	1			1	
Snake River near Asotin	10	10			
Grande Ronde River	5	3			2
Cottonwood/Wallow hatcheries	7			7	
Wallowa River	2	2			
Salmon River	23	20			3
Pahsimeroi/Sawtooth hatcheries	8			8	
Hell's Canyon Dam/Oxbow hatchery	3			3	

[1] Other includes recaptures at spawning grounds, found transmitters or found dead fish.
[2] Does not include fish recaptured at hatchery, released, and recaptured in Walla Walla basin

Ten transmitters (4% of 248) were recovered downstream from Bonneville Dam, including 8 found transmitters and 1 fish recaptured in sport and 1 in tribal fisheries. Between Bonneville and McNary dams, 102 steelhead (41% of 248) were recaptured, 51 at mainstem sites and 51 in tributaries. Fourteen percent (34 fish) were recaptured in the Bonneville Dam pool, 4% in The Dalles Dam pool, 2% in the John Day Dam pool, and 2 fish at unknown mainstem sites. Most recaptures in the mainstem were in tribal fisheries (34 of 51 fish = 86%), 10% were in sport fisheries and the remaining 4% were found transmitters (Table 34). Twenty-one steelhead were recaptured in sport fisheries in the Little White Salmon, White Salmon, Klickitat, Deschutes, and John Day rivers. Another 7 were recaptured in tribal fisheries in those tributaries, and 17 were recaptured at traps or weirs on the Deschutes and Umatilla rivers (Table 34).

Not including the Lower Granite Trap recaptures, 117 steelhead (47% of 248) were recaptured in the Snake River drainage. Sixty-eight of the 117 (58%) were in sport fisheries, including 14 in reservoirs or near dams. Four fish were recaptured in the Tucannon River, 15 in the Clearwater River drainage, 10 in the Snake River near Asotin, 5 in the Grande Ronde River, and 20 in the Salmon River drainage (Table 34). Of the 117, 43 (37%) were recaptured at hatcheries, traps or fish weirs in rivers, including 9 at Lyon's Ferry hatchery, 16 at facilities in the Clearwater River basin, 7 at facilities in the Grande Ronde River basin, 8 at facilities in the Salmon River basin, and 3 at Hells Canyon Dam (Table 34). There were no recaptures in tribal fisheries in the Snake River basin. Six transmitters were found or recovered at unknown sites in the basin.

In the mid Columbia River, 19 (8% of 248) steelhead were recaptured, including 18 in sport fisheries. Eight fish were recaptured in the McNary Dam pool, 3 in the Walla Walla River, 4 near the Ringold Trap, 1 near the Entiat River, 2 near the Methow River, and 1 transmitter was found in the Yakima River (Table 34).

We also summarized recapture information by four major basin subsections: downstream from Bonneville Dam, from the top of Bonneville Dam to the McNary Dam tailrace, from the top of McNary Dam upriver through the mid-Columbia, and the Snake River basin. Of 248 steelhead recaptured at locations other than the Bonneville and Lower Granite traps, 10 (4.0%) were recaptured downstream from Bonneville Dam, 97 (39.1%) between Bonneville and McNary dams, 24 (9.7%) in the mid Columbia River, and 117 (47.2%) in the Snake River basin. Of the 765 steelhead released with transmitters, 1.3% were recaptured or their transmitters were found downstream from Bonneville Dam, 12.7% were recaptured between Bonneville and McNary dams, 3.1% were recaptured in the mid-Columbia section upstream from McNary Dam, and 15.3% were recaptured in the Snake River basin (Table 35).

Eight of 10 (80%) recaptures downstream from Bonneville Dam were A-group steelhead and 9 did not have fin clips (Tables 34 and 35). One fish was recaptured in a sport fishery, 1 in a tribal fishery, 1 at an unknown location, and 7 were found in non-spawning areas (Table 35).

Of 97 fish recaptured in the lower Columbia River and its tributaries between Bonneville and McNary dams, 51 (53%) were recaptured in tribal fisheries, 26 (27%) in sport fisheries, and 16 (16%) in tributary traps or weirs. Another 2 fish were recaptured at unknown mainstem sites and 2 transmitters were found in tributaries (Table 35). About 67% (65 of 97 fish) of the recaptures in the Bonneville-to-McNary section of the Columbia River were A-group steelhead (Table 35), and 91% did not have fin clips (Table 36).

In the mid-Columbia River section upstream from McNary Dam, 75% of 24 recaptures were in sport fisheries, 21% were in tributary traps or weirs, and 4% were found in tributaries (Table 35). Seventy-five percent of recaptures in the mid-Columbia were A-group steelhead (Table 35) and 88% had fin clips (Table 36).

In the Snake River basin subsection, 68 of 117 recaptures (58%) were in sport fisheries, 40 (34%) were at hatcheries, 3% were at traps or weirs, and 3% were for transmitters found in tributaries (Table 35). Of 117 recaptures, 55% were A-group steelhead (Table 35) and 97% had fin clips when tagged (Table 36).

A total of 165 steelhead with transmitters were recaptured in sport (113 fish) or tribal (52 fish) fisheries in the run-year 1996-1997, with a median recapture date of 17 October (Figure 79). Fish were recaptured in sport fisheries every month from June, 1996 through April, 1997, with a peak of 36 fish (32%) in October; 23 (20%) were recaptured in November. The median sport fishery recapture date was 31 October. Almost 75% of recaptures by tribal fisheries were prior to 1 October, with a median recapture date of 18 September (Figure 79). No recaptures in tribal fisheries were reported for January or February, 1997.

Table 35. Number of A-group and B-group steelhead released in 1996 downstream from Bonneville Dam with transmitters that were recaptured or the transmitter was found somewhere in the basin and returned to us, and the number recaptured and percent of total recaptures in various locations.

	All steelhead		A-group steelhead		B-group steelhead	
	Number	Percent	Number	Percent	Number	Percent
Number released and % returned	765	32.4	487	31.8	278	33.5
Transmitter returned[1] from:						
Downstream from Bonneville	**10**	**1.3**	**8**	**1.6**	**2**	**0.7**
Sport fishery	1	0.1	1	0.2		
Tribal fishery	1	0.1	1	0.2		
Found in non spawning area	7	1.0	5	1.0	2	0.7
Unknown	1	0.1	1	0.2		
Bonneville to McNary dams	**97**	**12.7**	**65**	**13.3**	**32**	**11.5**
Weirs/traps in tributaries	16	2.1	13	2.7	3	1.1
Sport fishery	26	3.4	19	3.9	7	2.5
Tribal fishery	51	6.7	30	6.2	21	7.6
Found in tributary	2	0.3	2	0.4		
Unknown	2	0.3	1	0.2	1	0.4
Mid Columbia River	**24**	**3.1**	**18**	**3.7**	**6**	**2.2**
Weirs/traps in tributaries	5	0.7	4	0.8	1	0.4
Sport fishery	18	2.4	13	2.7	5	1.8
Found in tributary	1	0.1	1	0.2		
Snake River basin	**117**	**15.3**	**64**	**13.1**	**53**	**19.1**
Hatcheries	40	5.2	21	4.3	19	6.8
Weirs/traps in tributaries	3	0.4	1	0.2	2	0.7
Sport fishery	68	8.9	37	7.6	31	11.2
Found in tributary	3	0.4	1	0.2	2	0.7
Unknown	3	0.4	3	0.6		

[1] fish recaptured at Umatilla, Powderdale, and Sherars Falls traps released with transmitters

Twenty-one percent (35 of 165) of all recaptures in sport and tribal fisheries were after 1 December, with 91% in sport fisheries. Overall, 32 of 113 (28%) sport fishery recaptures were after 1 December, including 6 (5.3%) in December, 5 (4.4%) in January, 3 (2.7%) in February, 11 (9.7%) in March, and 7 (6.2%) in April. Just 3 steelhead with transmitters were recaptured in tribal fisheries after 1 December, 1 each in December, March, and April (Figure 79).

Fate of Steelhead with Transmitters

In addition to summaries of final distribution by location, and type and location of recapture, we made best estimates of the fate of each radio-tagged steelhead. In best-estimate summaries of fate, we calculated total escapement to tributaries and hatcheries, total reported harvest, and total unaccounted for fish. We also listed the approximate last recorded distribution of unaccounted for fish, and similar summaries for known or presumed regurgitated transmitters. Fish that regurgitated transmitters

Table 36. Number of steelhead with and without fin clips released in 1996 downstream from Bonneville Dam with transmitters that were recaptured or the transmitter was found somewhere in the basin and was returned to us, and the number of fish recaptured and percent of total recaptures in various locations.

	All salmon		Fin-clipped salmon		Unclipped salmon	
	Number	Percent	Number	Percent	Number	Percent
Number released and % returned	765	32.4	640	36.1	125	13.6
Transmitter returned[1] from:						
Downstream from Bonneville	**10**	**1.3**	**9**	**1.4**	**1**	**0.8**
Sport fishery	1	0.1	1	0.2		
Tribal fishery	1	0.1			1	0.8
Found in non spawning area	7	1.0	7	1.1		
Unknown	1	0.2	1	0.2		
Bonneville to McNary dams	**97**	**12.7**	**88**	**13.8**	**9**	**7.2**
Weirs/traps in tributaries	16	2.1	15	2.3	1	0.8
Sport fishery	26	3.4	26	4.1		
Tribal fishery	51	6.7	43	6.7	8	6.4
Found in tributary	2	0.3	2	0.3		
Unknown	2	0.3	2	0.3		
Mid Columbia River	**24**	**3.1**	**21**	**3.3**	**3**	**2.4**
Weirs/traps in tributaries	5	0.7	3	0.5	2	1.6
Sport fishery	18	2.4	18	2.8		
Found in tributary	1	0.1			1	0.8
Snake River basin	**117**	**15.3**	**113**	**17.7**	**4**	**3.2**
Hatcheries	40	5.2	39	6.1	1	0.8
Weirs/traps in tributaries	3	0.4	2	0.3	1	0.8
Sport fishery	68	8.9	66	10.3	2	1.6
Unknown	3	0.4	3	0.5		

[1] fish recaptured at Umatilla, Powderdale, and Sherars Falls traps released with transmitters

and those unaccounted for may have returned to spawning areas or to basin subsections other than those reported. We compiled estimates for all steelhead, A-group and B-group fish, and fin-clipped and unclipped fish.

The final distribution for all radio-tagged A-group and B-group steelhead based on our best estimate of the fate of each fish was 6.0% downstream from Bonneville Dam, 44.4% between the top of Bonneville Dam and the McNary Dam tailrace, 8.2% in the mid-Columbia River upstream from McNary Dam, and 41.3% in the Snake River basin (Table 37). Escapement was 37.9% to tributaries, 5.2% to hatcheries, 1.8% to the top of Priest Rapids Dam, 1.3% to the Hanford Reach or near Ringold trap, and 1.2% at Lower Granite trap without transmitters, for a total escapement of 47.5% (Figure 80). Another 20.9% were reported recaptured in sport and tribal fisheries. Known regurgitated transmitters downstream from Bonneville Dam or transmitters found in non-spawning areas made up 1.4% of the fish, and 5.4% were presumed regurgitated based on telemetry records and circumstances of the transmitter. Another 24.8% were unaccounted for throughout the study area (Table 37).

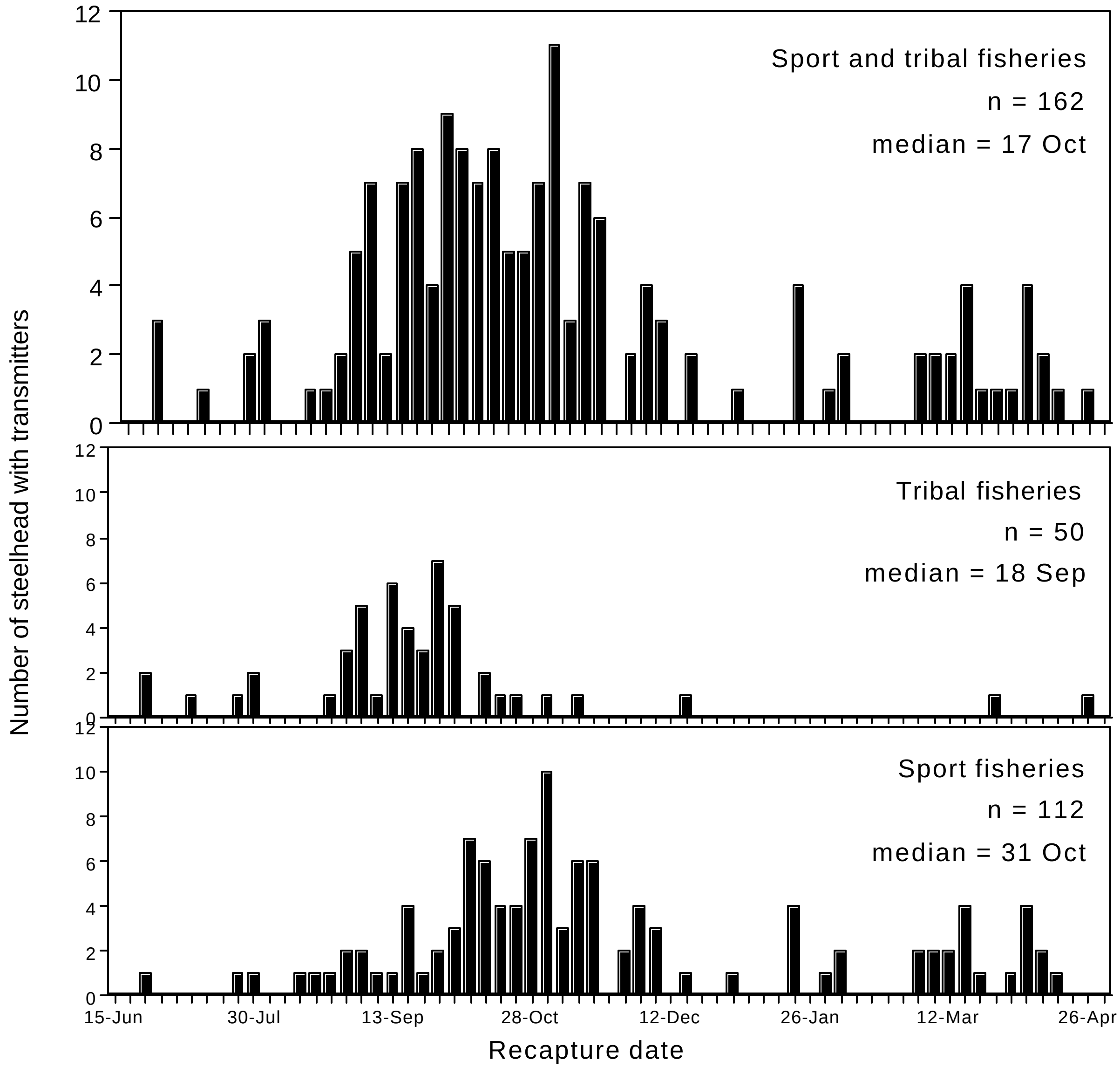

Figure 79. Reported recapture dates for steelhead with transmitters taken in sport and tribal fisheries in the run-year 1996-1997.

Of the 487 designated A-group steelhead, we determined that 6.6% ended up downstream from Bonneville Dam, 47.0% in the lower Columbia between Bonneville Dam and the tailrace of McNary Dam, 10.1% in the mid-Columbia, and 36.3% in the Snake River basin (Table 37). Escapement for A-group steelhead was 38.4% to tributaries, 4.3% to hatcheries, 2.3% past Priest Rapids Dam, 1.8% to the Hanford Reach or near Ringold trap, and 0.8% recaptured at the Lower Granite trap and released without transmitters, for a total escapement of 47.6% (Figure 81). Another 19.9% were recaptured in sport and tribal fisheries. Fish that we knew regurgitated their transmitters downstream from Bonneville Dam or their transmitters were found in non-spawning areas accounted for 1.8% of the A-group steelhead, and 6.0%

Table 37. Our best estimate of the fate of 765 steelhead released with transmitters in 1996 downstream from Bonneville Dam with the numbers released, numbers and percents of total that ended up in the various sections of the Columbia River basin.

	All steelhead		A-group steelhead		B-group steelhead	
	Number	Percent	Number	Percent	Number	Percent
Number released	**765**	**100**	**487**	**100**	**278**	**100**
Downstream from Bonneville	**46**	**6.0**	**32**	**6.6**	**14**	**5.0**
Entered a tributary	4	0.5	3	0.6	1	0.4
Sport fishery	1	0.1	1	0.2		
Tribal fishery	1	0.1	1	0.2		
Known regurgitated trans.	8	1.0	6	1.2	2	0.7
Presumed regurgitated trans.	23	3.0	15	3.1	8	2.9
Unaccounted for	9	1.2	6	1.2	3	1.1
Bonneville to McNary dams	**340**	**44.4**	**229**	**47.0**	**111**	**39.9**
Entered a tributary	127	16.6	95	19.5	32	11.5
Sport fishery	25	3.3	18	3.7	7	2.5
Tribal fishery	51	6.7	30	6.2	21	7.6
Known regurgitated trans.	3	0.4	3	0.6		
Presumed regurgitated trans.	18	2.4	14	2.9	4	1.4
Unaccounted for	116	15.2	69	14.2	47	16.9
Mid Columbia River	**63**	**8.2**	**49**	**10.1**	**14**	**5.0**
Entered a tributary	10	1.3	8	1.6	2	0.7
Sport fishery	16	2.1	11	2.3	5	1.8
Top Priest Rapids	14	1.8	11	2.3	3	1.1
Hanford Reach/Near Ringold trap	10	1.3	9	1.8	1	0.4
Unaccounted for	13	1.7	10	2.1	3	1.1
Snake River basin	**316**	**41.3**	**177**	**36.3**	**139**	**50.0**
Entered a tributary	149	19.5	81	16.6	68	24.5
Recaptured at hatchery	40	5.2	21	4.3	19	6.8
Sport fishery	66	8.6	36	7.4	30	10.8
Lower Granite Trap, no trans.	9	1.2	4	0.8	5	1.8
Unaccounted for	52	6.8	35	7.2	17	6.1
		Basin-wide summary				
Recorded in tributaries	**290**	**37.9**	**187**	**38.4**	**103**	**37.1**
Recaptured at hatcheries	**40**	**5.2**	**21**	**4.3**	**19**	**6.8**
Reported harvest	**160**	**20.9**	**97**	**19.9**	**63**	**22.7**
Top of Priest Rapids	**14**	**1.8**	**11**	**2.3**	**3**	**1.1**
Hanford Reach/near Ringold trap	**10**	**1.3**	**9**	**1.8**	**1**	**0.4**
Lower Granite Trap, no trans.	**9**	**1.2**	**4**	**0.8**	**5**	**1.8**
Known regurgitated trans.	**11**	**1.4**	**9**	**1.8**	**2**	**0.7**
Presumed regurgitated trans.	**41**	**5.4**	**29**	**6.0**	**12**	**4.3**
Transmitters unaccounted for	**190**	**24.8**	**120**	**24.6**	**70**	**25.2**

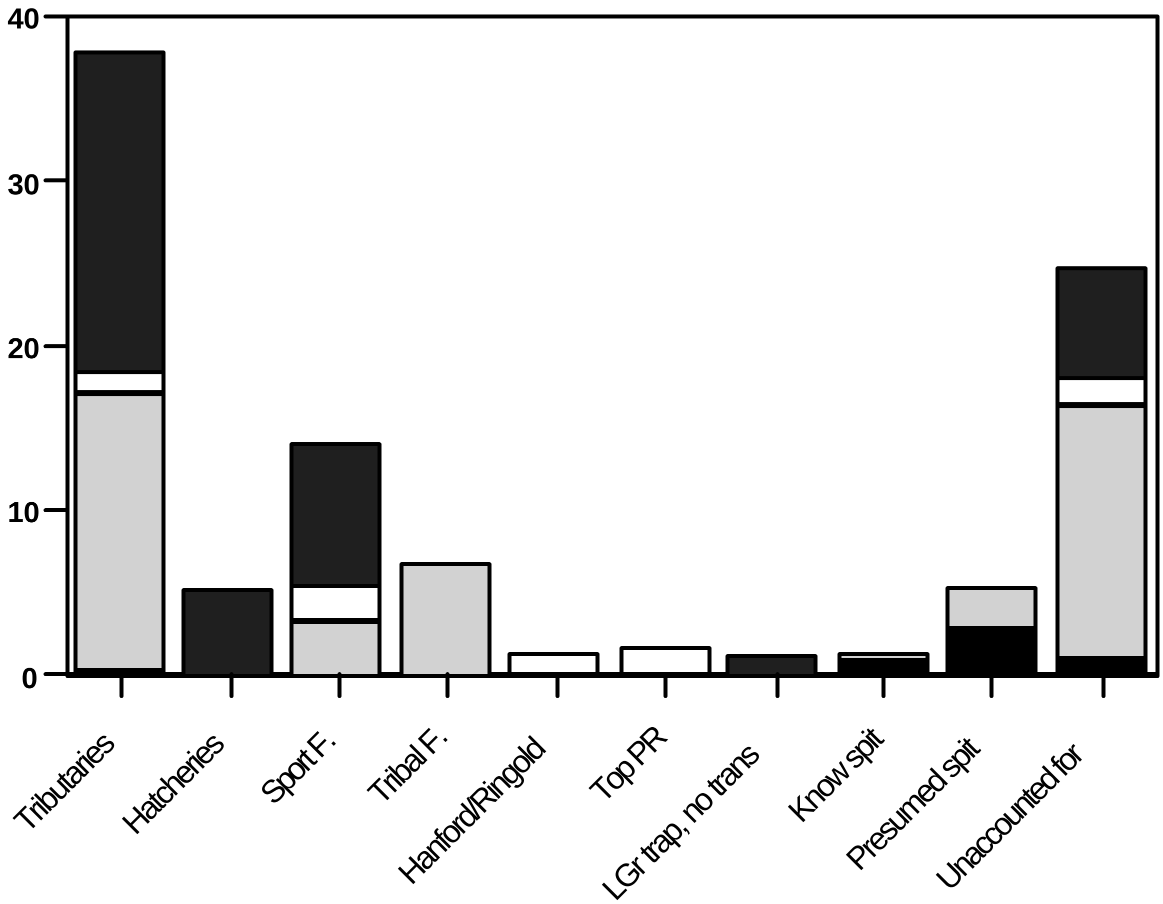

Figure 80. Our best estimate of the percentage of steelhead outfitted with transmitters in 1996 that ended up in tributaries, at hatcheries, in fisheries, in the Hanford reach, near Ringold Trap, passing Priest Rapids Dam, or were recaptured without transmitters at the Lower Granite trap, had known or presumed regurgitated transmitters, or were unaccounted for.

presumably regurgitated transmitters. Another 24.6% were unaccounted for throughout the study area.

Our best estimate of the fate of 278 fish designated B-group steelhead was that 5.0% ended up downstream from Bonneville Dam, 39.9% in the Columbia River and tributaries between Bonneville Dam and the tailrace of McNary Dam, 5.0% in the mid Columbia River, and 50.0% in the Snake River basin. Total escapement for B-group steelhead was 47.1%, with 37.1% to tributaries, 6.8% to hatcheries, 1.1% past Priest Rapids Dam, 0.4% to the Hanford Reach or near Ringold trap, and 1.8% recaptured and released at the Lower Granite trap without a transmitter (Table 37). Another 22.7% of the B-group steelhead were recaptured in sport or tribal fisheries. About 0.7% were known to have regurgitated transmitters and 4.3% presumably regurgitated

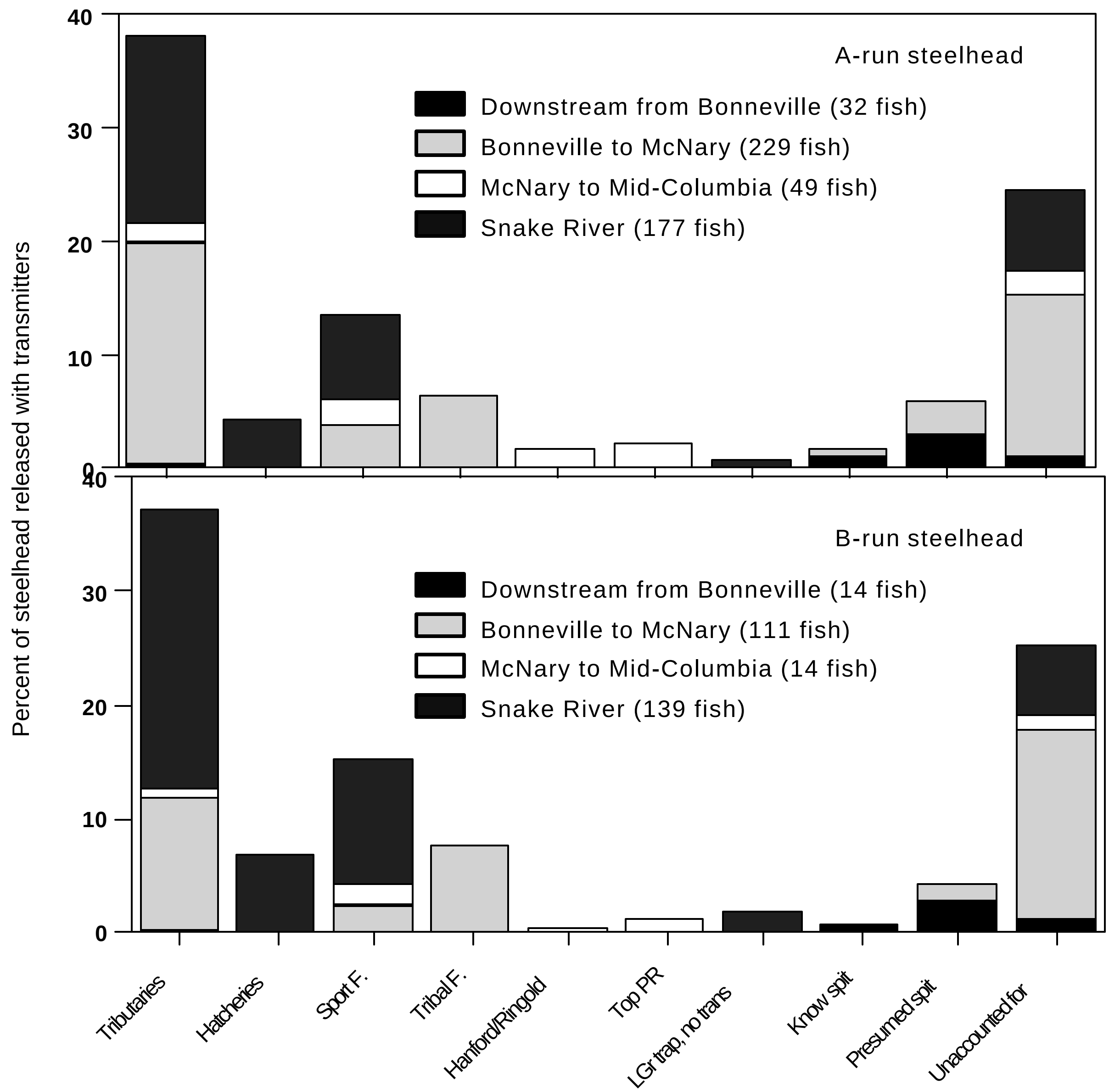

Figure 81. Our best estimate of the percentage of A-group and B-group steelhead outfitted with transmitters in 1996 that ended up in tributaries, at hatcheries, in fisheries, in the Hanford reach, near Ringold Trap, passing Priest Rapids Dam, or were recaptured without transmitters at the Lower Granite trap, had known or presumed regurgitated transmitters, or were unaccounted for.

transmitters. Another 25.2% were unaccounted for (Figure 81). We found no significant ($P < 0.05$, Z tests) differences in escapement or the overall proportion unaccounted for between B-group and A-group steelhead.

As described previously, all hatchery steelhead produced in the Columbia and Snake River basins should have been fin-clipped for the 1996 return year. Of 640 steelhead with transmitters that had fin clips, 5.6% ended up downstream from Bonneville Dam, 43.4% in the lower Columbia River and tributaries, 8.1% in the mid-Columbia River, and 42.8% in the Snake River basin (Table 38). A total of 45.8% percent of fin-clipped steelhead escaped, including those that escaped to tributaries (35.2%), hatcheries (6.1%), past Priest Rapids Dam (1.9%), to the Hanford Reach or near Ringold trap (1.3%), and and those that were recaptured and released at Lower Granite adult trap without transmitters (1.4%). Another 23.3% of the fin-clipped fish were reported as recaptures in sport and tribal fisheries, 1.7% were fish that we knew regurgitated transmitters at the release site or their transmitters were found in non-spawning areas, and 4.7% were presumably regurgitated. Another 24.5% of the fin-clipped steelhead were unaccounted for (Table 38).

For the 125 steelhead without fin clips, 8.0% ended up downstream from Bonneville Dam, 49.6% in the lower Columbia River and tributaries, 8.8% in the mid-Columbia River, and 33.6% in the Snake River basin (Table 38). Escapement for unclipped fish was 52.0% to tributaries, 0.8% to hatcheries, 1.6% past Priest Rapids Dam, and 1.6% to the Hanford Reach or near Ringold trap for a total escapement of 56.0%, significantly ($P = 0.04$, Z test) higher than the 45.8% escapement for fin-clipped fish. However, 8.8% of unclipped fish were reported as recaptures in sport and tribal fisheries, a significantly ($P < 0.005$) lower harvest rate than the 23.3% for fin-clipped steelhead. Another 8.8% of the unclipped fish were presumed to have regurgitated tags at the release site or had transmitters found in non-spawning areas, and 26.4% were unaccounted for (Table 38). We found no significant ($P < 0.05$) difference in the overall proportion of fin-clipped and unclipped steelhead that were unaccounted for.

The 46 transmitters (6.0%) we determined were downstream from Bonneville Dam included 23 (50%) fish that presumably regurgitated transmitters, 8 (17%) known regurgitated transmitters, 9 (20%) fish that were unaccounted for, 4 (9%) that entered tributaries, 1 recaptured in the sport fishery, and 1 recaptured in a tribal fishery (Table 37; Figure 82). Thirty-two of 46 (70%) transmitters with final fate downstream from Bonneville Dam were from A-group steelhead and 78% were from fish with fin clips. By category, the fate of A-group steelhead downstream from Bonneville Dam was similar to the pattern observed for A-group and B-group fish combined (Figure 82).

About 45% of the steelhead released in 1996 ended up in the Columbia River or its tributaries between Bonneville and McNary dams. Of 340 fish that ended up in that section of river, 127 (38%) entered tributaries (includes fish recaptured at traps and weirs), none were recaptured at hatcheries, 25 (7%) were reported as recaptures in sport and 51 (15%) in tribal fisheries, and 116 (34.1%) were unaccounted for (Figure 82). The escapement to tributaries in the lower Columbia River section was 16.6% of the 765 steelhead released with transmitters, the second largest proportion of the run in any category (Table 37). About 67% of the transmitters with final fate in the lower Columbia River section were A-group steelhead (Table 37), and 82% were from fish with fin clips (Table 38).

Table 38. Our best estimate of the fate of 765 steelhead released with transmitters in 1997 downstream from Bonneville Dam that had fin-clips or were unclipped when tagged, with the numbers released, numbers and percents of total that ended up in the various sections of the Columbia River basin.

	All steelhead		Clipped steelhead		Unclipped steelhead	
	Number	Percent	Number	Percent	Number	Percent
Number released	**765**	**100**	**640**	**100**	**125**	**100**
Downstream from Bonneville	**46**	**6.0**	**36**	**5.6**	**10**	**8.0**
Entered a tributary	4	0.5	3	0.5	1	0.8
Sport fishery	1	0.1	1	0.2		
Tribal fishery	1	0.1			1	0.8
Known regurgitated trans.	8	1.0	8	1.3		
Presumed regurgitated trans.	23	3.0	17	2.7	6	4.8
Unaccounted for	9	1.2	7	1.1	2	1.6
Bonneville to McNary dams	**340**	**44.4**	**278**	**43.4**	**62**	**49.6**
Entered a tributary	127	16.6	98	15.3	29	23.2
Sport fishery	25	3.3	25	3.9		
Tribal fishery	51	6.7	43	6.7	8	6.4
Known regurgitated trans.	3	0.4	3	0.5		
Presumed regurgitated trans.	18	2.4	13	2.0	5	4.0
Unaccounted for	116	15.2	96	15.0	20	16.0
Mid Columbia River	**63**	**8.2**	**52**	**8.1**	**11**	**8.8**
Entered a tributary	10	1.3	6	0.9	4	3.2
Sport fishery	16	2.1	16	2.5		
Top Priest Rapids	14	1.8	12	1.9	2	1.6
Hanford Reach/near Ringold trap	10	1.3	8	1.3	2	1.6
Unaccounted for	13	1.7	10	1.6	3	2.4
Snake River basin	**316**	**41.3**	**274**	**42.8**	**42**	**33.6**
Entered a tributary	149	19.5	118	18.4	31	24.8
Recaptured at hatchery	40	5.2	39	6.1	1	0.8
Sport fishery	66	8.6	64	10.0	2	1.6
Lower Granite Trap, no trans.	9	1.2	9	1.4		
Unaccounted for	52	6.8	44	6.9	8	6.4
		Basin-wide summary				
Recorded in tributaries	**290**	**37.9**	**225**	**35.2**	**65**	**52.0**
Recaptured at hatcheries	**40**	**5.2**	**39**	**6.1**	**1**	**0.8**
Reported harvest	**160**	**20.9**	**149**	**23.3**	**11**	**8.8**
Top of Priest Rapids	**14**	**1.8**	**12**	**1.9**	**2**	**1.6**
Hanford Reach/near Ringold trap	**10**	**1.3**	**8**	**1.3**	**2**	**1.6**
Lower Granite Trap, no trans.	**9**	**1.2**	**9**	**1.4**		
Known regurgitated trans.	**11**	**1.4**	**11**	**1.7**		
Presumed regurgitated trans.	**41**	**5.4**	**30**	**4.7**	**11**	**8.8**
Transmitters unaccounted for	**190**	**24.8**	**157**	**24.5**	**33**	**26.4**

Of 63 fish that ended up in the mid-Columbia River section, 10 (16%) returned to tributaries, 10 (16%) were last recorded in the Hanford Reach or near Ringold trap, 14 (22%) were last recorded at the top of Priest Rapids Dam, 16 (25%) were recaptured in

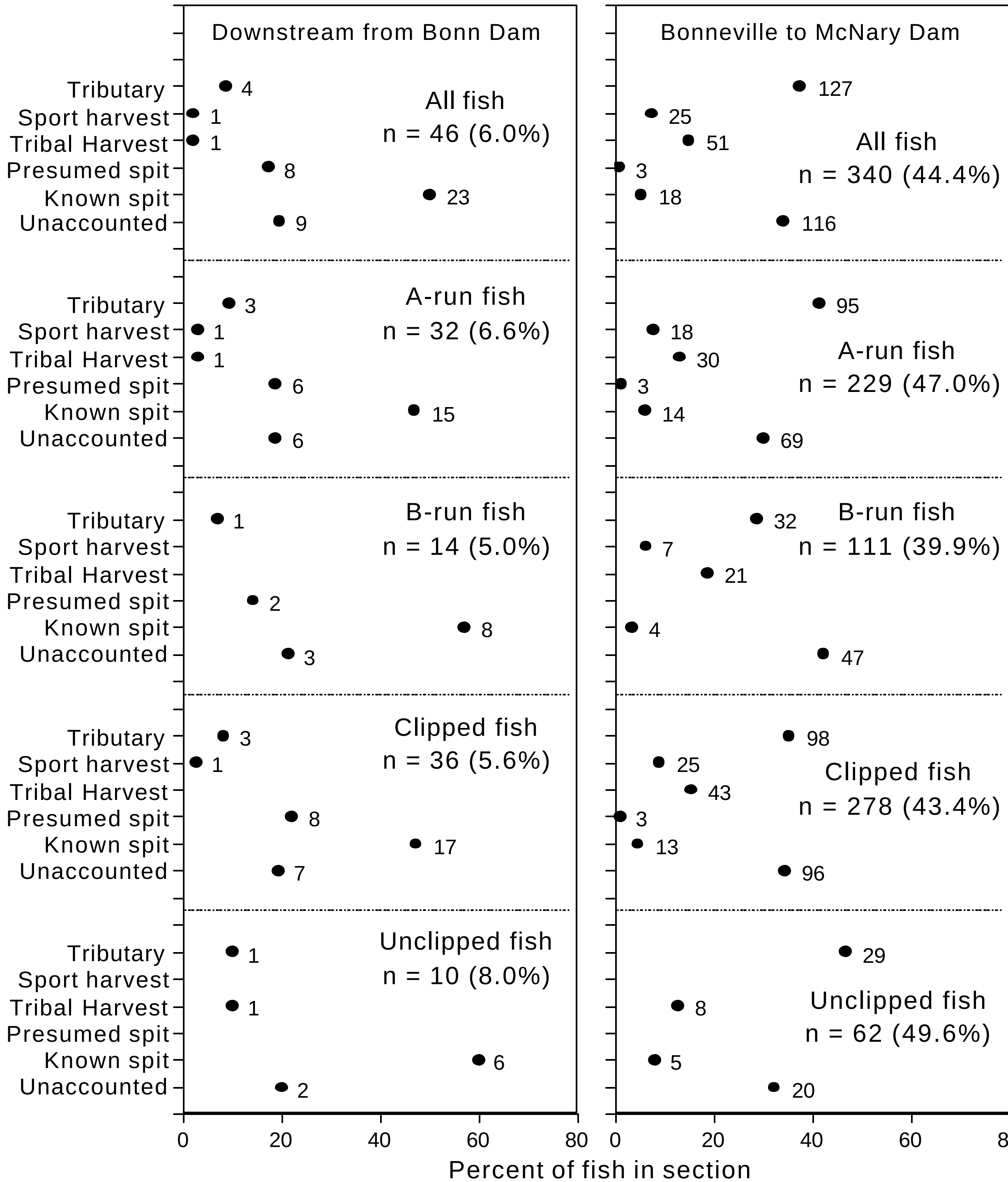

Figure 82. Our best estimate of the fate of 765 steelhead outfitted with transmitters in 1996, by basin subsection. Graphs show percentage of fish in tributaries, hatcheries, fisheries, in the Hanford reach, at Ringold Trap, at the top of Priest Rapids Dam, at Lower Granite trap without transmitters, with known or presumed regurgitated transmitters, and those unaccounted for.

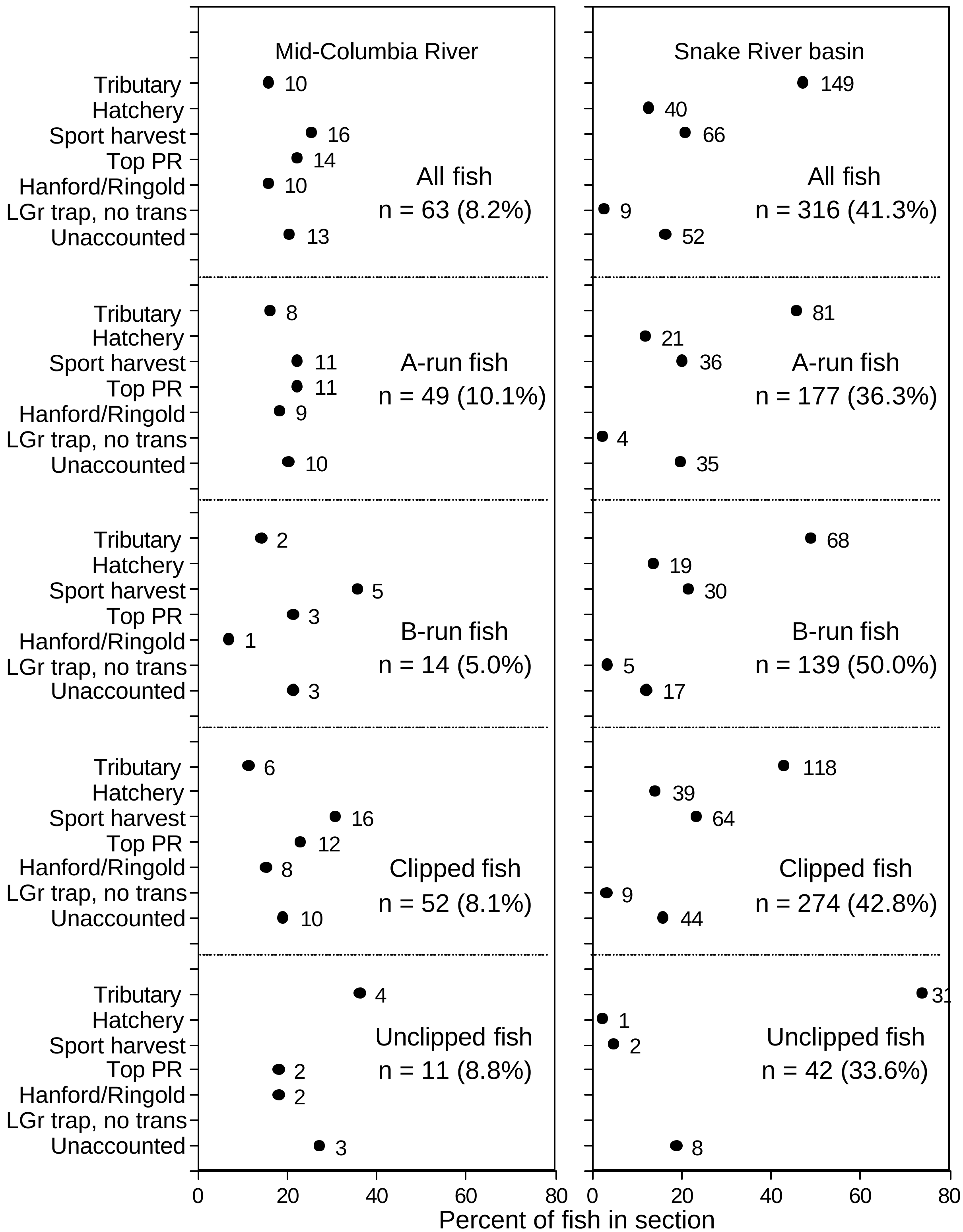

Figure 82 Continued.

sport fisheries, and 13 (21%) were unaccounted for (Table 37, Figure 82). About 78% of the fish that returned to the mid Columbia River section were A-group steelhead, and 83% had fin clips (Figure 82).

Of 316 salmon that ended up in the Snake River Basin, 149 (47%) returned to tributaries, 40 (13%) were recaptured at hatcheries, 9 (3%) were recaptured at the Lower Granite trap and released without transmitters, and 52 (16%) were unaccounted for, including 18 last recorded at the top of Ice Harbor Dam and 14 last recorded at the top or Lower Granite Dam (Table 37, Figure 82). Fifty-six percent of the fish that ended up in the Snake River basin were A-group steelhead and 44% were B-group steelhead. About 87% were fin-clipped and 13% did not have clips (Table 38). Forty-six percent of A-group steelhead and 49% of B-group steelhead returned to tributaries, 12% of A-group and 14% of B-group fish were recaptured in hatcheries, and 20% of A-group and 22% of B-group fish were recaptured in sport fisheries (Figure 82). The proportion of A-group fish that were unaccounted for (19.8%) was significantly higher ($P < 0.05$) than the proportion of B-group steelhead (12.2%).

The proportion of radio-tagged steelhead that were unaccounted for (190 of 765 fish released with transmitters = 24.8%) were primarily fish last recorded at dams and in lower Columbia River reservoirs. Fish with known or presumably regurgitated transmitters (as defined previously) were considered accounted for. Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated tags that were not recovered or not identified as presumably regurgitated, may have entered tributaries undetected, may have spawned at mainstem locations, or may have been mortalities with unrecoverable transmitters. Of the 190 fish we designated unaccounted for, 174 (22.7% of 765) were last recorded at dams or in reservoirs downstream from Lower Granite or Priest Rapids dams, and 16 (2.1% of 765) were last recorded at the top of Lower Granite Dam or in Lower Granite reservoir and not recorded at receivers or located by mobile trackers upstream from the reservoir.

The largest proportion of unaccounted-for fish (27.4%) were last recorded between the top of Bonneville Dam and the tailrace of The Dalles Dam, with 26 fish last recorded in the Bonneville Dam pool, 4 fish at The Dalles Dam, and 22 fish at the top of Bonneville Dam (Table 39). Another 38 (20.0%) were last recorded between the top of The Dalles Dam and the John Day Dam tailrace, 26 (13.7%) were last recorded between the top of John Day Dam and the McNary Dam tailrace, and 9 (4.7%) were last recorded downstream from Bonneville Dam. Eighteen fish (9.5%) were unaccounted for between the top of McNary Dam and the tailraces of Ice Harbor or Priest Rapids dams. Thirty-one of the unaccounted for steelhead (16.3%) were last recorded between the top of Ice Harbor Dam and the tailrace of Lower Granite Dam, and 16 (8.4%) were last recorded at the top of Lower Granite Dam or in the Lower Granite reservoir (Table 39).

We also calculated the proportion unaccounted for in each segment of the system. Downstream from Bonneville Dam, where 46 fish had last known locations (including regurgitated transmitters), 9 (19.6%) were unaccounted for (Table 39). Unaccounted for rates were 36.4% (52 of 143 steelhead) between Bonneville and The Dalles, 26.6% (38 of 143) between The Dalles and John Day dams, 47.3% (26 of 55) between John Day and McNary dams, 36.0% (18 of 50) from McNary to Priest Rapids and Ice Harbor dams,

Table 39. Last known locations for 190 steelhead unaccounted for by records in tributaries, at hatcheries, in fisheries, or recovery of transmitters in any other way[1] throughout the monitored reach of the mainstem Columbia and Snake rivers in 1996. Unaccounted for fish in each section and as a percentage of all fish in section, and percent of all unaccounted for fish and all fish released that retained transmitters.

River section Last record location	Fish unaccounted for	All fish in section	Percent unaccounted for	Percent of 190 fish	Percent of 765 fish
Downstream from Bonneville	**9**	**46**	**19.6**	**4.7**	**1.2**
At Bonneville Dam or in tailrace	9		19.6	4.7	1.2
Top of Bonneville to The Dalles	**52**	**143**	**36.4**	**27.4**	**6.8**
Top of Bonneville Dam	22		15.4	11.6	2.9
Bonneville pool	26		18.2	13.7	3.4
At The Dalles Dam	4		2.8	2.1	0.5
Top of The Dalles to John Day	**38**	**143**	**26.6**	**20.0**	**5.0**
Top of The Dalles Dam	4		2.8	2.1	0.5
The Dalles pool	20		14.0	10.5	2.6
At John Day Dam	14		9.8	7.4	1.8
Top of John Day to McNary	**26**	**55**	**47.3**	**13.7**	**3.4**
Top of John Day Dam	16		29.1	8.4	2.1
John Day pool	2		3.6	1.1	0.3
At McNary Dam	8		14.5	4.2	1.0
Top of McNary to Ice Harbor or Priest Rapids dams	**18**	**50**	**36.0**	**9.5**	**2.4**
Top of McNary Dam	7		14.0	3.7	0.9
At Ice Harbor Dam	5		10.0	2.6	0.7
McNary pool/Hanford Reach	5		10.0	2.6	0.7
At Priest Rapids Dam	1		2.0	0.5	0.1
Top of Ice Harbor to L. Granite	**31**	**54**	**57.4**	**16.3**	**4.1**
Top of Ice Harbor	18		33.3	9.5	2.4
Lower Monumental pool	1		1.9	0.5	0.1
At Lower Granite	12		22.2	6.3	1.6
Upstream from Priest Rapids	**n/a**	**18**	**0**	**0**	**0**
Upstream from Lower Granite	**16**	**256**	**6.3**	**8.4**	**2.1**
Top of Lower Granite	15		5.9	7.9	2.0
Lower Granite pool	1		0.4	0.5	0.1
Total	**190**		**100**	**100**	**24.8**

[1] steelhead known or presumed to have regurgitated transmitters based on circumstances associated with the transmitter were considered accounted for

57.4% (31 of 54) between the top of Ice Harbor Dam and the tailrace of Lower Granite Dam, and 6.3% (16 of 256) for those steelhead that passed over Lower Granite Dam (Table 39).

Sixty-three percent of the 190 unaccounted-for fish were A-group steelhead, and 83% had fin clips. Although we found no significant (P = 0.87) difference in the overall proportion of A-group and B-group fish that were unaccounted for, a significantly (P = 0.03, Z test) higher proportion of B-group fish were unaccounted for among those with final fate between the top of Bonneville Dam and the tailrace of McNary Dam (42.3% of B-group versus 30.1% of A-group fish). A higher proportion (P = 0.07, Z test) of A-group steelhead were unaccounted for among steelhead with final fate in the Snake River basin (19.8% of A-group versus 12.2% of B-group fish). We found no significant differences at P < 0.10 in the overall proportion of fin-clipped versus unclipped steelhead, and no significant differences in the proportion unaccounted for in the major basin sections.

Evaluation of release groups

Steelhead were released in eight groups (Figure 6) consisting of from 40 to 180 fish each, with five groups released during the A-portion of the run and three during the B-portion (Table 40). We made pair-wise comparisons between groups of behavior and composition, for 28 between-group pairs (Table 41).

The proportion of each release group last recorded in the lower Columbia (Bonneville-McNary) section of the basin did not differ between any pairings. The proportion that returned to the Snake River increased with each release group, and the mid-Columbia component decreased for the first five release groups and remained at < 8% for the final three groups. Comparisons of the proportions of Snake or mid-Columbia fish in each release group reflected differences in stock composition between early and late portions of the run.

The proportion of unclipped fish fell into two basic categories: release groups with relatively low (8-11%) proportions of unclipped fish (1, 5, 7, 8) and those with relatively high (17-34%) proportions of unclipped fish (2, 3, 4, 6). Twelve of 28 of the between-group comparisons were significantly different; each pair had a release group from both the high and low categories. The proportion of unclipped fish varied in a manner consistent with the final distribution of fish. The latest release groups had the highest Snake River component and correspondingly high proportions of clipped (hatchery) fish. Group 1, which had the highest mid-Columbia component, also had low numbers of unclipped (potentially wild) fish.

All comparisons of mean and median fork length (see Figure 9) for B-group releases differed significantly from those for A-group releases. Release group 1 was different from other A-group releases.

Median travel times from the Bonneville tailrace past McNary Dam were two to three times longer for the middle release groups than for those at the beginning and end of the migration. The longest times coincided with high mainstem water temperatures and widespread temporary straying. Between-group differences were significant for 19 of 28 (68%) of comparisons. Medians for groups 1, 2, 3, and 8 were within 1 d of each other, and comparisons between those groups did not differ. Median Bonneville-Lower Granite travel times followed the same seasonal pattern as Bonneville-McNary times, but varied more widely. Bonneville-Lower Granite sample sizes were smaller and release group 2 (n

Table 40. Summary of size, sex, fin clips, release timing, run-group, multiple-dam passage times, final distribution and escapement to tributaries for steelhead from 8 release groups in 1996.

	Release groups							
	1	2	3	4	5	6	7	8
Summary at time of tagging (N = 765)								
N	49	40	70	141	180	136	88	56
Start date	6/17	7/2	7/15	8/5	8/19	9/3	9/16	9/30
Run group	A	A	A	A	A	B	B	B
% Male	71	68	54	60	67	70	66	59
% no fin clips	8	28	34	17	9	23	9	11
FL (median cm)	71	63	63	62	62	76	81	77
Passage times								
BO-MN (357)	21	18	27	71	82	65	45	28
Time (med d)	10.0	10.8	10.8	29.0	29.2	22.0	12.0	9.6
BO-GR (231)	5	3	8	45	62	54	35	19
Time (med d)	21.4	75.7	30.3	51.0	43.7	32.0	22.8	19.2
Final distribution (N = 704[1])								
% Lower Col.	52	54	54	43	46	44	41	37
% Mid Col.	26	19	14	10	4	6	4	7
% Snake R.	15	24	29	46	48	50	53	54
Escapement to tributaries (N = 704[1])								
All fish	55.6	51.4	57.6	71.0	64.0	60.3	69.6	57.4

[1] 704 = number that retained transmitters

= 3) was excluded. Consequently, fewer between-group differences were significant than for the Bonneville-McNary reach. Escapement to tributaries was relatively consistent between release groups. Only the difference between the lowest (group 2, 51.4%) and highest (group 4, 71.0%) escapements was significant (Table 41).

Discussion

In 1996 we were able to successfully use radio telemetry on a large scale to assess and evaluate the passage of adult steelhead as they migrated past dams and through reservoirs in the Columbia and Snake rivers on their way to spawning grounds and hatcheries. We examined passage rates, fallback behavior, recaptures in fisheries and at hatcheries, survival to tributaries, and final fate from release downstream from Bonneville Dam into tributaries and upstream to Priest Rapids and Lower Granite dams.

Table 41. All pairs in table below had significantly different values (?^{2} tests for percentages, Kruskal-Wallis ?^{2} tests for median passage times and fork lengths). See Table 40 for data tested.

% Male	% No clip	Med FL	BO-MN time	BO-GR time	% Low. Col	% Mid Col	% Snake	% Escape
3-6	1-2	1-2	1-4	1-4		1-4	1-4	2-4
	1-3	1-3	1-5	4-5		1-5	1-5	
	1-6	1-4	1-6	4-6		1-6	1-6	
	2-5	1-5	2-4	4-7		1-7	1-7	
	2-7	1-6	2-5	4-8		1-8	1-8	
	2-8	1-7	2-6	5-6		2-5	2-4	
	3-4	1-8	3-4	5-7		2-6	2-5	
	3-5	2-6	3-5	5-8		2-7	2-6	
	3-7	2-7	3-6	6-7		3-5	2-7	
	3-8	2-8	4-5	6-8		3-7	2-8	
	4-5	3-6	4-6				3-4	
	5-6	3-7	4-7				3-5	
		3-8	4-8				3-6	
		4-6	5-6				3-7	
		4-7	5-7				3-8	
		4-8	5-8					
		5-6	6-7					
		5-7	6-8					
		5-8	7-8					
		6-7						

The 1996 steelhead run was 79% of the previous 10-year average at Bonneville Dam, while the steelhead count at Ice Harbor Dam was 90% of the previous 10-year average. Consequently, the proportion of steelhead passing Bonneville that were subsequently counted at Ice Harbor Dam (39%) was 116% of the 10-year average.

Of the 770 steelhead we collected at Bonneville Dam and outfitted with transmitters and released downstream from the dam, 765 were released with their transmitters in place. We believe an additional 3.3% of the steelhead regurgitated their tags at or near the release site resulting in 739 radio-tagged steelhead that migrated upstream from the release area and were used for the evaluations summarized in this report. An additional number (we estimated 4.6%) of steelhead may have lost their transmitters enroute to spawning areas, introducing a positive bias to survival and escapement estimates. When possible we used available information, such as detection of secondary tags, to reduce bias for relevant locations and objectives. We estimated the overall regurgitation rate following release was 8.0% in 1996. Had we double banded all tags, the regurgitation rate may have been closer to 5%. The 739 steelhead transmitters in our original sample represent 0.36% of the run counted at Bonneville Dam, or one radio-tagged fish for every 277 adult steelhead in the run at large.

We attempted to tag fish in proportion to their abundance in the run, using the ten-year average count as a guide to setting the tag schedule. We were fairly successful in this, although the peak number of fish tagged occurred about one week later than the peak in fish counts at Bonneville Dam in 1996. Also, because of warm water temperatures, tagging had to be halted for about ten days during late July/early August, causing more fish than originally intended to be tagged later in the run. As such, the median passage date for radio-tagged steelhead was 10 d later than the median count date at Bonneville Dam and 7 d later at The Dalles Dam. Median passage dates for the radio-tagged steelhead appeared to become progressively later relative to fish counts as the run moved upstream because of overwintering behavior and because of the arbitrary cutoff date (usually 1 November) used for the count schedule at the upstream projects.

Median times to cross dams were less than one day at all but Lower Granite Dam where the fish must pass through the adult trap as they ascend the fishway. At all dams, 75% (third quartile) of the steelhead passed in less than two days time each. As has been reported previously for adult migrants (Bjornn and Peery 1992; Liscom et al. 1979; Monan 1975; Stuehrenberg et al. 1995), passage times were strongly skewed to the right because some steelhead took one month or more to pass individual projects. The greatest number of outlyer fish occurred at John Day and Lower Granite dams. As mentioned previously, the trap at Lower Granite Dam appears to affect project passage times. It is unknown why some fish tended to take longer to pass John Day Dam relative to the other projects. One theory is that some fish destined for upstream locations, including the John Day River just upstream from the dam, were using the tailrace and even fishways at John Day Dam as overwintering locations. For example, of the 23 steelhead that took longer than 10 d to pass John Day Dam in 1996, six overwintered in the lower Columbia Rive after first being recorded in the tailrace of the dam and five steelhead eventually entered the John Day River. Median passage times were longer for A-group steelhead than for B-group steelhead at Bonneville and John Day dams, but the pattern was not consistently so at other dams and may not have a biological significance.

We saw little evidence that passage times at dams were related to spill levels that occurred in 1996. Spill rarely exceeded 100 kcfs and was terminated around 1 September at most dams in 1996. About three-quarters of the steelhead run and 61% of the radio-tagged steelhead passed Bonneville Dam during periods of spill, but as the run progressed, proportionally fewer steelhead passed during spill at upstream dams. The bulk of the radio-tagged steelhead passed dams upstream from The Dalles during periods of no spill. As a consequence, flow, spill and associated dissolved gas and turbidity conditions appeared to be favorable, or at least were not unfavorable, during most of the steelhead migration in 1996. Dam passage times were more directly explained by behavior of steelhead as they negotiated fishways, and are described in detail in a separate report (Keefer et al. 2002a).

As we saw with chinook salmon in 1996 (Keefer et al. 2002b) steelhead using fishways were primarily active during daylight hours. This seems to be a consistent behavior with adult migrants; restricting their movement to daylight periods when confronted with a passage obstacle. We saw that most (96% or more) fish that reached a dam eventually passed the dam. The exceptions were Priest Rapids Dam (90% passage) and John Day Dam (93% passage). Of the 33 fish that did not pass John Day Dam: 13 (39%) were last recorded in the Deschutes River and one returned to the Klickitat River. Only 2 steelhead did not pass Priest Rapids Dam, one was last recorded in the tailrace, the other was recaptured at Ice Harbor Dam.

Migration rates through reservoirs ranged from 24 to 43 km/d and up to a maximum of 80 km/d, resulting in median residence times of 1 to 3 d per reservoir. Longest times and slowest migration rates were for the Bonneville reservoir and correlated with the number of tributary streams that fish could stray into in that reservoir. John Day reservoir was the longest single reservoir in the Columbia River system and correspondingly had the second longest residence time. But steelhead also moved through the John Day reservoir at the fastest rate. A-group steelhead migrated more slowly through the Bonneville reservoir than did B-group steelhead, but the opposite occurred in The Dalles and John Day reservoirs. This behavior appears related to time fish spent temporarily straying into tributary streams in the Bonneville pool. Some A-group steelhead halted their migration and strayed into Bonneville pool tributaries during the heat of summer, but after the river cooled, they progressed upstream to McNary Dam faster than the later arriving B-group steelhead. The 42-44 km/d (median) speed we determined for adult steelhead in John Day reservoir may be most indicative of their uninterrupted reservoir migration rate. A-group steelhead again moved more slowly between McNary and Ice Harbor dams (difference of about 0.5 d in median times) and this may be related to water temperatures. For 27 steelhead that passed McNary Dam in August, the median pool passage time was 7.3 d when the average (August) temperature difference between McNary and Ice Harbor dams was 1.2°C, the Snake River being warmer. In September, 87 steelhead passed McNary Dam with a median pool passage of 1.87 d. During September the mean temperature difference between the two dams was –0.6°C, with the Snake River being cooler. Steelhead migration times through reservoirs were longer than those for spring/summer chinook salmon in 1996 because of time fish spent temporarily in tributaries. Migration rates we measured (24-43 km/d) were similar to or faster than previously observed for steelhead in reservoirs (12 to 19 km/d) and faster than those previously recorded for steelhead migrating through unimpounded sections of river (10 to 16 km/d) (Bjornn and Peery 1992).

Over all, total migration times from the Bonneville Dam tailrace were about 16 d to pass McNary Dam, 26 d to pass Ice Harbor Dam, and 35 d to pass Lower Granite Dam, with B-group steelhead migrating in about half the time required by A-group steelhead. Total passage times were best explained by the amount of time fish spent in tributaries, time of release and the occurrence of fallback events and fishway exits to the tailraces. Time fish spent in tributary streams, which was correlated with date of release and lower Columbia River water temperatures, had the highest correlation with total passage times. Water temperatures at Ice Harbor Dam were also weakly correlated with longer passage times. That and the additional 10 d to pass from McNary to Ice Harbor Dam may indicate wandering or delay for some fish entering the Snake River during warm water conditions. Spill, flow, water visibility, and the presence of descaling or injuries presumably from marine mammals explained relatively minor amounts of variation in passage times.

We found that most (61-65%) of the radio-tagged steelhead strayed temporarily into downstream tributaries before continuing their migration upstream. The number of fish and lengths of stay were greatest for the Little White Salmon, White Salmon, and Deschutes rivers. As would be expected, the more time fish spent in downstream tributaries the longer their migration time. The median stay in tributaries was 7.7 d per steelhead. The proportion of upstream steelhead that strayed, and the time they spent in the lower tributaries, was greatest during late August and September and appeared related to the adult migrants seeking cooler water refuge during periods of peak water temperatures in the lower Columbia River. Consequently, steelhead migration times peaked in August and were shorter earlier and later. Shorter total migration times for B-group steelhead, as compared to the A-group steelhead were also probably related to residence in tributary streams; A-group steelhead last recorded at upstream locations spent about three times the amount of time in tributaries as the B-group steelhead. Again this pattern was probably related to water temperatures at time of migration.

We determined that about 20% of the migrating steelhead fell back at least once during their upstream migration, adding approximately 1 d to their travel time if they fell back at Bonneville Dam and 8 to 21 d to their travel times if they fell back at other dams. Travel times were longest for steelhead that fell back more than once. As with chinook salmon, fallback rates were highest at the lower Columbia River dams. Unlike chinook salmon, fallback was only weakly correlated with spill levels at dams. This is partially explained by low levels of spill that occurred during portions of the steelhead migration period and because 16% of the fish that fell back entered a downstream tributary. The indication is that a portion of the steelhead overshot their natal stream and during their subsequent return downstream fell back at dams proximate to their final destination. Alternately, some steelhead may have strayed into downstream tributaries or been disorientated following fallback at a dam. The proportion of fish that fell back was highest at John Day Dam, probably because of its proximity to lower Columbia River tributaries, especially the Deschutes River which was the final location for the largest group of steelhead that fell back at John Day Dam. Steelhead fallback was probably related more to wandering behavior, overwintering and the physical location of projects rather than to factors related to river condition and operations.

We estimated that passage of steelhead through navigational locks was about 4% at Bonneville Dam and 0.8% to 1.5% at the other dams. Using those values and the information on fallback of radio-tagged steelhead we calculated adjustments to the fish counts at each dam. At Bonneville Dam, bias in fish counts introduced from fallback was partially or entirely offset by passage of steelhead through the navigational lock. At the other five projects monitored, negative adjustments to fish counts ranged from 4 to 9%. Count adjustments would have been more accurate if navigational locks had been monitored at all dams.

Steelhead slowed or stopped migrating upstream in winter. Most fish reached tributary streams or sections of river near spawning areas, or at least upstream from Lower Granite and Priest Rapids dams, prior to the onset of winter, and so presumably selected those areas to overwinter. Less than 3% of the radio-tagged steelhead first passed McNary Dam in the spring of 1997, and 6.6% first passed Lower Granite Dam in 1997, having overwintered at downstream locations. These are probably underestimates because we stopped tagging steelhead in October, so fish that passed Bonneville Dam later in 1996 and early 1997 were not represented in our analysis. John Day Dam is where we first observed appreciable numbers of steelhead that did not make their first passage until spring of 1997. The Dalles reservoir was thus the furthest downstream location where radio-tagged steelhead halted their migration to overwinter. Of radio-tagged steelhead that passed Bonneville Dam, about 6% overwintered somewhere in the hydrosystem prior to continuing their migration to spawning grounds in the spring. Once they stopped migrating, the steelhead spent about 140 d in the lower Columbia and Snake rivers before resuming their migrations in the spring. Many times the overwintering steelhead moved downstream, fell back at one or more dams and/or eventually strayed into a tributary for the winter. The resumption of movement by overwintering steelhead, indicated by when dam passage resumed, coincided with the increase in water temperatures from the winter low of 3 to 4?C in early February 1997. Steelhead that overwintered in the lower Columbia and Snake river hydrosystem had higher rates of loss than steelhead that reached upstream areas and spawning tributaries before the onset of winter, possibly because of increased exposure to fisheries.

Steelhead entered their final tributary streams from July of 1996 until the following April (at which time their transmitters could have started to fail). Median tag dates were during July for steelhead that returned to Hood and Klickitat rivers and to Lyons Ferry Hatchery, during September for steelhead that returned to the Clearwater River, and in August for the remaining drainages. Median arrival dates were earliest for the lower Columbia River tributaries, intermediate for the Snake, Yakima and John Day rivers and latest for Umatilla and Walla Walla rivers. The later arrival date for the John Day River as compared to other lower river tributaries may be related to their relative water temperatures.

Thirty-two percent of the radio transmitters were returned to us and counted as recaptured, the greatest proportion (46%) were caught in sport fisheries. The remaining recaptures were about evenly split between hatchery returns, tribal fishery harvest and fish and tags found in the river, either at spawning grounds or somewhere along the migration routes. Because of temporary straying, it is likely that some steelhead destined for the Snake River and mid-Columbia River were harvested in lower river tributaries.

As would be expected, the proportion of fish released downstream from Bonneville Dam that progressed upstream diminished at each successive dam. The greatest declines from all causes occurred between Bonneville and The Dalles dams (19% of released fish) and between The Dalles and John Day dams (17%). The fewest fish dropped from the run in the lower Snake River, between Ice Harbor and Lower Granite dams (8% through three dams and reservoirs).

Overall, 47.5% of the radio-tagged steelhead were considered to have escaped to tributary streams or passed Priest Rapids Dam. An additional 20.9% of the steelhead were harvested, about evenly divided between tributaries and mainstem fisheries. We estimated that 6.8% of the transmitters were regurgitated, leaving about 24.8% of the 765 radio-tagged steelhead released unaccounted for. The most probable cause for losses are deaths, indirect mortalities from fisheries and unreported harvests. A smaller portion of losses may have been from steelhead that were not detected entering tributary streams, who lost their tags, or whose tags failed or lost battery power during winter.

The final distribution for 431 steelhead known to have terminated in tributary streams (including fishery harvests) and hatcheries, was 1% below Bonneville Dam, 11.1% in the Bonneville reservoir, 18.8% in The Dalles reservoir (majority to Deschutes River), 5.8% in the John Day reservoir, 2.8% in the McNary reservoir, 4.2% passed Priest Rapids Dam, 3.9% between Ice Harbor and Lower Granite dams, and the remaining 52.4% were last recorded upstream from Lower Granite Dam. The steelhead that passed Lower Granite Dam and reservoir were about evenly divided (30-32% each) between the Clearwater, Salmon and Snake (from Asotin to Hells Canyon Dam) rivers, with 8% also returning to the Grande Ronde River.

Taking into account fishery harvests and suspected regurgitated tags, survival though the system was estimated to be 92% between Bonneville and The Dalles dams, about 94% for the remaining reaches to Ice Harbor Dam, 92% between Ice Harbor and Lower Granite dams (three reaches combined), and 90% through Lower Granite Reservoir. There was some evidence that head injuries and descaling at time of tagging was related to lower survival as fish migrated upstream, but none from the presence of marine mammal injuries. Fallback appeared to cause a 5% reduction in survival for adult steelhead.

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